GRAINS RESEARCH UPDATE

BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Wagga Wagga

Charles Sturt University
Joyes Hall, Pine Gully Road, Wagga Wagga

#GRDCUpdates

2019 Wagga Wagga GRDC Grains Research Update planning committee

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Wagga Wagga GRDC Grains Research Update
convened by ORM Pty Ltd.

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DISCLAIMER - TECHNICAL

Welcome to the 2019 GRDC Grains Research Updates

Growers, advisers and industry stakeholders are constantly faced with challenges to farm profitability and productivity, which makes staying informed about the latest research and development outcomes a critical part of being in business.

Keeping growers and advisers informed is the key role of the annual Grains Research and Development Corporation (GRDC) Grains Research Updates, which are premiere events on the northern grains industry calendar and bring together some of Australia's leading grain research scientists and expert consultants.

For more than 25 years the GRDC has been driving grains research capability and capacity with the understanding that the continued viability of the industry hinges on rigorous, innovative research that delivers genuine profit gains. GRDC's purpose is to invest in research, development, and extension (RD&E) to create enduring profitability for Australian grain growers.

Despite the tough seasonal conditions currently being experienced across much of the Queensland and New South Wales grainbelts, the industry remains confident about the future and committed to learning more about innovation and technology and embracing practice change that has the potential to make a tangible difference to on-farm profits.

In response, this year's GRDC Grains Research Updates offer regionally relevant, credible and new science-based information covering priority issues like climate and environmental variability, new technology and market conditions to ensure growers and their advisers have up-to-date knowledge to make informed decisions on-farm.

So, I hope you enjoy the 2019 Updates and that the events provide an invaluable opportunity for learning, knowledge sharing and networking.

Luke Gaynor,

GRDC Senior Manager Extension and Communication

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NORTHERN REGION*

PREDICTA® B

KNOW BEFORE YOU SOW

*NORTHERN NSW AND QUEENSLAND

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)
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- Root lesion nematodes
- Yellow leaf spot
- Common root rot
- Pythium clade f
- Charcoal rot
- Ascochyta blight of chickpea
- Sclerotinia stem rot
- Long fallow disorder
- Phytophthora root rot
- Fusarium stalk rot
- White grain disorder
- Sclerotinia stem rot

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CONTACT:
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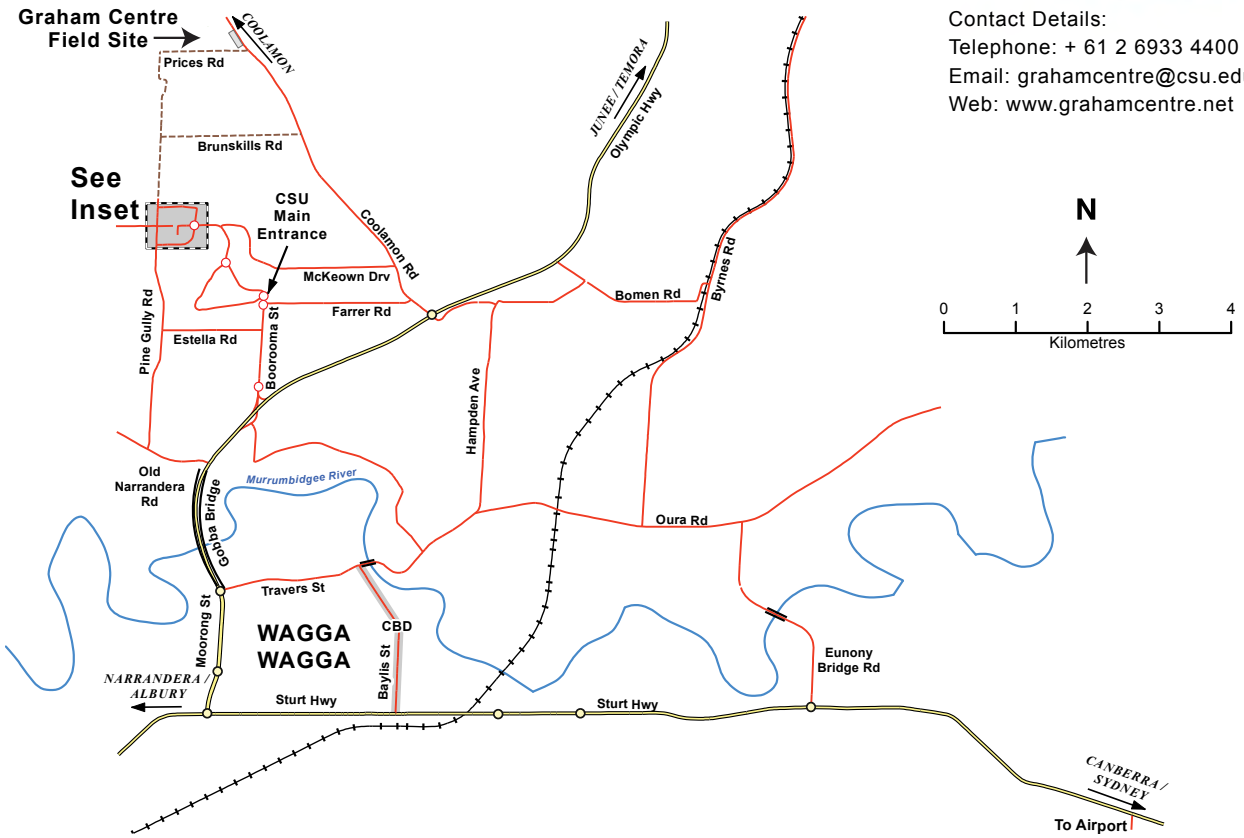

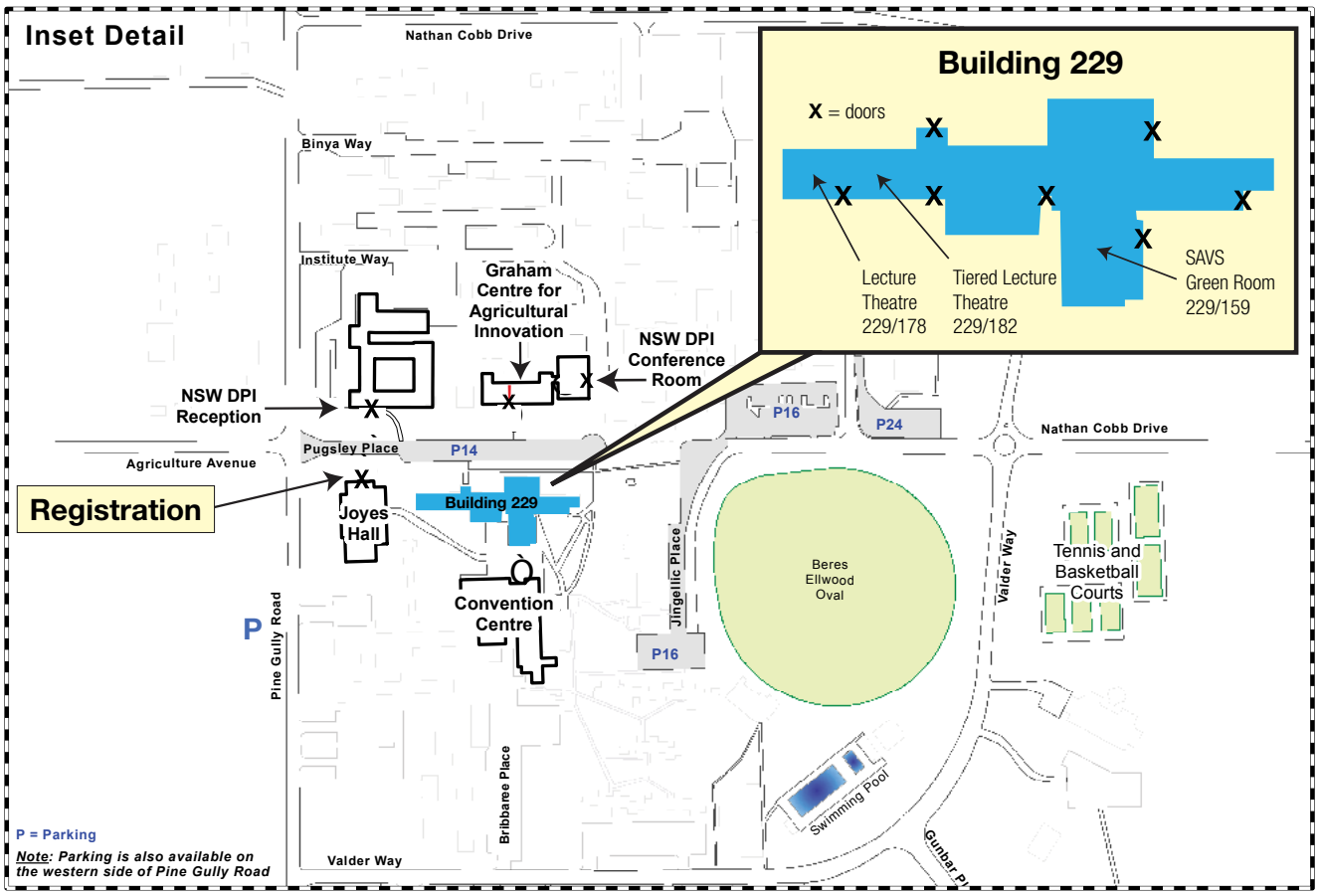

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FURTHER INFORMATION

BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

PROGRAM DAY 1 - FEBRUARY 19th

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	**Nitrogen and soil organic matter decline - what is needed to fix it?**– P23	***Jeff Baldock,*** *CSIRO*
10.30 am	**Morning tea**	

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

	Joyes Hall	Room 229/182	Room 229/178	SAVS Green Room
11.05 am	**Protecting the longevity of new fungicide products (R)** – P35 ***Nick Poole,*** *FAR Australia*	**Crown rot - what is the threat coming out of a dry year? (R)** – P41 ***Steven Simpfendorfer,*** *NSW DPI*	**Managing crop nutrient supply after a long dry period (R)** – P49 ***Graeme Sandral,*** *NSW DPI*	**Effective soil sampling – high and low cost options to gain soil fertility information for management (R)** – P51 ***Jason Condon,*** *CSU and NSW DPI*
11.45 am	**Canola agronomy forum** **Key learnings from the 'Optimised Canola Profitability' project including management lessons from the low rainfall year. Effect of temperature stress. Root development of fast versus slow spring sown canola.** – P57, 63 and 69 ***Rohan Brill and Rajneet Uppal,*** *NSW DPI* ***Wayne Pitt,*** *CSU*	**Post drought pasture management (R)** – P77 ***Jeff McCormick,*** *CSU*	**Biology and control options for wild radish, prickly lettuce and sow thistle (R)** – P83 ***Hanwen Wu,*** *NSW DPI*	**Ameliorating subsoil constraints - new information on testing and diagnosing sodic soils (R)** – P95 ***Ehsan Tavakkoli,*** *NSW DPI*
12.25 pm		**Fixing more N - improving the performance of inoculants in suboptimal conditions (R)** – P105 ***Ross Ballard,*** *SARDI*	**Effective soil sampling – high and low cost options to gain soil fertility information for management** – P51 ***Jason Condon,*** *CSU and NSW DPI*	**Protecting the longevity of new fungicide products** – P35 ***Nick Poole,*** *FAR Australia*

1.00 pm **LUNCH**

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

	Joyes Hall	Room 229/182	Room 229/178	SAVS Green Room
2.00 pm	**Phenology drivers in barley - how is Planet shaping up? (R)** – P113 *Felicity Harris, NSW DPI*	**Ameliorating subsoil constraints - new information on testing and diagnosing sodic soils** – P95 *Ehsan Tavakkoli, NSW DPI*	**Black leg - latest on upper canopy infection management (R)** – P121 *Susie Sprague, CSIRO*	**On the couch informal Q& A discussion** *with Jeff Baldock*
2.40 pm	**Fixing more N - improving the performance of inoculants in suboptimal conditions** – P105 *Ross Ballard, SARDI*	**Post drought pasture management** – P77 *Jeff McCormick, CSU*	**Managing crop nutrient supply after a long dry period** – P49 *Graeme Sandral, NSW DPI*	**On the couch informal Q& A discussion** *with Harm van Rees*
3.20 pm	**Crown rot - what is the threat coming out of a dry year?** – P41 *Steven Simpfendorfer, NSW DPI*	**Black leg - latest on upper canopy infection management** – P121 *Susie Sprague, CSIRO*	**Biology and control options for wild radish, prickly lettuce and sow thistle** – P83 *Hanwen Wu, NSW DPI*	**Phenology drivers in barley - how is Planet shaping up?** – P113 *Felicity Harris, NSW DPI*

3.55 pm	**AFTERNOON TEA**	
4.25 pm	**Can wheat be vernalised during grain development** – P131	*Javier Atayde, student*
4.35 pm	**Effects of surface incorporation of organic matter on subsurface soil acidity and wheat growth** – P137	*Han Hoang Nguyen, student*
4.45 pm	**Pesticides and regulatory impacts - the road ahead** – P143	*Richard Holzknecht, GRDC*
5.25 pm	**Drinks and finger food at the Thirsty Crow**	

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PROGRAM DAY 2 - FEBRUARY 20th

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

	Joyes Hall	Room 229/182	Room 229/178	SAVS Green Room
9.00 am	**Emerging management tips for early sown winter wheats (R)** – P159 ***Felicity Harris,*** *NSW DPI*	**Assessing key pulse crops including lentils and chick peas (R)** – P167 ***Mark Richards,*** *NSW DPI*	**Pest patrol – RWA under the spotlight (R)** – P173 ***Jessica Lye,*** *cesar*	**Super high oleic oil safflower - a future crop option for southern NSW** – P185 ***Rosemary Richards,*** *Go Resources*
9.40 am	**Sustaining our herbicides into the future (R)** – P193 ***Chris Preston,*** *University of Adelaide*	**Utilising precision agriculture for better agronomic decisions (R)** – P199 ***Quenten Knight,*** *Agronomy Focus*	**Phosphorus stratification - affects on utilisation and access (R)** – P203 ***Graeme Sandral,*** *NSW DPI*	**Companion cropping - should we be considering it? (R)** – P215 ***John Kirkegaard,*** *CSIRO and* ***Greg Condon,*** *Grassroots Agronomy*
10.20 am	**MORNING TEA**			
10.50 am	**Phosphorus stratification - affects on utilisation and access** – P203 **Graeme Sandral, NSW DPI**	**Integrated weed management round up forum** **Overview of current adoption of HWSC, impact of chaff lining and stripper fronts on weed seed management and IWM technology based solutions** – P221 ***Mike Walsh,*** *Uni of Sydney,* ***Greg Condon,*** *AHRI, and* ***John Broster,*** *CSU*	**Utilising precision agriculture for better agronomic decisions** – P199 ***Quenten Knight,*** *Agronomy Focus*	**Canola establishment - learnings around precision planting, sowing depth and density (R)** – P229 ***Col McMaster,*** *NSW DPI*
11.30 am	**Assessing key pulse crops including lentils and chick peas** – P167 ***Mark Richards,*** *NSW DPI*		**Sustaining our herbicides into the future** – P193 ***Chris Preston,*** *University of Adelaide*	**Pest patrol – RWA under the spotlight** – P173 ***Jessica Lye,*** *cesar*

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

	Joyes Hall	Room 229/182	Room 229/178	SAVS Green Room
12.10 pm	**Applying R&D to help drive farm business profitability** – P237 ***Jordan Lindgren,*** *2018 Saskatchewan Young Farmer of the Year*	**Emerging management tips for early sown winter wheats** – P159 ***Felicity Harris,*** *NSW DPI*	**Canola establishment - learnings around precision planting, sowing depth and density** – P229 ***Col McMaster,*** *NSW DPI*	**Companion cropping - should we be considering it?** – P215 ***John Kirkegaard,*** *CSIRO and* ***Greg Condon,*** *Grassroots Agronomy*

12.50 pm **LUNCH**

1.30 pm **Served with a side of science - building community trust in food production** – P241 — ***Heather Bray,*** *The University of Western Australia*

2.10 pm **Herbicide residues in soil -what is the scale and significance?** – P247 — ***Mick Rose,*** *NSW DPI*

2.50 pm **CLOSE AND EVALUATION**

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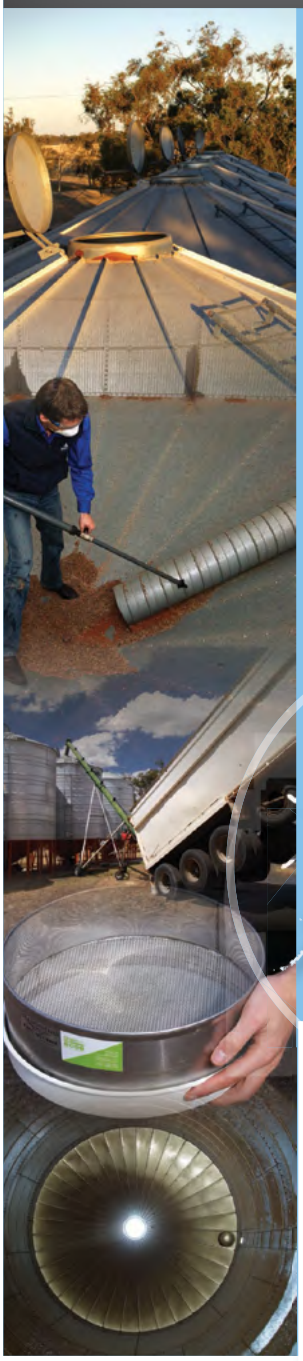

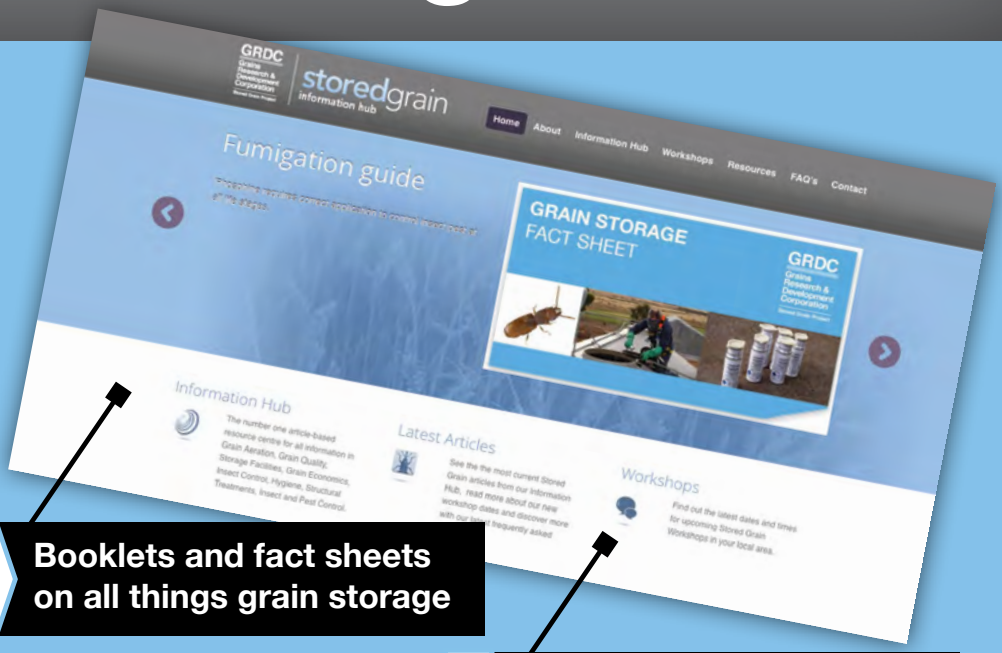

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National Paddock Survey – closing the yield gap and informing decisions

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

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

GRDC project code: BWD00025

Keywords

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

Take home messages

(from work undertaken on 15 paddocks in southern NSW, 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.
- Over the four-year rotation, 120 paddock zones were intensively monitored. Out of these, 100 paddock zones were planted to a cereal or canola. Insufficient nitrogen (N) was the main cause for the yield gap in 34 paddock zones. Half of these occurred in 2016, with the other half distributed between 2015 (10) and 2017 (7). No N deficiencies were seen in 2018. Waterlogging in 2016 caused significant damage and decreased yield. Diseases, weeds and insects also contributed, but were less severe in impact. Frost and heat shock were also a significant cause of the yield gap, especially 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

National Paddock Survey (NPS) is a four-year (2015 to 2018) GRDC 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 WA and northern NSW/Qld, and 90 in southern NSW, Vic and 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- 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 fifteen paddocks from one consultant, Chris Minehan, working in southern NSW. The results are discussed as a paddock specific yield gap analysis over four seasons focused on outcomes for the grower and 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.
- The Yield Gap is calculated as the % difference between Yw and Ya using the equation ((Yw-Ya)/Yw).

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).*

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

Results and discussion

Annual individual paddock results

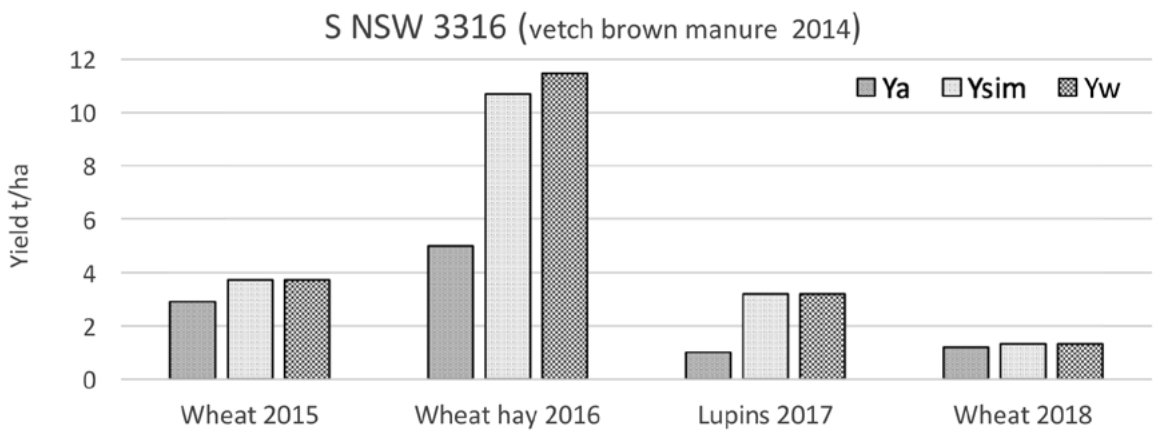
Data from three paddocks in southern NSW are presented as examples of outputs as informed by the paddock monitoring.

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: vetch brown manure (2014), followed by wheat, wheat, lupins, wheat.

Paddock southern NSW. NPS 3316 Zone A: sandy loam over 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 vetch brown manure): 189kg/ha
N available 2016 (following wheat): 216kg/ha
N available 2018 (following lupins): 172kg/ha
Water available# 2015: 296mm
Water available 2016: 524mm
Water available 2018: 182mm

*Note: * N available = soil N pre sow – N post harvest + fertiliser N*
 # Water available = water pre sow – water post harvest + in-crop rain

Disease
PREDICTA® B: all years: Pythium* mod level
Root Health GS30: 2015, 16 Low to Mod
(Fusarium observed on roots in 2015)
Fusarium stubble: not observed
In-crop GS65: not observed

Weeds
In-crop GS30: 2015 Wild Oats 1/m^2
2016 Ryegrass 6/m^2
In-crop GS65: 2015 none
2016 Toadr 80, WO 2, Stonecrop 7/m^2

Insects: not detected

Days of Heat and Frost during GS60-79

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

(note: temperature records from nearest BoM)

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

Interpretation

Crop 2014: Vetch brown manure

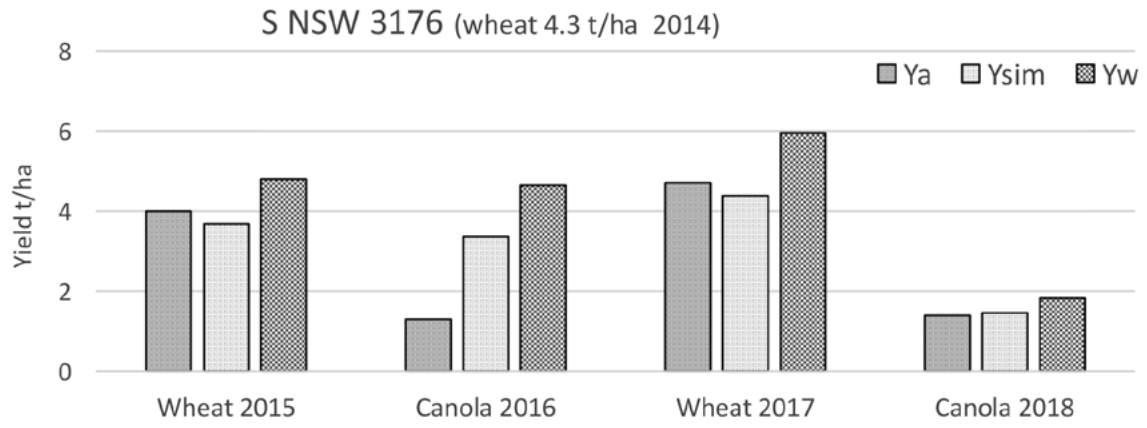
Wheat 2015: Ya<Ysim=Yw. When Ysim=Yw, it is a strong indication that the crop is not N limited. Simulated yield was 0.8t/ha (28%) higher than the actual yield which indicates some factors were limiting production. The crop did not have measurable disease, weed or insect problems. A possible factor contributing to the loss in yield appears to be one hot day during flowering and grain filling. *(Consultant note: Dart$^{\phi}$ sown on 30cm spacings on 18 May, 2015)*

Wheat hay 2016: Ya<Ysim=Yw. N unlimited yield (Yw) was similar to simulated yield (Ysim), indicating the crop was not N deficient. *(Consultant note: Ya<Ysim: The paddock was heavily grazed during the wet winter, compaction resulted and recovery was poor)*

Wheat 2018: Ya=Ysim=Yw. Dry season with a low yield (1.2t/ha) and no factors were limiting production (i.e. the crop achieved its water limited yield potential)

Example 2. Rotation: wheat (2014), followed by wheat, canola, wheat, canola.

Paddock southern NSW. NPS 3176 Zone A: sandy clay loam over light 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): 225kg/ha (68kg N from fertiliser)
N available 2016 (following wheat): 292kg/ha (100kg N from fertiliser)
N available 2017 (following canola) : 169kg/ha (73kg N from fertiliser)
N available 2018 (following wheat) : 86kg/ha (8kg N from fertiliser)
Water available# 2015: 398mm
Water available 2016: 531mm
Water available 2017: 276mm
Water available 2018: 197mm

*Note: * N available = soil N pre sow – N post harvest + fertiliser N*
 # Water available = water pre sow – water post harvest + in-crop rain

Disease
PREDICTA® B: all years: Pythium* mod level
Root Health GS30: 2015, 2017 Low to Mod
2017 Prats High
Fusarium stubble: not observed
Disease in-crop GS65: not observed
Weeds
in-crop GS30: 2015 Ryeg. 30; 2016 132, 2017 11, 2018 18/m^2
in-crop GS65: 2015 none
2016 Toadr 36/m^2
Insects: Aphid 1/m^2

Days of Heat and Frost during GS60-79

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

(note: temperature records from nearest BoM)

Consultant observations: 2016 waterlogging - lost crop; 2017 – frost damage significant

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

Interpretation

Crop 2014: wheat

Wheat 2015: Ya=Ysim<Yw. Ya = Ysim is a strong indication that the crop is not limited by biotic or abiotic stresses. Yw, potential yield, was higher than Simulated and Actual yield indicating N is limiting.

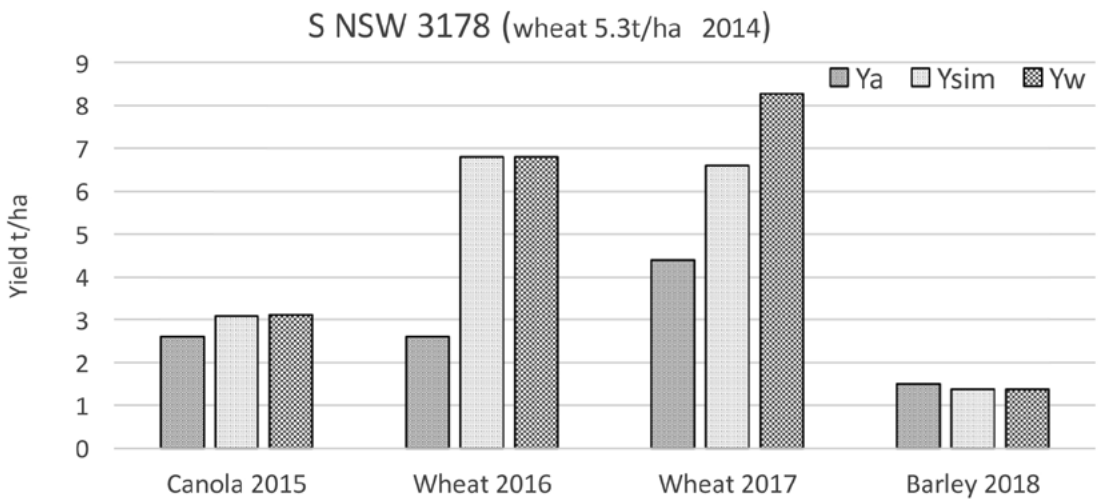
Canola in 2016: Ya<Ysim<Yw indicating that N was limiting, waterlogging was common for most of the winter. It is possible that Pythium had an effect on root development and possibly one day of frost (between 0 and -2) could have had an impact on the canola yield.

Wheat in 2017: Ya=Ysim<Yw is N limited.

Canola in 2018: Ya=Ysim=Yw no limiting factors.

Example 3. Rotation: wheat (2014), followed by canola, wheat, wheat, barley.

Paddock southern NSW. NPS 3176 Zone A: clay loam over 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): 282kg/ha (117kg N from fertiliser)
N available 2016 (following canola): 259kg/ha (115kg N from fertiliser)
N available 2017 (following wheat) : 200kg/ha (97kg N from fertiliser)
N available 2018 (following wheat) : 136kg/ha (26kg N from fertiliser)
Water available# 2015: 345mm
Water available 2016: 422mm
Water available 2017: 382mm
Water available 2018: 159mm

*Note: * N available = soil N pre sow – N post harvest + fertiliser N*
 # Water available = water pre sow – water post harvest + in-crop rain

Disease
PREDICTA® B: all years: YLS high;
Pythium* mod level in 2015, 2016 and 2017
Root Health GS30: 2016, 2017 Mod
2017 Fusarium Mod
Fusarium stubble: 2017 very low level
Disease in-crop GS65: not observed
Weeds
in-crop GS30: Ryegr. 2016 28; 2017 28, 2018 54/m^2
in-crop GS65: 2016 Prick. Let. 4/m^2
2017 Silvg 4, WO 18/m^2
Insects: not detected

Days of Heat and Frost during GS60-79

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

(note: temperature records from nearest BoM)

Consultant observations: 2016 severe waterlogging in Zone A. 2018 30% tillers frosted.

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

Interpretation

Crop 2014: wheat

Canola 2015: Ya=Ysim=Yw crop is not N limited, and no other limiting biotic or abiotic stresses.

Wheat 2016: Ya<Ysim=Yw crop is not N limited, yield penalty likely to be due to severe water logging.

Wheat 2017: Ya<Ysim<Yw crop is N limited and has been impacted by abiotic or biotic stresses (Fusarium was recorded in the stubble but only at very low levels). Wild oats were prolific (18 pl/m^2).

Barley 2018: Ya=Ysim=Yw low yielding crop with no yield penalties in a dry year.

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 break through 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 2018 southern NSW 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 & Schultz, 1984, and Sadras & Angus, 2006, calculated as Yw = 22 x (Crop Water Use – 60), 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 & Schultz (1984) and Sadras & 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 their 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 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 due to severe waterlogging in some NPS paddocks in southern NSW in 2016.

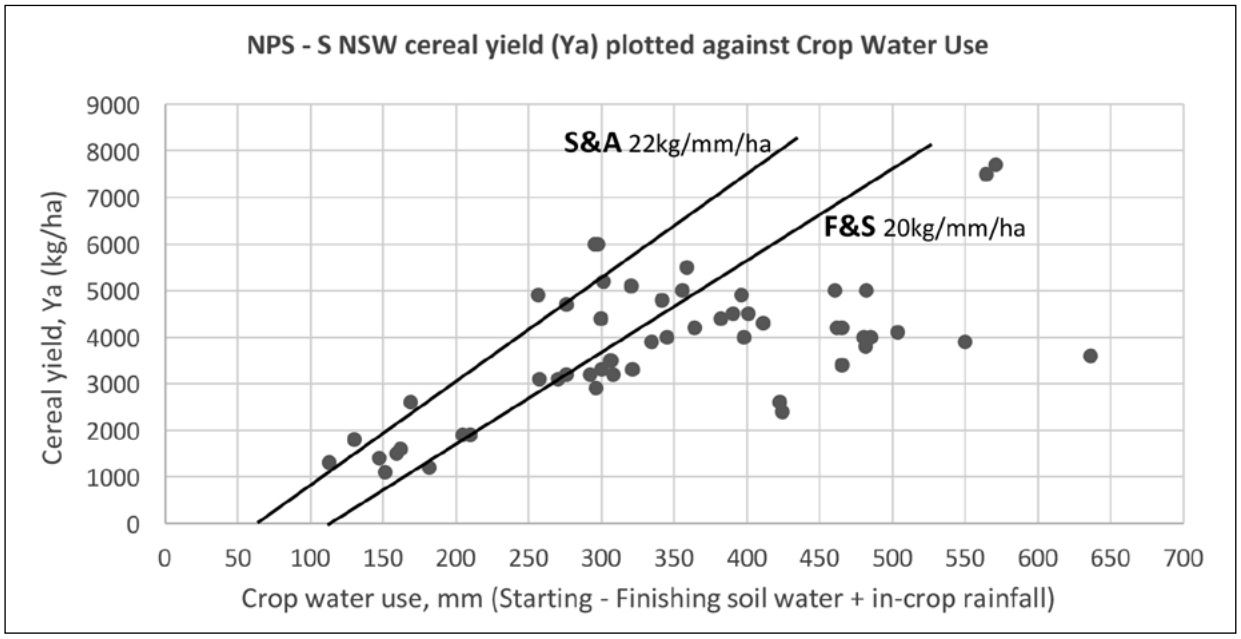


Figure 1. NPS – Southern NSW cereal yields (Ya) plotted against Water Use (2015 to 2018).

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.

High and low temperatures at critical times of crop development can further cause devastating yield loss.

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 dramatic yield loss and less serious infestations may cause greater losses than are commonly appreciated and remain unknown without careful paddock monitoring.

The nature of these biotic causes of yield loss vary 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, our 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, we need to incorporate on-the-go modelled outputs to 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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Contact details

Harm van Rees
RSD Mandurang South, Victoria 3551
0419 325 252
Harm@cropfacts.com.au

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

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

[1]*CSIRO Agriculture and Food.*

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

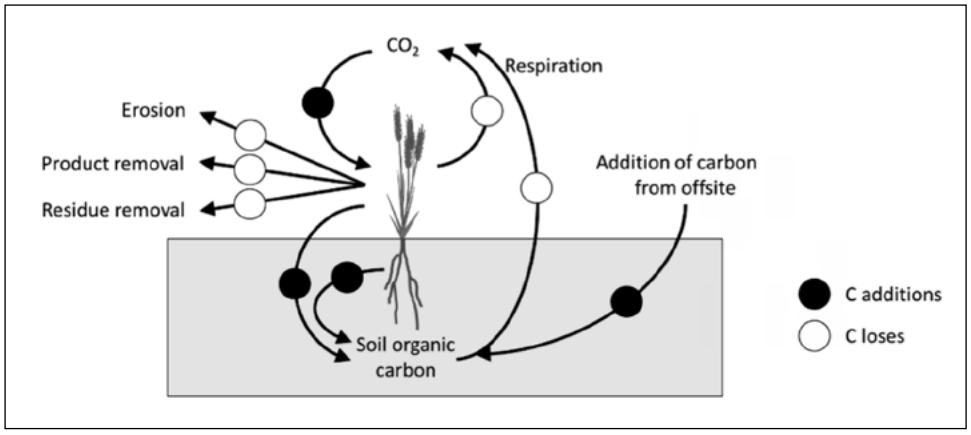

Figure 1. Carbon cycle in agricultural soils showing inputs and losses of organic carbon

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

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.

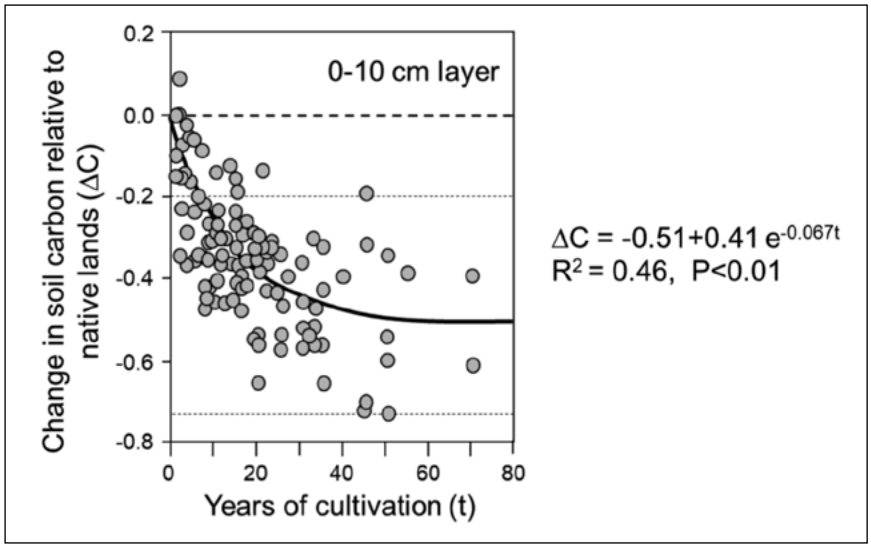

Figure 2. Change in soil organic carbon stocks of the 0cm-10 cm layer with increasing duration of cultivation relative to the stock in soils under native condition.

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

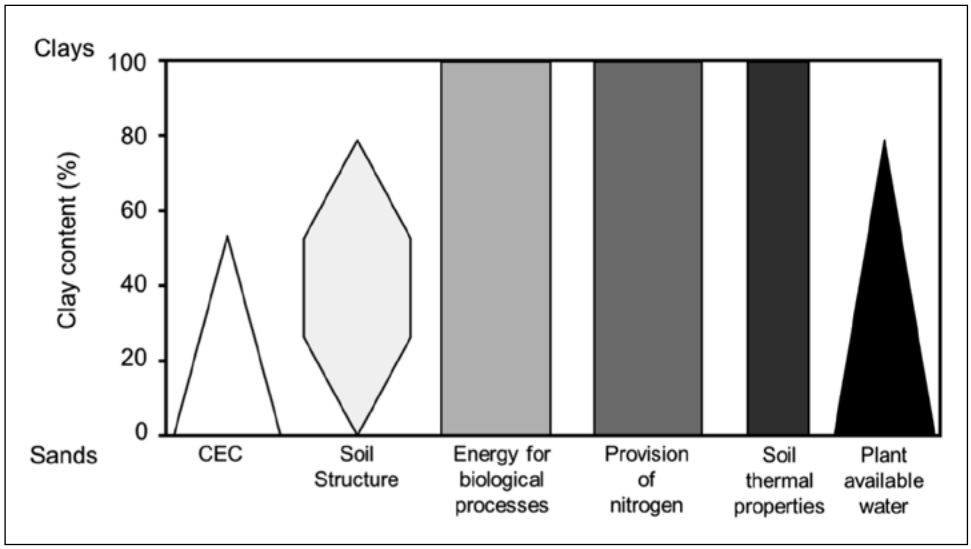

Figure 3. Conceptual contributions of the contribution of organic matter to various soil properties and functions and how this varies across soils with changes in clay content. The width of the shape corresponds to the ascribed importance at a given clay content.

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.

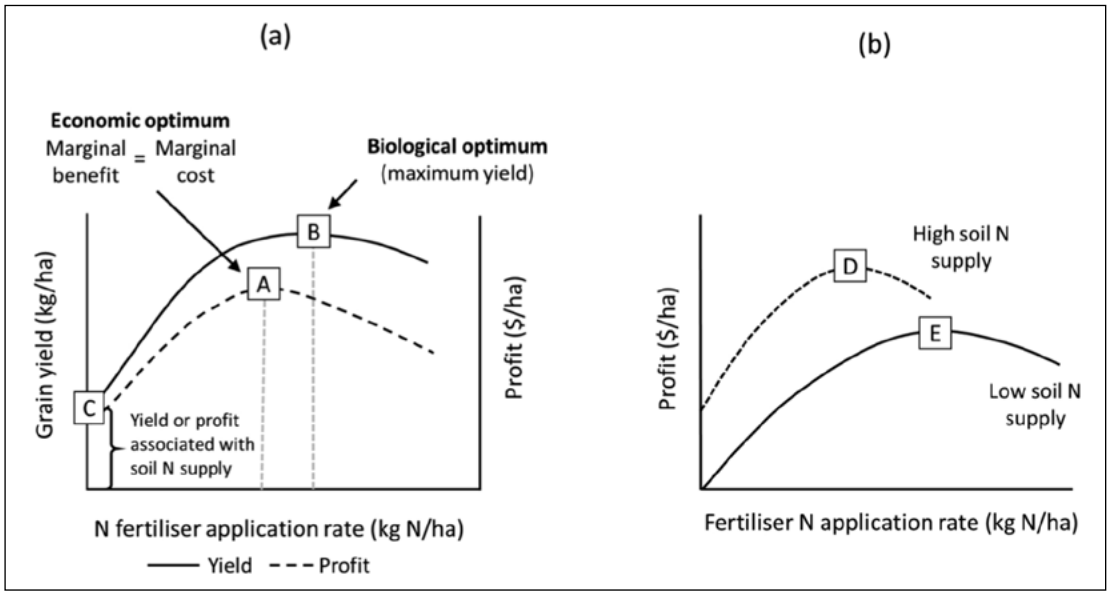

Figure 4. Changes in (a) the efficiency of fertiliser N use in terms of grain producing grain and potential relationship between biological and economic optimum yields (b) profitability of grain production with increasing fertiliser N application rates for soil with a low (solid line) or high (dashed 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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Contact details

Jeff Baldock
Locked Bag 2, Glen Osmond, SA 5064
08 8303 8537
Jeff.Baldock@csiro.au

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Nick Poole[1], Tracey Wylie[1], Kat Fuhrmann[1], Wesley Mair[2] and Fran Lopez-Ruiz[2].

[1]FAR Australia; [2]Curtin University, Centre for Crop and Disease Management, School of Molecular and Life Sciences.

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Keywords

- fungicide resistance, SDHI, QoI (strobilurin), DMI, spot form of net blotch, net form of net blotch, *Pyrenophora teres*, Septoria tritici blotch, Ramularia leaf spot.

Take home messages

- Of the three principal fungicide modes of action used regularly for broadacre disease control:
  - Group 11 quinone-outside inhibitors (QoIs) (strobilurins) are at the highest risk of pathogen resistance development, particularly the pathogens responsible for Septoria tritici blotch (STB) in wheat, and spot form of net blotch (SFNB) and powdery mildew in barley.
  - Group 7 succinate dehydrogenase inhibitors (SDHIs) are at moderate to high risk of resistance development in the pathogen with evidence in New Zealand (NZ) and Europe of pathogen shifts in sensitivity to Ramularia leaf spot in barley and net form of net blotch (NFNB) and STB in Europe.
  - Group 3 demethylase inhibitors (DMIs – triazoles) are generally considered at low to moderate risk, however recent developments in WA have challenged this view.
- Recent evidence from WA in the net blotch pathogens has revealed sinister mutations in the DMI target site governed by the *Cyp51A* gene that result in the over production of the target leading to highly resistant strains of net blotch.
- Use integrated disease management (IDM) measures (rotations, seed hygiene, resistant varieties, cultural control) to minimise the number of fungicide applications in a season. Ideally no more than one foliar application of the QoIs and SDHIs per season and no more than two DMIs.
- Never repeat the use of the same fungicide product or active ingredient in a growing season.
- Optimise foliar fungicide timings by considering the importance of the key yield bearing leaves of the crop — top four leaves in barley and top three in wheat.
- Continued monitoring of disease pathogens by the Centre for Crop and Disease Management (CCDM) is essential for early detection of pathogen resistance.

New fungicide active ingredients for better disease control

Over the past decade, there has been an unprecedented change in the fungicide armoury available to Australian growers and their advisers. At the start of the millennium, available fungicides in Australia were primarily from the older classes of DMI chemistry. Fungicide availability was limited and product introductions were a decade behind Europe. That has all changed and Australian broadacre croppers have much earlier access to newer chemistry at prices that allow far greater use. In part this availability is thanks to the manufacturers and GRDC who not only recognised the need to benchmark the sensitivity of common pathogens against available fungicide products, but also the need to encourage the registration of new active ingredients for the Australian market. The GRDC New Fungicide Actives project led by Curtin University (Project CUR 00019 and the new bilateral between Curtin/GRDC Program 9) in collaboration with the Foundation of Arable Research (FAR) Australia has worked with different target diseases in cereals and other major broadacre crops. This research has generated efficacy data that combined with manufacturers' data has led to the registration of new fungicides with new modes of action. Now that there is access to newer fungicides, such as Group 7 (SDHIs) and Group 11 (QoIs), it comes with a responsibility to look after these chemistries as although they are very effective, they are also at high risk of the pathogen's developing resistance and reduced sensitivity.

What is the current status of fungicide resistance and reduced sensitivity in Australia?

Over the past six years, the CCDM has been working with industry and other researchers to establish a fast, cost-effective monitoring system for the common diseases of broadacre grains crops. Current cases of fungicide resistance and reduced sensitivity in Australian broadacre crops are outlined in Table 1.

Table 1. Fungicide resistance and reduced sensitivity cases identified in Australian broadacre grains crops.

Disease	Pathogen	Fungicide Group	Compounds affected	Region	Industry implications
Barley mildew powdery	*Blumeria* graminis f.sp. *hordei*	3 (DMI)	Tebuconazole, propiconazole, flutriafol	Qld, NSW, Vic, Tas, WA	Field resistance to old generation Group 3 fungicides
Wheat powdery mildew	*Blumeria graminis* f.sp. *tritici*	3 (DMI)	None	NSW, Vic, Tas	This is a gateway mutation. It does not reduce the efficacy of the fungicide but is the first step towards resistance evolving.
		11 (QoI)	All group 11	Vic, Tas	Field resistance to all Group 11 fungicides
Barley net-form of net blotch	*Pyrenophora teres* f.sp. *teres*	3	Tebuconazole, propiconazole, prothioconazole	WA	Reduced sensitivity that does not cause field failure
Barley spot-form of net blotch	*Pyrenophora teres* f.sp. *maculata*	3 (DMI)	Tebuconazole, epoxiconazole	WA	Field resistance to old generation Group 3 fungicides
Canola blackleg maculans	*Leptosphaeria*	2 (MAP-Kinase)	Iprodione	WA	Not registered for this disease but used against diseases that share the same host
		3	Fluquinconazole	NSW, Vic , SA , WA	Field implication unclear
Wheat septoria leaf blotch	*Zymoseptoria tritici*	3	Tebuconazole, flutriafol, propiconazole, cyproconazole, triadimenol	NSW, Vic, SA, Tas	Reduced sensitivity that does not cause complete field failure
Chocolate spot	*Botrytis fabae*	1 (MBC)	Carbendazim	SA	Field resistance to carbendazim
Ascochyta blight	*Ascochyta lentis*	1	Thiabendazole	SA	Field resistance to carbendazim

Table 2. Mean 50% effective concentrations (EC_{50}) and resistance factors of Group 3 MR isolates, HR isolates, and eight sensitive NFNB isolates collected 1996–2012, to the fungicides tebuconazole, epoxiconazole and prothioconazole.

	Tebuconazole	Epoxiconazole	Prothioconazole
Sensitive (1996–2012)	0.23	0.11	0.07
Moderately Resistant	3.72	0.17	0.18
Resistance Factor	16.2	1.5	2.8
Highly Resistant	17.36	0.69	0.77
Resistance Factor	75.4	6.1	11.5

DMI fungicide resistance in NFNB (*Pyrenophora teres* f. *teres*) in WA

Since 2013, isolates of the pathogen causing NFNB have been detected with reduced levels of sensitivity to several DMI fungicides. Strains were classified as either sensitive, moderately resistant (MR), or highly resistant (HR) based on 50% effective concentrations (EC50) to the Group 3 compounds — prochloraz, difenoconazole, propiconazole, prothioconazole, tebuconazole and epoxiconazole (Table 2). MR strains were first found in the Great Southern (Kojonup) region in 2013 and subsequently detected throughout the WA wheatbelt and Great Southern regions. Highly resistant isolates were found in the Esperance (Scaddan), southern wheatbelt (West Arthur) and central wheatbelt (Dandaragan) regions from 2017 onwards.

Analysis of the gene for the DMI target, called *Cyp51A*, in resistant isolates revealed the presence of a point mutation, F489L, in the coding sequence found in all resistant isolates and not in any sensitive isolates. In MR isolates, a single copy of the F489L mutated allele was present. In HR isolates, up to 10 additional copies of the mutated allele were detected, indicating over production (or expression) of the *Cyp51A* gene with the F489L mutation.

DMI fungicide resistance in SFNB (*Pyrenophora teres* f. *maculata*)

Isolates of the pathogen causing SFNB with reduced levels of sensitivity to several DMI fungicides have been detected in WA since 2016. In vitro testing sorted strains into sensitive, MR, and HR groups based on 50% effective concentrations (EC_{50}) to the Group 3 compounds prochloraz, difenoconazole, propiconazole, prothioconazole and tebuconazole.The MR and HR groups showed a similar level of reduced sensitivity to epoxiconazole (Table 3). MR strains were detected from the Esperance region (Gibson and Munglinup) from 2016 onwards, and HR isolates were found in the Great Southern (South Stirling and Wellstead) and Esperance (Dalyup) regions from 2017 onwards.

Analysis of the target gene for the Group 3 (DMI) fungicide, *Cyp51A*, revealed the presence in MR and HR isolates of two different mutations that were not observed in sensitive isolates. In MR isolates, the mutation was a small fragment of DNA that was inserted in the fungicide target gene. This small fragment of new DNA was found at three different positions and its effect was over-production of the fungicide target. The presence of more fungicide target requires an increase in the amount of fungicide necessary to kill the MR isolates.

Table 3. Mean effective concentration 50 (EC_{50}) in µg/ml of Group 3 MR isolates, HR isolates, and a reference population of sensitive SFNB isolates collected between 1996 and 2013. Resistance factors (fold number difference between EC_{50} values from resistant isolates and average of sensitive isolates) are shown in brackets. Cultures were grown at different concentration ranges of the fungicides tebuconazole, epoxiconazole, prothioconazole and propiconazole.

	Tebuconazole	Epoxiconazole	Prothioconazole	Propiconazole
Sensitive (1996–2013)	0.31[a]	0.17[a]	0.07[a]	0.16[b]
Moderately Resistant (MR)	2.56 (8.6)	1.72 (10.6)	0.49 (6.8)	0.46 (2.9)
Highly Resistant (HR)	16.69 (55.9)	1.45 (8.9)	1.67 (22.9)	6.8 (43.2)

[a]Mean of 20 sensitive SFNB isolates; [b]mean of a subset of three sensitive SFNB isolates.

The small DNA fragment was also found in HR isolates, but at a different position, together with another mutation, F489L. This latter mutation has been previously observed in the closely related pathogen *P. teres* f. *teres*, the causative agent of NFNB, where it has been correlated with reduced sensitivity to a range of DMI fungicides (Mair et al. 2016).

MR strains were detected from the Esperance region (Gibson and Munglinup) from 2016 onwards, and HR isolates were found in the Great Southern (South Stirling and Wellstead) and Esperance (Dalyup) regions from 2017 onwards.

These new mutations in the net blotch pathogen in WA populations are sinister as they represent only the second example in Australia of gene overproduction (expression), the first being in NFNB pathogen in 2016 (Mair et al. 2016).

Anti-resistance measures when using fungicides

Clearly the best way to avoid fungicide resistance is not to use fungicides. However, in an IDM approach, when a variety's genetic resistance breaks down or is incomplete, it is imperative that growers and advisers have access to a diverse range of fungicides (in terms of mode of action) for controlling the disease. The main anti-resistance measures in cereal crops that growers can adopt when using fungicides are:

- To minimise the number of fungicide applications using the same mode of action using other IDM measures to assist in controlling disease (rotations, seed hygiene, resistant varieties, cultural control and grazing used in conjunction with less fungicides).
- Avoid repeat applications of the same product and mode of action in the same crop and/or year after year, particularly when using QoI (strobilurins) and SDHIs alone, such as the seed treatment fluxapyroxad (Systiva®).
- Never apply the same DMI (triazole) Group 3 fungicide twice in a row.
- Avoid using tebuconazole as a stand-alone product in barley for any disease to avoid indirect fungicide resistance selection.
- Triazoles used alone are best reserved for less important spray timings targeted at less important plant structures that have historically given poorer economic returns and in situations where disease pressure is low.
- Ideally, use DMI-based mixtures (e.g. Prosaro® containing prothioconazole and tebuconazole) only once, followed by mixtures containing other actives (preferably from Groups 7 or 11).
- Ideally, apply no more than one QoI (strobilurin) or one SDHI in the course of a growing season (the current limit for registered foliar products is two applications of each mode of action in a season with seed treatments effective on foliar disease counting as one of those applications).
- For most scenarios in Australia, with the exception of Tasmania and some parts of the high rainfall zone (HRZ), two broad spectrum fungicide inputs should be regarded as a maximum in order to control the vast majority of disease outbreaks in susceptible varieties, with most crops requiring none or one application.
- With SDHI seed treatments that have activity on foliar diseases later in the spring, such as fluxapyroxad (Systiva®), consider foliar fungicide follow ups, which have a different mode of action and avoid repeat usage of Systiva® alone in successive years.

Influence of fungicide rate

The reality is that using the most appropriate rate for effective disease control (lower label rates for lower disease pressure and higher label rates for higher disease pressure) is the best strategy for managing resistance. Label rates have been developed to provide robust and reliable control of the target disease.

In many cases, the full label rate is the most appropriate rate for control. However, for diseases, the lower rate from the label range of a fungicide can be used in conjunction with a crop variety that has a good disease resistance rating, because disease pressure will be lower. There is evidence that using a higher rate than necessary increases the risk of resistance as removing all of the sensitive pathogen isolates provide more opportunity for resistant isolates to dominate the population and hence be the strain colonising the plant.

Conclusion

In summary, there are some exciting new fungicides available to us as an industry. Whilst we should not be afraid to use these agrichemicals when necessary, their longevity needs to be protected by considering the number of times they are used in a growing season. The evidence in Australia is increasing to suggest that whilst there

is more rapid access to new fungicides than 15 years ago, there are also more issues with fungicide resistance. With the sound principles of IDM applied and a good monitoring system, we can at least slow down the development of resistance and increase the longevity of the fungicides being used.

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Contact details

Nick Poole and Kat Fuhrmann
FAR Australia
23 High St, Inverleigh, Victoria 3221
03 5265 1290
nick.poole@faraustralia.com.au

Fran Lopez-Ruiz
Curtin University, Centre for Crop and Disease Management
School of Molecular and Life Sciences
Perth WA 6845
08 9266 3061
fran.lopezruiz@curtin.edu.au

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Notes

Crown rot – what is the threat coming out of a dry year?

Steven Simpfendorfer[1] and Alan McKay[2].

[1]NSW DPI, Tamworth; [2]SARDI, Adelaide.

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- Fusarium, wheat, barley, stubble, infection, disease expression, decomposition, PREDICTA®B.

Take home messages

- Dry seasons which reduce crop biomass production and yield still increase crown rot inoculum levels within paddocks, but to a lesser extent than in good seasons.
- Decomposition of previous cereal stubbles which harbour the crown rot pathogen, even under break crops (e.g. canola), is reduced in dry seasons. Hence, inoculum levels may not have declined significantly since harvest of 2017 cereal crops.
- PREDICTA® B is a reliable technique for assessing the risk of crown rot and a range of other soil-borne or stubble-borne pathogens prior to sowing in 2019.
- PREDICTA® B also has new tests for sclerotinia stem rot in canola as well as pulses and yellow spot in wheat. Tests for septoria tritici blotch of wheat and net blotches in barley are under consideration for next season.
- Follow sampling recommendations in the manual V10.2 (http://rootdisease.aweb.net.au), including the addition of pieces of cereal stubble to improve the detection of stubble-borne pathogens such as the crown rot fungus.

Background

Grain producers have become more proficient at Crown rot, caused predominantly by the fungus *Fusarium pseudograminearum*, is a significant disease of winter cereals across Australia, including southern NSW. Infection is characterised by a light honey-brown to dark brown discolouration of the base of infected tillers, while major yield loss from the production of whiteheads is related to moisture and/or temperature stress post-flowering. It is critical to understand that there are three distinct and separate phases of crown rot, namely survival, infection and expression. Management strategies can differentially affect each phase.

Survival

The crown rot fungus survives as mycelium (cottony growth) inside winter cereal (wheat, barley, durum, triticale and oats) and grass weed residues, which it has infected. The crown rot fungus will survive as **inoculum** inside the stubble for as long as it remains intact, which varies greatly with soil and weather conditions as decomposition is a **very slow** process. The crown rot fungus has been shown to survive as mycelium for up to three years in infected cereal residues (Summerell and Burgess 1988).

Infection

Given some level of soil moisture, the crown rot fungus grows out of stubble residues and infects new winter cereal plants through the coleoptile, sub-crown internode or crown tissue which are all below the soil surface. The fungus can also infect plants above ground **right a**t the soil surface through the outer leaf sheathes. However, with all points of infection, direct contact with the previously infected residues is required and infections can occur throughout the whole season given moisture. Hence, wet seasons favour increased infection events by the crown rot fungus and when combined with the production of greater stubble loads significantly builds up inoculum levels.

Expression

Yield loss is related to moisture/temperature stress around flowering and through grain-fill. This stress is believed to trigger the crown rot fungus to proliferate in the base of infected tillers, restricting water movement from the roots through the stems, and producing whiteheads that contain either no grain or lightweight shrivelled grain. The **expression** of whiteheads in plants infected with crown rot (i.e. still have basal browning) is restricted in wet seasons and increases greatly with increasing moisture/temperature stress during grain-fill. Focus attention to crops around trees within a paddock or along tree lines. Even in good years, whiteheads associated with crown rot infection are likely to be seen around trees. This is due to the extra competition for water.

Correct diagnosis is important

In southern NSW in 2018, the expression of whiteheads from crown rot was confused with stem frost and/or drought tipping of wheat heads. In wetter seasons, whiteheads associated with crown rot can also be confused with those caused by a different fungal pathogen (*Gaeumannomyces graminis* var. *tritici*) which causes take-all (hay-die). Whiteheads (deadhead) caused by crown rot can be confirmed by tracking that head down to the tiller base which will always have a brown discolouration under the leaf sheath. Deadheads associated solely with stem frost will not have brown tiller bases but tend to have blistering on the stem at the point where the frost formed. This is quite often at a uniform height in adjacent plants. Drought stress tends to make the tip of the heads die rather than the whole head and equally will not have brown tiller bases if crown rot is not also present.

Take-all and crown rot can also be differentiated easily. Take-all causes all heads on an infected plant to form whiteheads while individual tillers normally only produce whiteheads with crown rot, unless the severity of infection is very high. Take-all causes the tiller bases to have a black rather than honey brown appearance, as with crown rot. Take-all infected plants will also have areas of blackened roots. Take-all affected plants are easily pulled out of the ground, while plants affected by crown rot are generally anchored well. However, plants with severe crown rot may snap at the lowest nodes if plants are pulled from dry soil around harvest. Crown rot can infect roots, but it does not cause the same level of damage as take-all.

If you are unsure, then samples can be submitted to NSW DPI pathology services at Wagga Wagga or Tamworth for confirmation.

But we don't get crown rot in southern NSW

Even with recent research on the distribution and management of crown rot in southern NSW farming systems (Milgate and Baxter 2018), some growers, advisers and researchers are still surprised when whiteheads appear in wheat crops in this region, such as in 2018. The crown rot fungus is a stubble-borne pathogen which hosts inside residue of all winter cereals and grass weeds (especially barley grass, phalaris, annual ryegrass and wild oats). Grass weeds are a major concern as they not only act as a source of crown rot inoculum, but also compete for soil water during the crop or fallow phase, which can induce crop stress and exacerbate the expression of whitehead. The increased adoption of stubble retention practices has seen an associated rise in the incidence of fusarium crown rot globally. So why would southern NSW be any different?

So, to answer the following statements:

- **We don't get crown rot in southern NSW.** Yes, you do. Medium to high levels of **infection** occur in some paddocks. Southern NSW tends to have less stress during grain-filling which reduces the **expression** of whiteheads, except in dry seasons such as 2018.
- **Crown rot is only a disease of dry seasons.** Incorrect. Crown rot **infection** is favoured by moist conditions and increased cereal biomass in wetter seasons increases potential inoculum loads (Table 1). Rather, the **expression** of whiteheads in tillers infected with crown rot only occurs when dry and/or hot conditions occur during grain filling.

- **Cropping systems in southern NSW are favouring build-up of crown rot inoculum within paddocks with infection of cereal crops occurring in all seasons. We simply tend to get lower expression of whiteheads associated with crown rot infection, except in seasons with dry/hot conditions during grain filling.** Correct.

A quantitative DNA-based soil testing service, PREDICTA® B, is available in Australia to assist grain growers to predict the likely risk of soil-borne and stubble-borne diseases by measuring pathogen levels prior to planting. Growers have the option of changing varieties or modifying cropping programs in situations where the risk of crop loss is high. Presenting PREDICTA® B results mapped to each town as pie charts helps to highlight higher risk cropping areas for different diseases, such as crown rot, prior to sowing which can be used to inform industry. Note, the size of each pie chart is proportional to the number of samples mapped to the town and the numbers of low, medium and high disease risk samples are presented as green, orange and red sectors, respectively (Figure 1, n.b. colour version available at http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b)

Although the level of PREDICTA® B testing (size of each pie chart and number) is generally lower in southern NSW, especially in central NSW, than other regions of Australia, there were still a considerable number of the paddocks tested with a medium (orange) to high (red) risk of developing crown rot in 2018 (Figure 1). Encouragingly, there are a higher proportion of paddocks in southern NSW where inoculum of the crown rot fungi were not detected (white colour). The build-up of inoculum levels is very much on a paddock-by-paddock basis dependent on initial presence of the pathogen, rotation (frequency of cereals), grass weed control, stubble management, row placement and biomass production (yield).

Inoculum of the crown rot fungus is present in many paddocks in southern NSW (Figure 1). However, the increased reliability of rainfall plus cooler relative temperatures during flowering and grain-filling, especially in south-east NSW, normally limits expression of whiteheads in crown rot infected tillers.

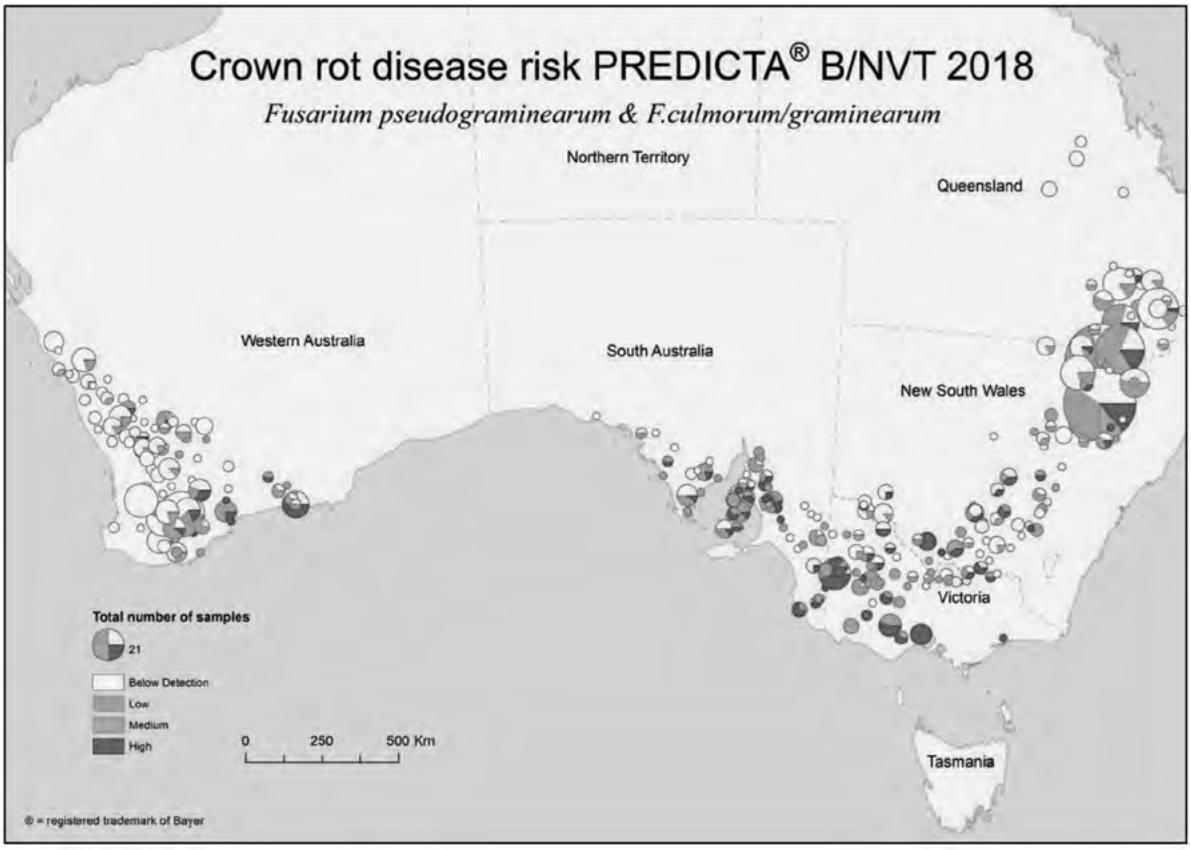

Figure 1. Distribution and levels of Fusarium spp. associated with causing crown rot prior to sowing in 2018 *(Source: PIRSA).*

What happens to crown rot inoculum in a dry year?

Just remember the key fact here is that the crown rot fungus is a stubble-borne pathogen of cereal crops and grass weeds. Hence, inoculum levels are a function of the number of plants infected with the crown rot fungus and the biomass (number of tillers) produced by the cereal crop. A simple equation was developed by Backhouse (2006) to forecast likely crown rot infection levels in successive wheat crops where:

Incidence of infection in 2019 = 5.25 x square root of (incidence of infection in 2018 x yield)

In the equation, 5.25 is an average infection constant developed from field experiments and yield of the previous wheat crop is taken as a surrogate for biomass (Backhouse 2006). The equation can be used to highlight the likely impact of a dry season, with reduced biomass production (crop yield), on crown rot inoculum levels and hence infection in a following cereal crop (Table 1).

A similar level of crown rot infection in 2019 (23%) will occur in theory following a failed crop (1.0t/ha) with 20% infection in 2018, or a moderate yielding crop (2.0t/ha) with 10% infection in 2018, or even a good crop (4.0t/ha) with 5% infection in 2018 (Table 1). Note that the incidence of infection in 2018 is not based on e**xpression** of whiteheads as this can underestimate crown rot levels. It should be based on the incidence of characteristic basal browning or plating to recover the causal pathogen Fp. This process is simplified by using PREDICTA®B testing prior to sowing.

Decomposition of previous cereal stubbles which harbour the crown rot pathogen, even under break crops (e.g. canola), is reduced in dry seasons. Inoculum levels may not have declined significantly since harvest of 2017 cereal crops. Hence, dates in Table 1 could be changed to reflect cereal crops grown in 2017 in regards to measured crown rot infection levels and yield, even though a canola break crop may have been grown in 2018.

The actual risk of yield loss from crown rot in 2019, however, is more complicated as it is a function of inoculum levels present at sowing (PREDICTA®B or other assessment), cereal crop and variety grown, soil water storage, sowing time, sowing implement, row placement, biomass production (e.g. nitrogen (N) nutrition and tiller number/m^2), in-crop rainfall and temperature during grain filling (i.e. evapotranspiration stress). Unfortunately, an equation does not currently exist to determine the actual risk of yield loss from crown rot (????). Do you want to add a comment here that CR risk category will be developed in future?

Crown rot detection using PREDICTA®B

PREDICTA®B is a reliable technique for assessing the risk of crown rot and a range of other soil-borne or stubble-borne pathogens prior to sowing in 2019. PREDICTA®B has been used extensively in recent crown rot experimentation in southern NSW (Milgate and Baxter 2018).

Additionally, studies undertaken in collaboration with National Variety Trial (NVT) and National Paddock Survey (NPS; BWD00025) projects, showed that avoiding stubble when collecting PREDICTA®B samples led to a significant under estimation (failure to warn) of the risk of crown rot. This can be fixed by adding one 5cm piece of stubble (including crown) from the base of the previous winter cereal or grass weed plants (one to several years old) from the 15 different locations where soil cores are collected. Adding stubble in this way also facilitates testing for other stubble-borne pathogens (e.g. yellow leaf spot and septoria tritici blotch in wheat or net blotches in barley, when tests for the latter are added).

PREDICTA® B new developments

PREDICTA® B is under continual development to provide a comprehensive assessment of the levels of soil-borne and stubble-borne pathogens that pose a potential risk to cereals and increasingly, pulse and oilseed crops. The aim is to provide a fast

Table 1. Simple model predicting the incidence of crown rot infection in cereal crops in 2019 (Backhouse 2006).

% infection 2018	Cereal yield in 2018 (t/ha)				
	1.0	2.0	3.0	4.0	5.0
5	12	17	20	23	26
10	17	23	29	33	37
20	23	33	41	47	53
30	29	41	50	58	64
40	33	47	58	66	74
50	37	53	64	74	83

and cost-effective way for growers to determine the soil-borne and stubble-borne disease risks within a paddock, to help inform decisions of crop and variety choice and guide management to minimise losses.

Further information on the 'tests under evaluation' can be found at http://pir.sa.gov.au/research/services/molecular_diagnostics. SARDI accredited consultants can obtain information on new tests and management options in Version 10 of the Broadacre Soilborne Disease Manual, available at: http://rootdisease.aweb.net.au/

To fast track delivery of new tests, these results are reported with categories based on population density so growers and consultants can benchmark levels of pathogen DNA detected in paddocks against the rest of industry. When the relationship between the initial pathogen level and disease has been defined, the level detected in the sample is reported with a disease risk rating. Of particular interest to southern NSW cropping systems is a new test reporting population densities of *Sclerotinia sclerotiorum*, which causes sclerotinia stem rot in canola and pulse crops (Figure 2 n.b. colour version available at http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b). A further test for population densities of Pyrenophora tritici-repentis, the cause of yellow spot in wheat, is also being reported in 2019. Tests for septoria tritici blotch of wheat and net blotches in barley are also currently being implemented.

Conclusions

Southern NSW is not immune from crown rot in cereal crops. Dry seasonal conditions (e.g. 2018) favour the **expression** whiteheads, making the disease more conspicuous to growers, advisers and even researchers. Longer term management to reduce losses from crown rot requires understanding of the pathogen across seasons whether they be wet, dry or in between. PREDICTA®B offers a reliable technique to monitor crown rot inoculum levels across seasons (wet and dry); rotation sequences; and the success of varying integrated management strategies which may be implemented, but do not forget to add stubble to the soil sample. A single PREDICTA®B test further allows levels of a range of other soil-borne and stubble-borne pathogens (e.g. rhizoctonia root rot, take-all, root lesion nematodes) to be determined with newer tests for yellow spot in wheat, along with sclerotinia stem rot in canola and pulses recently being included.

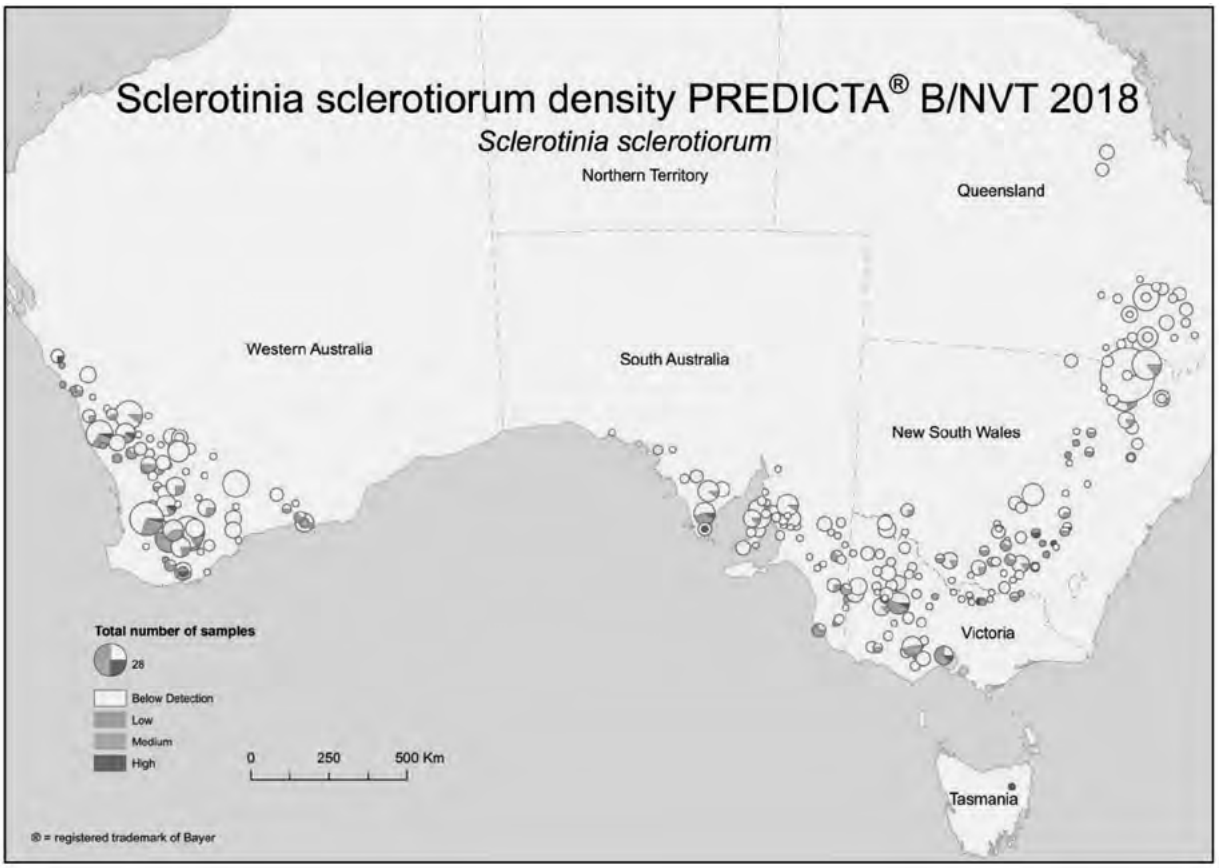

Figure 2. Distribution and levels of Sclerotinia sclerotiorum prior to sowing in 2018.

Useful resources

https://grdc.com.au/resources-and-publications/groundcover/ground-cover-supplements/groundcover-issue-130-soil-borne-diseases/correct-sampling-a-must-to-accurately-expose-disease-risk

https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/tt-crownrotwintercereals

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Contact details

Steven Simpfendorfer
NSW DPI
4 Marsden Park Rd, Tamworth NSW 2340
0439 581 672
steven.simpfendorfer@dpi.nsw.gov.au
@s_simpfendorfer

Alan McKay
SARDI
Adelaide SA 5064
08 8429 2216
alan.mckay@sa.gov.au

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Nutrition decisions following a dry season

Graeme Sandral[1], Ehsan Tavakkoli[1,2], Rohan Brill[1], Felicity Harris[1], Russell Pumpa[1], Maryam Barati[1], Eric Keotz[1] and John Angus[3].

[1]New South Wales Department of Primary Industries, Wagga Wagga Agricultural Institute, Wagga Wagga, NSW; [2]Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga, NSW; [3]CSIRO Agriculture and Food, PO Box 1700, Canberra ACT 2601 and EH Graham Centre, Charles Sturt University, Locked Bag 588, Wagga Wagga, NSW.

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

Contact details

Graeme Sandral
NSW DPI, Wagga Wagga Agricultural Institute
0409 226 235
graeme.sandral@dpi.nsw.gov.au
@gsandral

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Effective soil sampling – high and low cost options to gain soil fertility information for management.

Jason Condon.

Graham Centre for Agricultural Innovation, Charles Sturt University and NSW Department of Primary Industries, Wagga Wagga, NSW.

Keywords

- soil sampling, variability, zonal management.

Take home messages

- Soil is inherently variable.
- Grid sampling can create high density information but perhaps is not necessary.
- No/low cost tools exist to enable zones to be identified for sampling and potential management.

Background

Efficient nutrient and soil management of agricultural land relies on soil testing to provide the analytical data to be used in decisions relating to fertiliser and soil amendment application. Soil testing is comprised of soil sampling, analysis and interpretation, which then allows an informed recommendation to be made. Of these, soil sampling provides possibly the greatest unrealised error.

There are different methods which can be utilised to sample a paddock. In the past, the recommended method was to take a multicore (25-30 cores), composite sample to be sent to an accredited laboratory for analysis. The locations of the sites to be cored could be completely random or situated along transects marked by features such as posts on fence lines or recorded global position system (GPS) locations. To decrease the time taken to obtain samples, cluster sampling has evolved. This involves taking five samples at each of five sites within the area to be sampled. With more thought, areas within the paddock could be identified as different zones to be managed. These zones may be identified by production (areas of good or bad growth) or soil properties (colour, texture, slope). Once identified, each zone can be multi-cored to produce separate composite samples for analysis, interpretation and fertiliser recommendation for each zone.

With the greater availability of GPS equipped machinery and variable rate technology, there has recently been more interest in obtaining greater spatial precision in soil sampling and creating site specific soil recommendations. Some businesses are now offering grid sampling, using composite multicores of multiple grid sites, or in-field 'on the go' or point sampling services which provide growers with variable rate recommendations for their paddocks at a fine scale (e.g. 10 points per hectare). However, these services come at a cost which currently exceeds traditional soil sampling costs leaving growers with questions relating to the cost/benefits of soil sampling methods. Some have answered these questions by creating maps of, for example, soil pH and variable lime rate recommendations based on grid sampling and then comparing these to a single rate lime application based on a soil test value created by multicore-composite sampling of the same area. Not surprisingly this makes the higher cost option of grid sampling seem beneficial in cases where it is not necessary to lime the whole area. However, it may be argued that 'adequate' or 'efficient' recommendations could be made utilising low or no cost information to identify zones to be sampled. In order to do this, knowledge of factors creating soil and production variability needs to be understood.

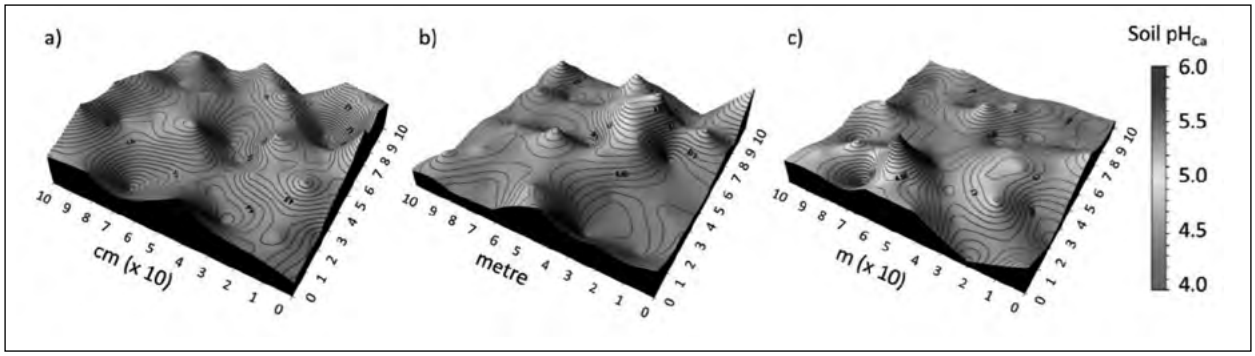

Figure 1. Soil pHCa from the 0cm - 5cm soil layer from a 10 x 10 grid within areas of 1m^2, 10m^2 and 100m2 *(Source: Moodie and Condon, unpublished).*

Soil variability

Spatial variability in soil physical and chemical (and therefore biological) properties exists horizontally and vertically. That is, soil properties can be expected to be different as we move across a paddock or as we dig down into soil. If we treat a paddock as one management unit and sample it as such, the variability is not realised in the information created by the analysis and inefficiencies are likely to occur in the fertiliser applications made.

The magnitude of variability of commonly measured soil properties has been reviewed (Rossel and McBratney 1998). Conyers and Davey (1990) demonstrated that in grazed pastures the magnitude soil pH variation that existed over a grid of 16m also existed in a 1m grid located within the larger area. This magnitude of spatial variability is visually represented in Figure 1 where soil from a visually uniform area was core sampled (20mm diameter cores) from the 0 - 5cm layer of soil from 10 x 10 point sample grids at scales of 10cm, 1m, 10m' i.e. 100 samples each from an area of 1m^2, 10m^2 and 100m^2, respectively (Moodie and Condon, unpublished).

To account for this level of variability in a measured soil sample in the field, multiple cores are taken to find the average pH of the area. Statistically, 25 to 30 subsamples provided a sample mean that represents the mean of the area. With the use of grid sampling and software that allows values from point samples to estimate unmeasured areas between the grid points (a process called kriging), maps can be made that report kriged values for management pixels. The density of sampling points required to give confident kriged values is determined by the variability of the measured property in the field. Based on values of variability reported in the literature, it has been estimated that to manage land at pixels of 20m x 20m scale using precision agriculture technologies, a sampling interval of 30m would be required for grid sampling (McBratney and Pringle 1999), making the process economically unviable if using traditional laboratory analysis (Rossel and McBratney 1998). As a response to this limitation, 'on the go' measurement technologies are being developed which lower the cost of gaining a data point which can then be used to formulate management recommendations. For example, commercial services for 'on the go' measurement of soil pH, clay and organic matter content and EM38 services are currently available. Another option is to create composite samples (e.g. 8- 12 cores) from each subsampled grid cell (e.g. 1-4 hectares). That is, create sampling grid cells that are multi-cored to enable more confidence that the composite sample from each grid better represents the soil in the field within that grid cell. Then use the grid to create maps and spatially variable fertiliser recommendations. An example of this is shown in Figure 2 where soil pH was measured from approximately 39 sampling grid cells.

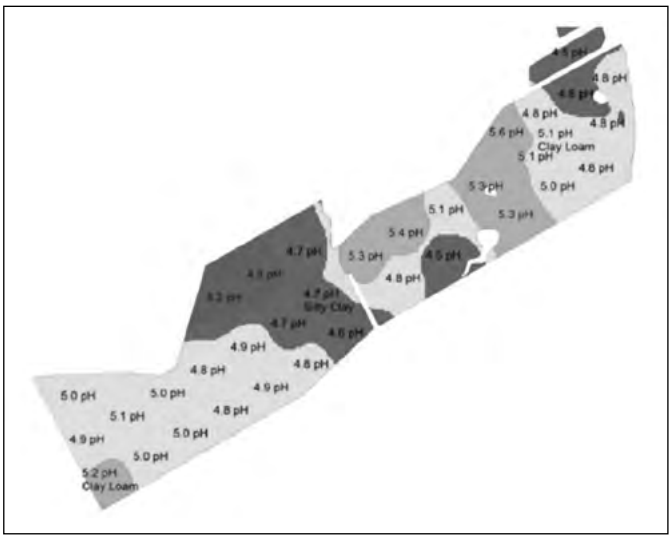

Figure 2. Soil pH map of a paddock. Data produced from 0-10cm multi-cored composite samples of 2 hectare grids.

The economic comparison of these methods is highly dependent on the cost of analysis, the actual variability in the field, and the factors that are influencing yield within the paddock. Some comparisons demonstrate theoretical savings compared to single rate applications of lime while experimentally, a lack of economic return can occur (Rossel et al. 2001, Bianchini and Mallarino 2002). Regardless, knowledge of why soil variability exists may enable low cost alternatives to high cost, data rich sampling strategies.

What causes spatial variability?

Variation in soil properties exist as a result of processes or factors that form and change the soil. The five main soil forming factors are climate, organisms, relief (topography), parent material and time (Jenny 1941). Understanding these soil-forming factors helps enable us to identify where differences in soils may exist.

At a paddock scale, climate can be discounted in our discussion to identify within paddock variability. Organisms can alter soil due to biochemical processes, but they are also tools which enable soil variability to be identified. For example, remanent vegetation species are often linked to the soil properties; pine trees are found on one soil type, eucalyptus trees on another, acid tolerant weed species can mark areas of low pH, and salt tolerant species may indicate locales of possible salinity.

Changes in parent material can influence soil colour, texture and nutrient status. It is possible to have parent material changes at a paddock scale and these are often also linked to relief (topography). For example, moving from a hill top to a gentle slope to an alluvial flat. Topography also influences soil depth and determines water movement through the landscape. When the land was initially cleared, changes in soil colour, texture and topography were the basis for setting paddock boundaries as it was understood that changes in these soil properties would create soils that require different management.

The final factor, time, in the context of soil formation, relates to geologic time but for identifying within paddock variation, is probably best represented as the effect of our management on soil over time. For example, clearing land and burning trees, the agricultural enterprise selection and fertiliser use can all influence soil chemical properties in each paddock; and there tends to be more variation of soil chemical properties in grazed pastures than in cultivated cropping fields (Conyers and Davey 1990). The use of precision placement of fertiliser in, under or beside the sowing row has now created a new (but perhaps predictable) source of variability of some measured properties, (e.g. soil pH), as fertilisers are placed in the same location each time crops are grown. Another source of management derived variation within paddocks is the removal of fences and consolidation of paddocks as the scale of machinery and area of land managed increases. This essentially brings soil of different management history within the same paddock and introduces another source of variation to the paddock.

Application of knowledge to create savings

Using the paddock demonstrated in Figure 2 as an example, the paddock was part of a recently acquired property, no yield data were available, topography was relatively flat, and only a small number of one species of remanent trees existed. The most recent, free imagery available (Figure 3a)

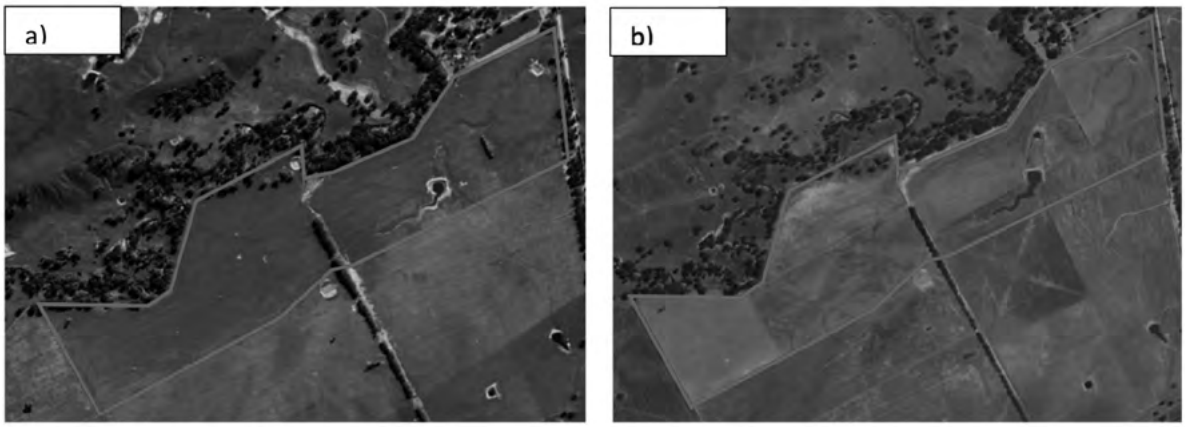

Figure 3. Imagery taken in (a) 2018 of a recently acquired paddock under management and (b) the same area in 2010.

showed some variability in plant growth around the dams and slight drainage line. However, utilising historic free imagery (Figure 3b) from 2010, it could be seen that the current paddock is a composite of seven prior paddocks. These prior paddocks (Figure 3b) could easily be designated separate zones for sampling (i.e. to produce seven multi-cored-composite samples). Within each of the prior paddocks, areas of visual difference are apparent and could be used to create additional zones for sampling. Using this method 11 zones could be identified (Figure 4) which could be multi-cored-composite sampled at low cost with only 11 samples sent for analysis. This strategy would greatly decrease the cost of data acquisition to enable utilisation of variable rate lime application.

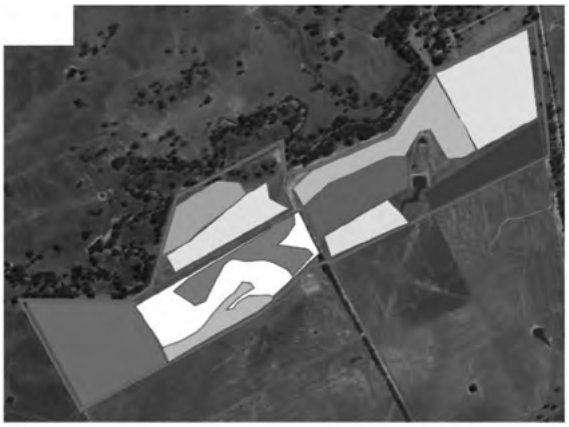

Figure 4. Zone designation based on prior fences and differences in vegetation colour evident in Figure 3b.

The use of free normalised difference vegetation index (NDVI) images and yield maps are also useful in the process of identifying zones of different plant production which may be the result of variations in soil properties. In addition to these plant-based spatial variability identifiers, the low-cost tools available to growers to identify different zones based on soil formation knowledge are collated in Table 1. The information created by grid sampling is highly valuable to the identification of zones or implementation of site specific management, however that information comes at significant cost.

The informed identification of sampling (and potential management) zones using the tools listed in Table 1 would appear to be the lowest cost method of gaining information to utilise variable rate technology. Utilisation of other forms of spatial data (EM38) or other examples of 'on-the-go' sampling further contributes to the information gained but the cost of acquisition then becomes a factor in the economic benefit of the process. The example provided here (Figure 4) was able to pick the areas of pH extremes that were evident in Figure 2. Though not all zones would require different management, the lower number of samples sent for analysis, compared to grid sampling, allows financial resources to be repurposed for the analysis of greater numbers of depth increments, e.g. 5cm intervals for A horizons (soil before the clay begins) in duplex soils, providing more information on the soil profile rather than just 0cm-10cm soil fertility. For example, if the analysis of a sample cost $100, the 39 samples of the grid would cost $3900 for analysis alone. Sampling from 11 zones in the 0-5cm, 5-10cm, 10-20cm layers (or 0-10cm, 10-20cm, 20-30cm) would cost $3300. The process of sampling would also allow the opportunity to experience soil variability in soil physical properties during sampling (e.g. hard pans, structural changes, etc). At the very least, 0-10cm sampling of the 11 zones would come at cost of $1100 representing lower cost information acquisition than grid sampling.

It should be acknowledged that the information obtained from soil testing is used to formulate fertiliser recommendations based on relationships between soil test values and plant production (calibration curves) that are not perfect and that exhibit their own variability. Therefore, precision in sampling does not necessarily ensure improved outcomes from fertiliser recommendations.

Table 1. Identifying factors and no or low-cost tools available to designate zones of potentially different soil fertility.

Source of variability	Identifying factor	No/low cost tool	Confirmation by yield map	Management
Soil type change	Soil colour Soil texture Remanent vegetation	Free digital imagery, coring, observation	Yes	Zonal
Topography	slope	Elevation from RTK GPS, DEM	Yes	zonal
Paddock consolidation (fence removal)	Presence of strainer posts or gate posts	Historic records, Free digital imagery through time	Yes	zonal
Grazing animals	Vegetation (urine/dung patches)	In field observation	No	Cannot be zoned or managed
Fertiliser rows	None	On row coring	No	Row zoning

Conclusion

The sampling strategies mentioned here aim to decrease errors in sampling. Spatial differences in soil properties are only one source of variation in agricultural productivity from a paddock. However, identifying areas of different input requirement and managing them separately can be a method of increasing production efficiency. Ultimately the grower may choose to employ whatever sampling services at their disposal and of their interest, but in terms of resource optimisation, the implementation of soil knowledge with low cost or free information can allow for adequate zonal management decisions to be made.

Useful resources

www.grdc.com.au/GRDC-FS-SoilTestingS

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Acknowledgements

The image presented as Figure 2 was provided by an undisclosed third party. Digital images presented in Figures 3, 4 were obtained from Google Earth.

Contact details

Jason Condon
Graham Centre for Agricultural Innovation,
Locked Bag 588, Charles Sturt University,
Wagga Wagga
02 6933 2278
jcondon@csu.edu.au

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Canola agronomy – consistent messages on canola agronomy hold strong in a Decile 1 season

Rohan Brill[1], Hongtao Xing[1], Tony Napier[1], Don McCaffery[1] and John Kirkegaard[2].

[1]NSW DPI; [2]CSIRO Canberra.

GRDC project codes: CSP00187, DAN00213

Keywords

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

Take home messages

- Ensure flowering date is matched to the environment and grow enough biomass for the targeted grain yield.
- High biomass was necessary for a high yield potential. There is no advantage in utilising management strategies that reduce growth in order to increase harvest index and grain yield.
- Select two or three varieties with differing phenology or one single variety with flexible phenology to capitalise on variable sowing opportunity dates.
- Early sowing of slow developing spring canola varieties was successful in experiments in 2018 but is best suited to eastern regions with a higher frequency of late March to mid-April rainfall.
- The performance of hybrid canola continues to improve across all herbicide tolerance groups and across diverse environments.
- Nitrogen (N) response was modest in 2018 due to lower grain yield potential. Choosing a paddock with high starting N levels reduces the risk in growing canola in dry seasons as large upfront inputs of N are not required.

Introduction

The consistent recommendations from the Optimised Canola Profitability (OCP) project to date have been:

- Ensure canola flowering date is matched to the environment (i.e. target optimal flowering times as outlined in 10 Tips to Early Sown Canola -https://grdc.com.au/10TipsEarlySownCanola)
- Maximise the conversion of plant available water into crop biomass using tactical management of sowing date, hybrids and N.

With low in-crop rain and frosts across southern NSW, 2018 was the year to put the system to the test, particularly point 2. The 2018 season more than reinforced the above recommendations – it gave full confidence that the recommendations will hold over highly variable and risky seasons.

Matching flowering date to the environment is an ongoing challenge as the date of the autumn break is highly variable. Based on the sowing rule developed by Unkovich et al. (2015), there is a 22% chance of having enough seedbed moisture to germinate canola in the second half of March and a 17% chance in the first half of April at Condobolin. In contrast, there is a 43% chance in the second half of March at Wallendbeen and a 41% chance in the first half of April. Therefore, sowing opportunities will influence varietal phenology choice. There are only limited opportunities to sow a slow or mid-slow canola variety before mid-April at Condobolin, therefore fast or fast-mid varieties

are recommended. At Wallendbeen, there would likely be a more than 50% chance of canola before mid-April, therefore the slow and slow-mid varieties should be considered.

A combination of strict fallow management and maintenance of even residue cover will increase the chance of establishing canola successfully in any window. Conversely, poor summer weed control, overgrazing, cultivation and early stubble burning will decrease the chances of successful early establishment.

To ensure flowering date targets are met, while also responding to variable seasonal breaks, growers need to either

- have access to two or three canola varieties with contrasting phenology (e.g. a slow and a fast-mid) or
- select a canola variety with relatively flexible phenology, specifically a variety that is relatively slow from early sowing, but faster from later sowing – some examples of these are highlighted below.

2018 phenology results

To determine the phenology of recently released canola varieties, a phenology experiment was established at Wagga Wagga in 2018 with 30 spring varieties sown in late March and early May and three winter varieties sown in late March only. The early sowing was done following 7mm of rain and was provided with an extra 7mm through dripper lines to ensure even establishment. There was approx. 100mm plant available water in the soil at sowing and 160mm rainfall from April to October.

There were subtle development differences between the winter varieties. Phoenix CL was slightly quicker to flower than the more widely grown Edimax CL and Hyola®970CL (Figure 1). There was still a large gap (32 days) in flowering date between the fastest winter variety (Phoenix CL) and the slowest spring variety (Victory 7001CL).

There were also large differences in the development of the spring varieties, particularly from early sowing. Fast varieties included Hyola®350TT, Hyola®506RR, ATR Stingray$^{\phi}$ Diamond and 43Y23 (RR). In 2018, early sowing of these fast varieties resulted in early flowering and significant frost damage, with a resultant machine harvest yield of <0.5t/ha. However, commercial varieties that were relatively slow from early sowing included 45Y25 (RR), 45Y91 (CL), Victory 7001CL, InVigor® 5520P, ATR Wahoo$^{\phi}$, GT-53 and SF Ignite. These varieties yielded in a range from 1.1t to 1.7t/ha from early sowing. The fast varieties had higher yield sown in early May, while the slow varieties had reduced yield from later sowing (1-1.4t/ha vs 0.4-0.8t/ha).

A key tactic to stabilise flowering date across and within seasons is to select a variety that slows its development when sown early, but then speeds up when sown later, providing a relatively stable flowering date despite different sowing dates. The best examples of this 'flexible' phenology were 44Y90 (CL) and 44Y27 (RR) which, along with HyTTec® Trophy Quartz and 43Y92 (CL), were the only varieties to yield >1t/ha from both sowing dates.

2018 biomass results

A continuation of the 'Biomass' series of experiments at Wagga Wagga (with a combination of two sowing dates, two N rates and eight varieties) reinforced the recommendations of the OCP project. High biomass (combination of early sowing and hybrids) was necessary to generate a high yield potential, but optimising flowering date was important to realise the potential yield. For example, Diamond sown on 4 April produced similar biomass as 4 April sown 45Y91 (CL) (approx. 11t/ha), but Diamond flowered in mid-July, one month before 45Y91 (CL) and yielded 30% less (1.7t/ha vs. 2.6t/ha) due to frost damage. Diamond produced only 7t/ha biomass from the 27 April sowing date, but flowered in mid-August, and with less frost damage yielded 1.9t/ha. There was no response to increasing N from 30kg to 180kg/ha as the starting soil N at the site

Table 1. Chance (%) of a canola sowing (germination) opportunity within defined date ranges in autumn in southern NSW. A sowing opportunity is defined as when rainfall > pan evaporation in a 7-day period (Unkovich et al. 2015).

	16-31 March	1-15 April	16-30 April	1-15 May	16-31 May
Canowindra	33	31	52	53	67
Condobolin	21	17	33	43	57
Corowa	29	26	50	57	79
Wagga Wagga	30	30	45	50	83
Wallendbeen	43	41	55	67	81

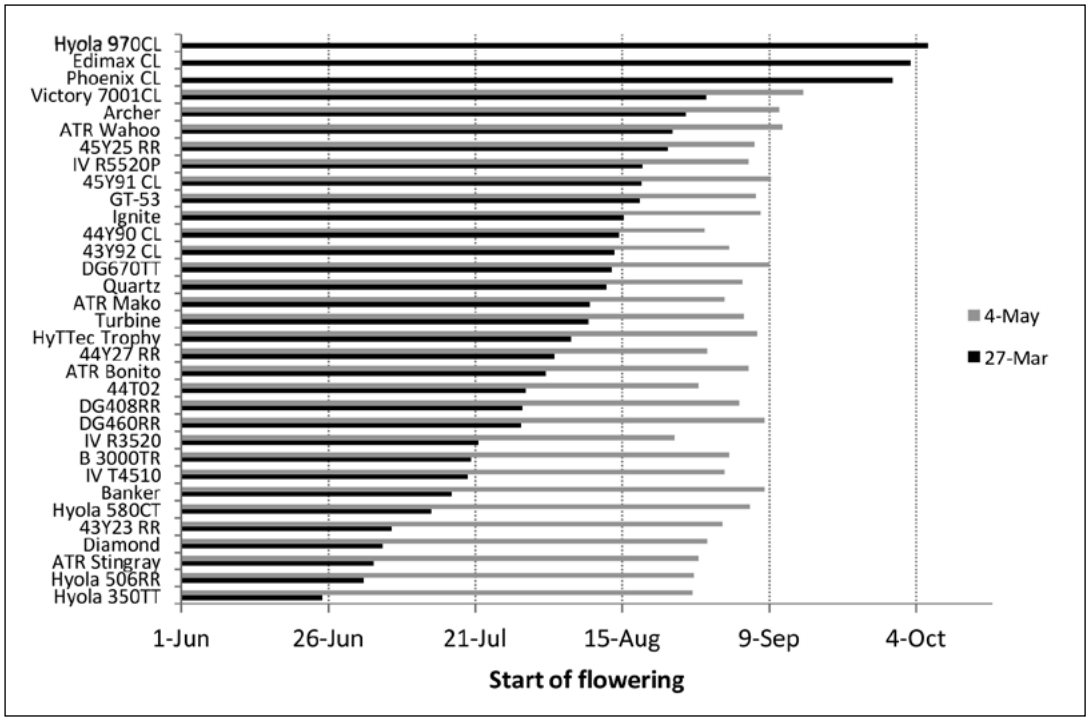

Figure 1. Phenology (start of flowering) of 30 spring varieties from two sowing dates and three winter varieties from one sowing date at Wagga Wagga in 2018.

was 227kg/ha. This highlights the value of stored N for canola, reducing the risk of applying high rates of N early in the season.

A comparison of similar phenology pairs of hybrid Clearfield® and open-pollinated (OP) triazine tolerant (TT) varieties sown within their highest yielding window highlighted the advantages of hybrids even in a very dry year. On average, the hybrid Clearfield® varieties yielded 40% more than the OP TT varieties (Table 2) largely due to their higher biomass.

High yielding canola

Over the past two seasons, a collaborative project (NSW DPI and GRDC) named 'High Yielding Canola' has been running in southern NSW, aiming to determine management strategies to achieve 5t/ha canola. One site has been at Wallendbeen with 210mm in-crop rainfall (April to October) and approx. 120mm plant available water at sowing in 2018. The second site has been at Leeton, which has been fully irrigated.

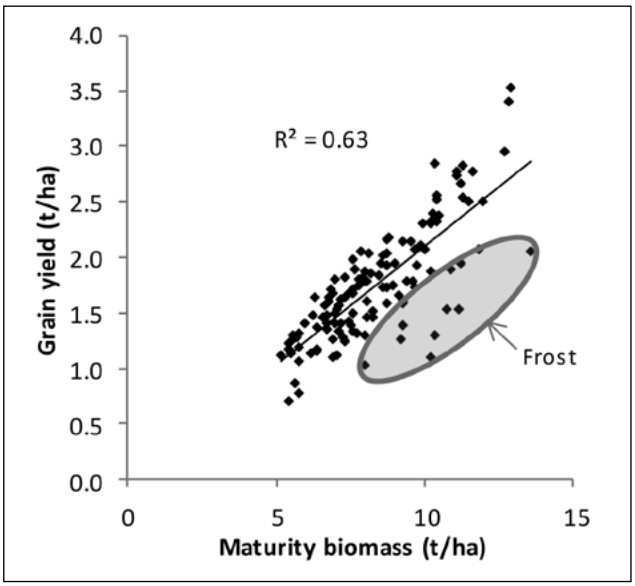

Figure 2. Relationship between maturity biomass and grain yield at Wagga Wagga in 2018. Treatments with high biomass, but relatively low grain yield, were generally early flowering and damaged by frost.

Table 2. Comparative yield of canola phenology pairs (hybrid Clearfield® versus OP TT) from their highest yielding sowing date at Wagga Wagga in 2018 (l.s.d. $P<0.05$ = 0.32t/ha).

Phenology	Sow date	Hybrid CLF	OP TT	Hybrid CLF Yield (t/ha)	OP TT Yield (t/ha)
Mid-slow	4-Apr	45Y91 (CL)	ATR Wahoo$^{\Phi}$	2.6	1.9
Mid-fast	4-Apr	44Y90 (CL)	ATR Bonito$^{\Phi}$	2.5	1.6
Fast	27-Apr	Diamond	ATR Stingray$^{\Phi}$	1.9	1.5

Table 3. Grain yield of 11 canola varieties sown at their recommended sowing date at Wallendbeen in 2018 (l.s.d. $P<0.05$ = 0.44t/ha) and Leeton (l.s.d. $P<0.05$ = 0.76t/ha) in 2018.

Sowing date	Variety	Phenology	Grain yield Wall. (t/ha)	Grain yield Leeton (t/ha)
30-April	Diamond	Fast spring	3.4	5.3
13-April	44Y90 (CL)	Mid-fast spring	3.9	4.4
13-April	ATR Bonito$^{\Phi}$	Mid-fast spring	2.8	4.2
13-April	45Y91 (CL)	Mid spring	3.6	5.0
13-April	45Y25 (RR)	Mid-slow spring	3.2	5.4
13-April	ATR Wahoo$^{\Phi}$	Mid-slow spring	2.6	4.1
27-March	Archer	Slow spring	3.7	5.1
27-March	Victory 7001CL	Slow Spring	2.6	4.1
27-March	Phoenix CL	Winter	2.7	3.2
27-March	Edimax CL	Winter	2.9	3.6
27-March	Hyola®970CL	Winter	2.5	3.5

In 2018, highest yields came from sowing spring hybrid canola varieties, with lower yields from the winter varieties at both sites. The hybrid varieties 45Y25 (RR) and 44Y90 (CL) were on average 28% and 19% higher yielding than the OP TT varieties with matching phenology, ATR Bonito$^{\Phi}$ and ATR Wahoo$^{\Phi}$, respectively.

In an adjacent trial at Wallendbeen, an extra 100mm of irrigation was applied to 45Y25 (RR) to determine the water unlimited yield potential. This resulted in a 9% grain yield increase compared to the non-irrigated 45Y25 (RR), suggesting that even in a relatively dry year, management factors such as variety choice (especially hybrids vs. OP TT) can have a larger impact than rainfall quantity.

Conclusion

A very dry 2018 (Decile 1 in-crop rainfall) did not alter the consistent messages from the OCP project. Matching flowering date to the environment and generating as much growth as necessary for the target yield is important to maximise grain yield. Where the date of the autumn break is highly variable, it is recommended to select more than one canola variety, each with differing phenology, or select a variety with flexible phenology. Early sowing of mid and slow spring varieties was successful in 2018 as they generated high biomass and delayed pod-fill till after the severe frosts. This strategy should especially be considered by growers in the eastern part of southern NSW where autumn rainfall is higher, especially those with management practices (stubble retention and strict fallow management) that maximise seedbed moisture retention.

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Further Reading

https://grdc.com.au/10TipsEarlySownCanola

Contact details

Rohan Brill
Wagga Wagga Agricultural Institute
02 6938 1989
rohan.brill@dpi.nsw.gov.au

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Effect of heat stress on canola grain yield and quality

Rajneet Kaur Uppal, Rohan Brill and John Bromfield.

NSW DPI, Wagga Wagga.

GRDC project code: BLG 108-1

Keywords

- grain yield, seed number, thousand seed weight, oil, protein.

Take home messages

- A novel method of simulating heat stress in canola fields was successfully developed and tested using portable heat chambers.
- Grain yield, yield components and quality were significantly reduced when heat stress was applied between 22 days to 60 days after first open flower (BBCH 60).
- With irrigation (175mm), there was a 61% increase in grain yield and a 37% increase in biomass in ATR Stingray[1].
- In canola, the critical period sensitive to heat stress is 50% flowering to mid podding.

Background

Canola (*Brassica napus* L.) is an economically important oilseed globally (FAOSTAT 2013) and the third most economically important crop in Australia, contributing $2.67 billion to the Gross Domestic Product. Abiotic stresses, such as elevated temperature and moisture shortage, particularly during flowering, result in significant yield loss (Morrison and Stewart, 2002). With the projected climate change, the frequency of extreme climatic events is expected to increase (IPCC, 2007), exacerbating the impact of abiotic stress. Canola is notably susceptible to heat and drought stress at meiosis, coincident with late bud stage and also during flowering (Angadi et al. 2000; Annisa et al. 2013), with heat stress most evident when temperatures above 27°C occur between bolting and reproductive development. Specifically, short periods of high temperature at the pre-flowering and flowering stages can reduce grain number and grain yield, allied to floret abortion (Morrison and Stewart, 2002; Annisa et al. 2013).

Research gap

There are limited reports on canola heat stress research — most of the research has been undertaken in controlled conditions in growth chambers where flowers are exposed to a constant high temperature during similar growth stage. However, in the field environment, all the plants are not exposed to the same heat intensity, resulting in seed setting from non-stressed flowers, particularly in the crops with indeterminate growth habit. Field-based heat stress experiments focused on different sowing dates, which are generally confounded by differences in the insidious effects of temperature, water stress and vapour pressure deficits, therefore limiting the wider application of experimental results. A reliable method of imposing heat stress in the field environment, for research purposes, without impacting on other environmental variables, is therefore needed.

More recently, a novel method of imposing heat stress in the field environment has been developed

and applied to wheat and lentil research (Alexander et al. 2010; Talukdar, 2014; Nuttal et al. 2015; and Thistlewaite 2017). Thistlewaite (2017) used heat chambers to impose heat shock at anthesis in wheat and reported a reduction in grain number allied to pollen sterility. Alexander et al. (2010) used heat chambers for imposing heat stress of 35°C in wheat, raising temperatures by up to 12°C above ambient temperature. Nuttal et al. (2015) reported a variation of 5°C within the chamber while targeting a higher temperature of 38°C and achieved a yield reduction of 13% during post-anthesis heat stress in wheat. However, in the above studies, a smaller chamber size was used (<1m^2) which was difficult to manage in canola canopy and non-portable chambers make the experiments laborious. Therefore, the aim of study was to develop and test heat chambers (2.5 L x 1.8 W x 1.2 H metres covering 4.5m^2) in canola. This is the first report on using heat chambers in canola to simulate heat stress in a field environment.

The critical growth period for canola has been determined as 300 °Cd after first flowering and extends up to 400 °Cd (Kirkegaard et al. 2018). During the critical period, yield formation is most affected by seed number, allied to both reduction in pods/m and seed number/pod and partial compensation with increase in seed size. Heat stress studies in canola show that both seed number and seed size are affected by heat stress. However, there is little information on the sensitivity of reproductive development to heat stress. A narrow window of 1–2 weeks post- first flower is considered as most sensitive to heat stress (Angadi et al. 2000), whereas Gan et al. (2004) reported pod development as most sensitive to heat stress. Therefore, the present study reports the effect of heat stress on canola yield, yield components and quality and identifies the most sensitive stage to heat stress during reproductive development. To understand the interaction between heat stress and water availability, two water regimes were established.

Material and methods

A field experiment was conducted at Wagga Wagga Agricultural Institute located at 35.01379°S latitude and 147.1940°E longitude. Soil at the experimental site was red brown chromosol with pH $_{Ca}$ 5.3 and soil nitrogen (N) 75kg/ha at the time of sowing. The experiment was sown on 7 May 2018 with the variety ATR Stingray$^{\Phi}$. To establish the different water regimes, four irrigations (175mm total) were supplied to wet plots using drip lines. All the crop husbandry operations were carried out as per best management practices for canola. Plot yield, biomass, thousand seed weight, seed number and harvest index (HI) were assessed from 1.5m^2 samples from each plot.

Simulating heat stress in the field environment

Heat chambers

Eight chambers (2.5 L x 1.8 W x 1.2 H m) were constructed with Suntuf Sunlite twin wall polycarbonate clear sheets fitted in a metal frame. The heating was provided by two standard 1200 W fan heaters in each chamber, with the power in the field being supplied by a 6 KVA generator. The heaters drew fresh air from outside the plots. A ceiling fan was used to ensure that heated air was evenly distributed through the chamber. A commercially available thermostat was used with extended thermocouples to control the heaters. Temperature and humidity inside the box were monitored at one-minute intervals using a TinyTag Plus2 temperature and humidity logger placed inside a small radiation screen.

Heat treatments

A randomised complete block design with two heat treatments (Control vs Heat stress 35°C), seven timings of heat stress (before the start of flowering till end of flowering), two water regimes (wet vs dry) and four replications were used. When 50% of the plot reached first flowering, heat treatments (35°C) were applied for eight days. Each chamber enclosed six rows of plot for a length of 2.5m. The chambers were placed on the plots at 11.30am, then the heaters were switched on at 12.00pm. The chambers were then heated to 35°C, the time taken for this dependent on the ambient conditions. The heaters were turned off at 3.30pm and the chambers removed at 4.00pm.

Results and discussion

Heat treatments

Days to first flowering (DAFF) was recorded when 50% of the plot had one open flower on the plants and thermal time was calculated using a base temperature of 0 °C.

The temperature imposed for eight days within the chamber shown for heat treatment (T5) i.e. 400-550 °Cd after first flowering. Ambient temperature is also shown to indicate the increase in temperature in treated plots compared to control plots.

Table 1. Thermal time before/after the start of flowering.

Timing of heat stress	Days after first flowering (DAFF)	°C.d
T1	−20 to -11	200–100
T2	-6 to +4	-50–+50
T3	8–17	100–200
T4	22–31	250–350
T5	36–45	400–550
T6	50–59	600–800
T7	64–73	900–1100

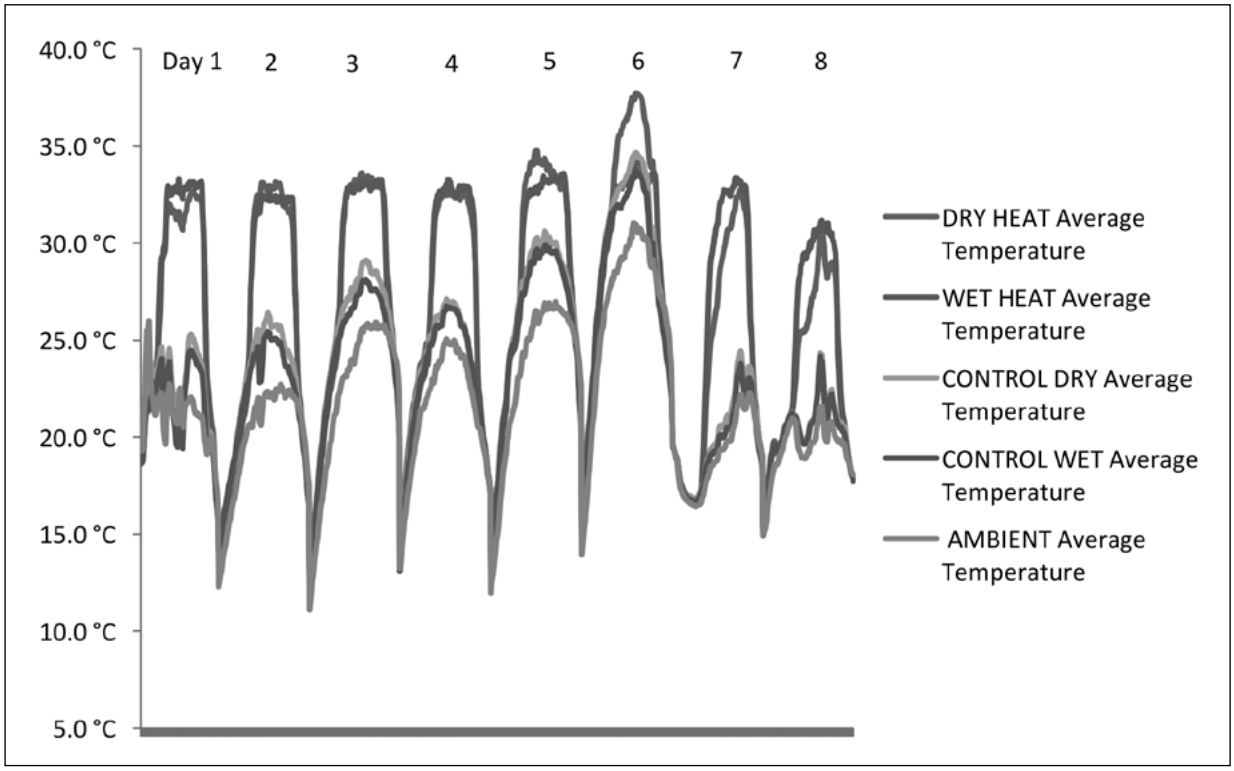

Figure 1. Heat treatment (T5) imposed at 400-500 °Cd after first flowering.

Effect of heat stress on grain yield and yield components

There was a significant effect of heat stress (P<0.001) and irrigation (P <0.001) on grain yield, biomass yield, HI and seed number, however there was no interaction between heat stress and irrigation. With irrigation, there was a 61% increase in grain yield and a 37% increase in biomass.

Grain yield and HI were significantly reduced when heat stress was applied between 22 days to 60 days after first open flower (BBCH 60) when compared with control plots (Figure 2). Maximum reduction in grain yield and HI was recorded at 400–550 °Cd i.e. at the end of flowering stage which coincides with ovule formation stage (Kirkegaard et al. 2018). At this stage, the reduction in grain yield was 63% and 52%, respectively, in dry and wet treatment. Reduction in grain yield and HI was associated with reduction in grain number. There was an increase in thousand seed weight at the same period that decreased seed number, however not enough increase to compensate for yield penalty. Heat stress applied before the start of flowering did not affect grain yield and other yield components. Biomass was significantly reduced when heat stress was applied at end of flowering compared to the control.

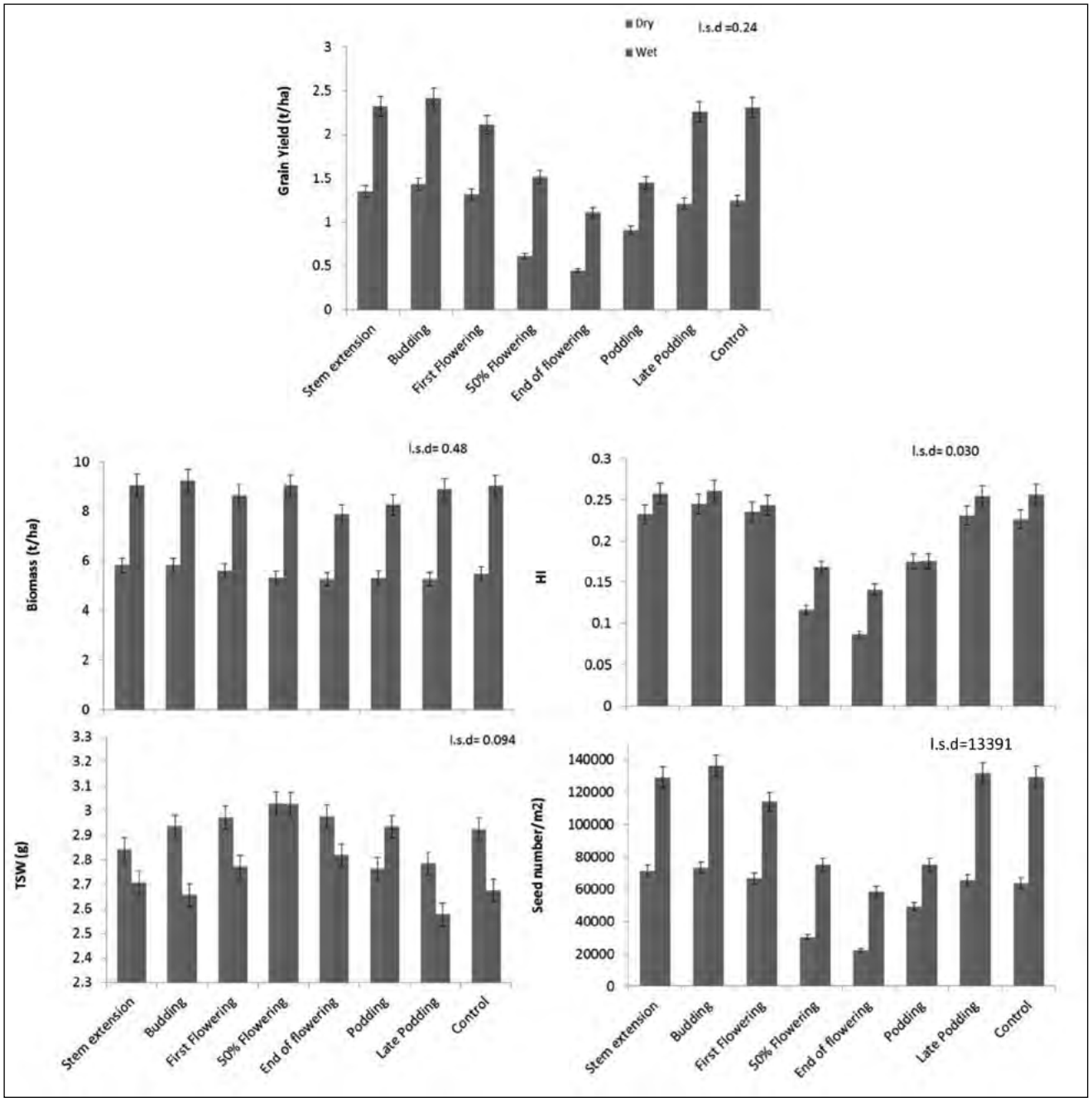

Figure 2. Effect of timing of heat stress on grain yield, biomass, HI, thousand seed weight and seed number under dry and irrigated treatments.

Effect of heat stress on oil quality

Oil percentage and protein percentage were significantly affected by timing of heat stress and irrigation however interaction was not significant. Similar to grain yield, oil content was reduced when heat stress occurred at 400–550 °Cd (Figure 3). Protein percentage showed a reverse trend with oil percentage, which is consistent with previous observations that oil and protein often trade-off in canola seed (Kirkegaard et al. 2018).

Conclusions

Heat stress can be applied to canola plots successfully using specially designed portable heat chambers. Grain yield or quality was not reduced by heat stress until the period commencing around 100° Cd after flowering. Grain yield, yield components and oil quality significantly reduced when heat stress occurred at 400–550 °Cd i.e. end of flowering and grain formation stage. In canola, the critical period sensitive to heat stress is from

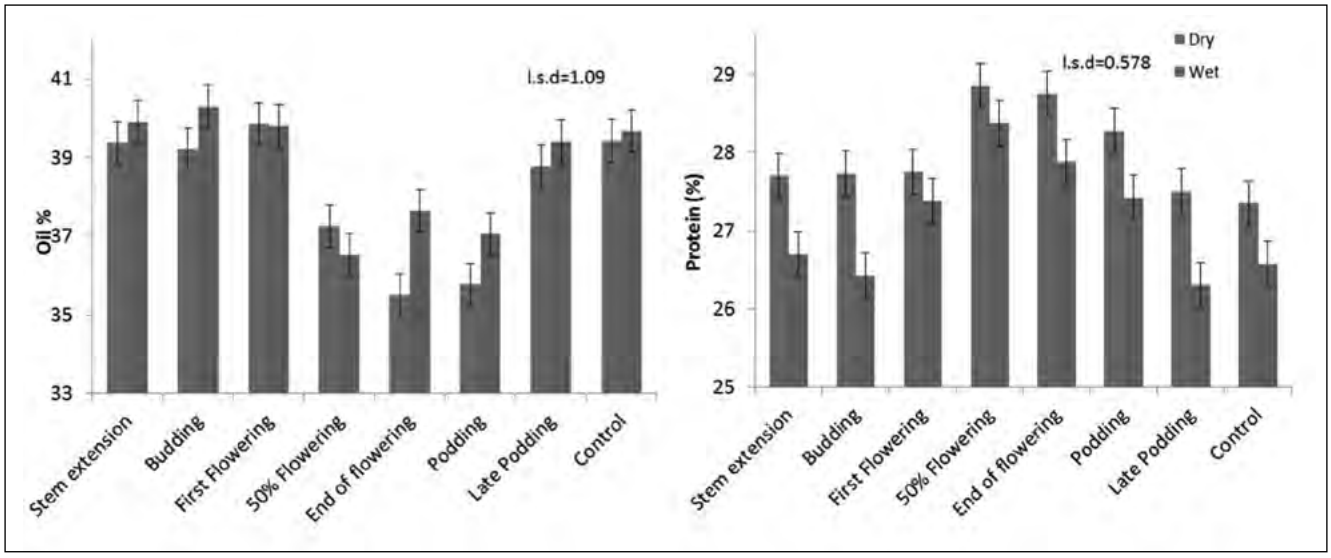

Figure 3. Effect of timing of heat stress on oil and protein percentage in canola under dry and irrigated treatments.

50% flowering to mid pod formation stage. Portable heat chambers can be used to screen varieties for heat tolerance in the field which will be critical for breeding heat tolerant varieties in the future.

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Contact details

Rajneet Kaur Uppal
Wagga Wagga Agricultural Institute
02 6938 1910
Rajneet.uppal@dpi.nsw.gov.au

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Deeper roots may improve the water use of early sown canola

Wayne Pitt[1,2], J. Sergio Moroni[1,2], Rohan Brill[3], Don McCaffery[3], Jeremy Whish[4], Julianne Lilley[4] and John Kirkegaard[4].

[1]Graham Centre for Agricultural Innovation (Charles Sturt University and NSW Department of Primary Industries); [2]School of Agricultural and Wine Sciences, Charles Sturt University; [3]NSW Department of Primary Industries, Wagga Wagga Agriculture Institute; [4]CSIRO, Agriculture and Food Canberra.

GRDC project code: CSP00187

Keywords

- canola, water use, biomass, sowing date, flowering date.

Take home messages

- Ensure canola variety and sowing date are matched to achieve an optimal flowering period.
- Manage crop to ensure sufficient biomass is produced to support the yield target.
- Early-sown (early April), slow hybrid varieties can perform well in dry seasons.
- Deeper rooting to access stored water explains part of the advantage shown by early-sown slow hybrid varieties in dry seasons.

Background

Optimising the sowing date of canola in specific environments is an important determinant of yield (Kirkegaard et al. 2016). A central theme of the Optimised Canola Profitability (OCP) project has been to evaluate interactions between sowing time and variety to determine the feasibility of earlier sowing of canola (early April), and to develop management protocols for optimal biomass to produce the most profitable crops. The Agricultural Production Systems sIMulator (APSIM) simulations from historical data predict higher yield potential for earlier sown canola in a number of locations in southern NSW, and many of the sowing date/variety trials conducted to date demonstrated that higher yields were achieved when canola was sown earlier than the traditional Anzac Day sowing window following good summer fallow management (Brill et al. 2015).

For a given environment, there is an optimum flowering window that minimises the combined risk of frost in crops flowering too early, and heat and water stress in crops that flower too late. Ensuring that flowering date is matched to the environment is essential to maximise yield (Lilley et al. 2015). Yield is also positively correlated with post-anthesis biomass production, so producing sufficient biomass for the target yield in the most cost-effective way will maximise profit potential with least risk.

However, there is a perception that excessive water-use by early-sown, high vigour hybrid varieties may reduce the water available during the critical period of flowering and pod-fill resulting in increased water stress and lower yields in low-medium rainfall environments in dry seasons. This also leads to conservative nitrogen (N) management on these crops. Experiments have been conducted to determine whether earlier-sown hybrids do suffer increased water stress compared to faster maturing hybrids sown later, and whether deeper rooting in earlier sown crops makes more water available to offset this risk.

Methods

Field experiments (NSW DPI and CSIRO) and a rhizolysimeter experiment (CSU) were established at Wagga Wagga and Greenethorpe in 2018 to study the physiological mechanisms that canola might employ to respond to water stress. Both field and rhizolysimeter experiments aimed to compare the water use patterns and root dynamics of an early-sown, slow maturing variety (Archer) with that of a later sown faster maturing variety (Nuseed Diamond). The experiments were planned to achieve the same flowering date for both varieties and involved both irrigated (Wet + 115mm) and non-irrigated (Dry) conditions. It was hypothesised that the differences in yield and biomass production were likely to be compensated for by changes in plant architecture and partitioning of yield components, and that earlier-sown crops would benefit from deeper rooting to access water under dry conditions. While the rhizolysimeter complex enabled detailed studies of root and water use dynamics, the facility did not allow for destructive measurements, such as biomass or root sampling. These activities/measurements were undertaken in the associated field experiments. The Wagga Wagga and Greenethorpe field experiments generated simular results and Wagga Wagga results will be the focus in this paper.

In the field, Archer was sown on the 4 April following 10mm of irrigation applied through dripper lines to ensure even establishment, while Nuseed Diamond was sown on the 14 May, following a 14mm rainfall event on the 10-11 May. Fertiliser was applied at sowing (120kg/ha of mono-ammonium phosphate (MAP) (10% N), with a further 130kg/ha N applied between the 23 March and 7 June. There was approximately 100mm plant available water at sowing, and 170mm of rainfall between 4 April and 5 November, when harvest occurred. Irrigated treatments received an additional 115mm over three watering events, with the last (approximately 50mm) applied on the 13 September, to coincide with the midpoint of the 'critical period' that extends from approximately 100 to 500°C days after anthesis (Biologische Bundesandstalt, Bundessortenamt and Chemical industry (BBCH)60), to ensure that final yields were representative of the yield potential developed during the vegetative phase.

To compare the water use efficiency (WUE) of the two treatments, water use was estimated from the time of sowing which defined the season length and potential evapotranspiration (ET). Seasonal WUE was estimated as yield/seasonal ET, where ET was the sum of [in-crop rainfall + irrigation + change in plant available water (PAW)], from the first time of sowing to harvest.

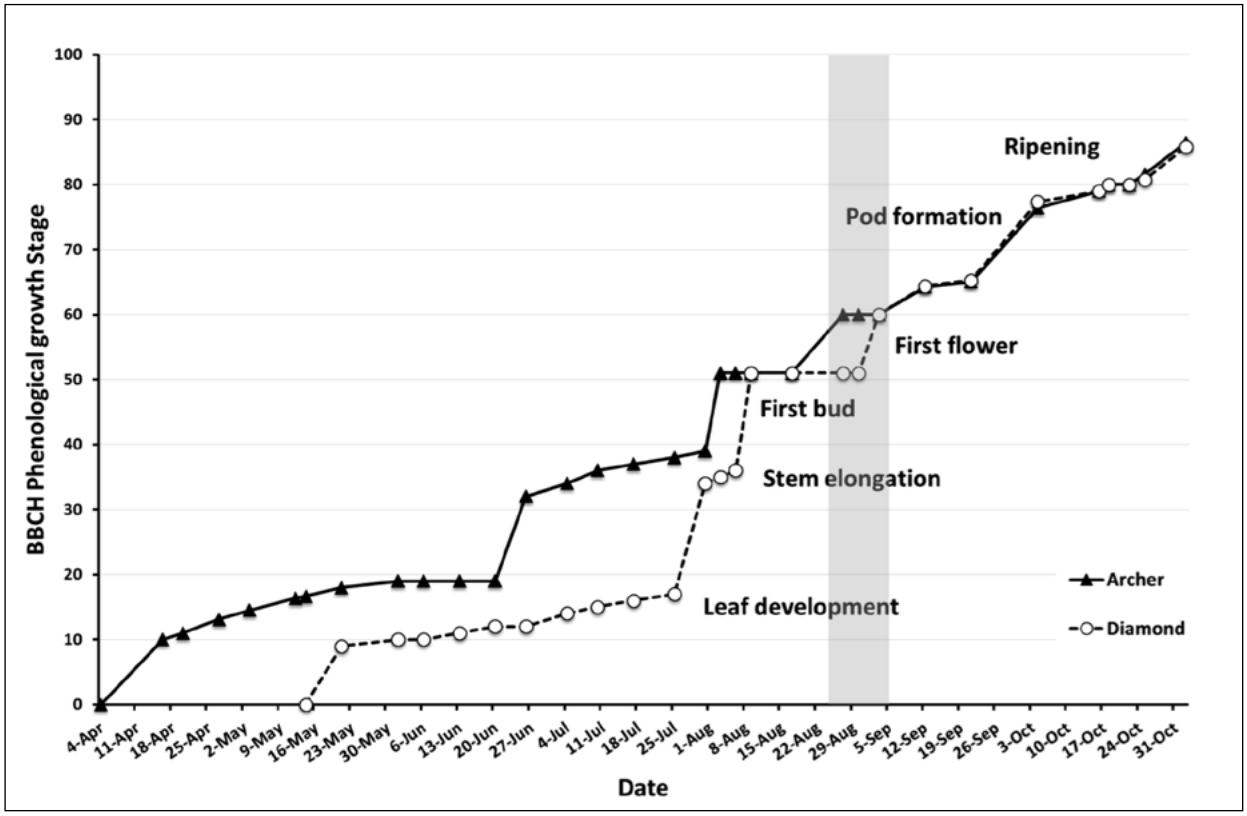

Figure 1. Phenological development of early-sown (Archer, 4 April) and later-sown (Nuseed Diamond, 14 May) canola varieties at Wagga Wagga in 2018 showing the common flowering window.

Table 1. Effect of time of sowing and irrigation on yield components and water use efficiency.

Variety	Sowing Date	Maturity Date	Irrigation Trt	Yield t/ha	Yield WUE kg/ha/mm	Biomass t/ha	Biomass WUE kg/ha/mm	Harvest Index %
Archer	4-Apr	5-Nov	Dry	2.80	11.00	10.70	42.14	25.9
Archer	4-Apr	5-Nov	Wet	4.08	10.88	16.37	43.47	25.0
Diamond	14-May	5-Nov	Dry	1.87	8.54	6.12	27.60	30.9
Diamond	14-May	5-Nov	Wet	2.92	8.80	10.32	31.22	28.1
Lsd P < 0.05	-	-	-	0.86	3.01	2.52	8.89	2.3

Results and discussion

In both experiments, both varieties flowered (50% of plants with one flower open) within a common flowering window between 27 August and 3 September (Figure 1).

Archer sown early under irrigated conditions (Wet) yielded an average of 4.1t/ha compared to 2.8t/ha in the non-irrigated plots (Dry), while Nuseed Diamond sown late produced 2.9 and 1.9t/ha, respectively, for the Wet and Dry treatments (Table 1). Biomass production was positively correlated with yield. Archer sown early produced greater quantities of biomass than Nuseed Diamond both in Wet and Dry treatments, with consistent harvest index and water use efficiencies. In comparison, Nuseed Diamond was able to convert more of its biomass to grain, but given the later sowing date, could not generate the biomass necessary to match Archer for yield potential, even when grown under irrigated conditions (Table 1).

Comparison of soil water profiles for Wet and Dry treatments of Archer and Nuseed Diamond in the field at maturity suggested that both varieties were able to extract a similar quantity of water from the soil to the depth of coring (90cm). At 90cm, approximately 16mm of PAW remained in irrigated treatments, and approximately 3mm in non-irrigated treatments sown with Nuseed Diamond, which represented levels insufficient to account for the reduction in yield (Figure 2).

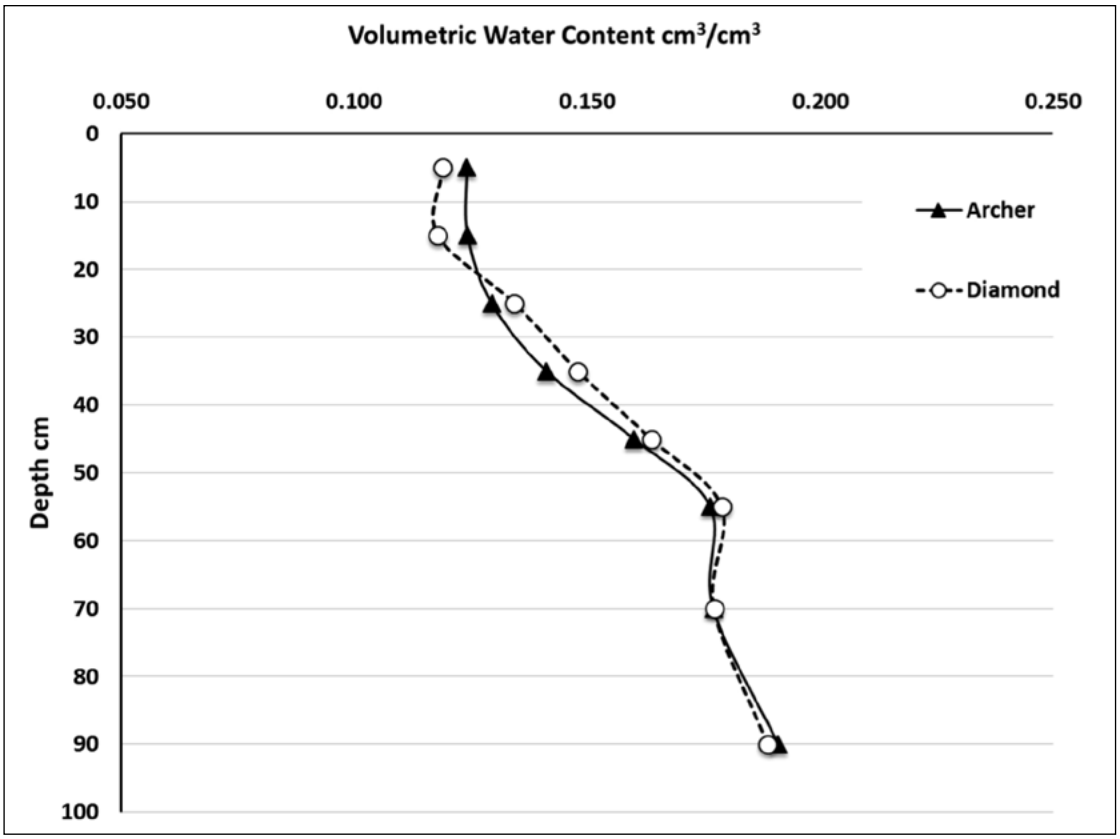

Figure 2. Soil water storage profiles of non-irrigated Archer and Diamond at maturity at Wagga Wagga in 2018.

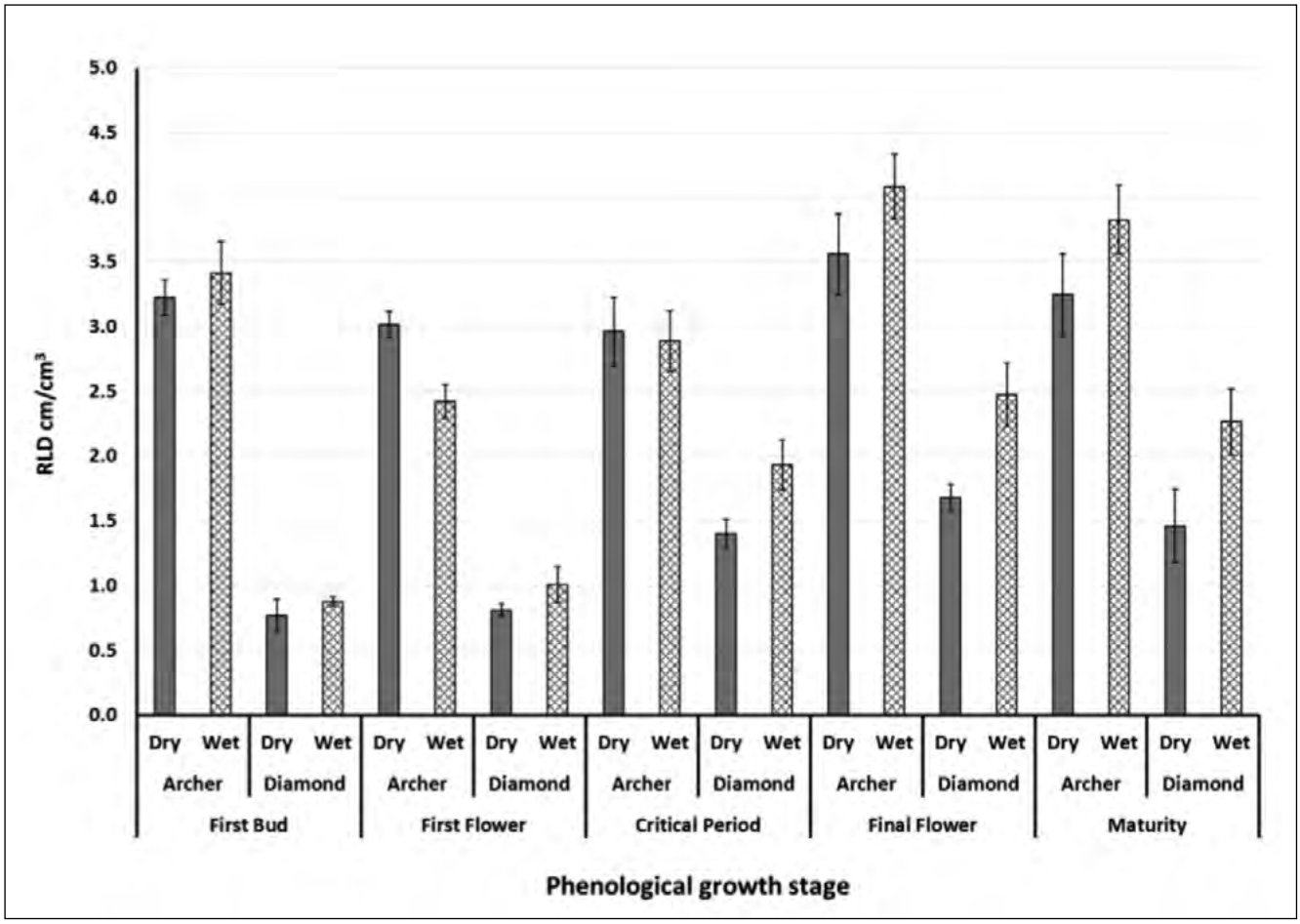

Figure 3. Root length densities (cm/cm3) of Archer and Nuseed Diamond in irrigated and non-irrigated treatments at Wagga Wagga in 2018. Bars represent standard error of the mean.

To produce an additional tonne of yield per hectare, Archer must have had increased access to deeper stored water. Kirkegaard et al. (2016) hypothesised that aspects of early sowing such as increased access to deeper stored water due to a longer vegetative stage and deeper rooting may have some advantages for improving yield potential and water use efficiency. Although the field site at Wagga Wagga in 2018 had an impenetrable soil layer at 1-1.2m making deeper coring impossible, the root length density measured did confirm that Archer produced a greater quantity of roots per unit area of soil throughout the season (Figure 3).

In the sister field experiment on a deep red Kandosol at Greenethorpe in 2018, Archer had roots that were 100cm deeper than Nuseed Diamond at harvest (3.2m compared with 2.2m) and had extracted 35mm more water (Kirkegaard pers comm. 2019) demonstrating the likelihood that Archer was deeper rooted at Wagga Wagga. Archer's increased rooting capacity was confirmed with the more detailed root measurements possible in the rhizolysimeter where Archer had consistently deeper roots than Nuseed Diamond at every growth stage recorded throughout the season (Figure 4), as well as greater root numbers (Figure 5).

Conclusion

Given reasonable knowledge of the PAW prior to sowing, results from trials conducted in Wagga Wagga and Greenethorpe in 2018 suggest that in low to medium rainfall zones, early sown, long-season canola varieties are likely to produce more biomass and offer greater yield potential than faster shorter season varieties sown later in the season, even in seasons with a dry spring. The notion that early sown, vigorous hybrids may set themselves up to fail in a dry spring seems unfounded, at least when stored soil water is available at depth. In fact it appears that delayed sowing to gamble on

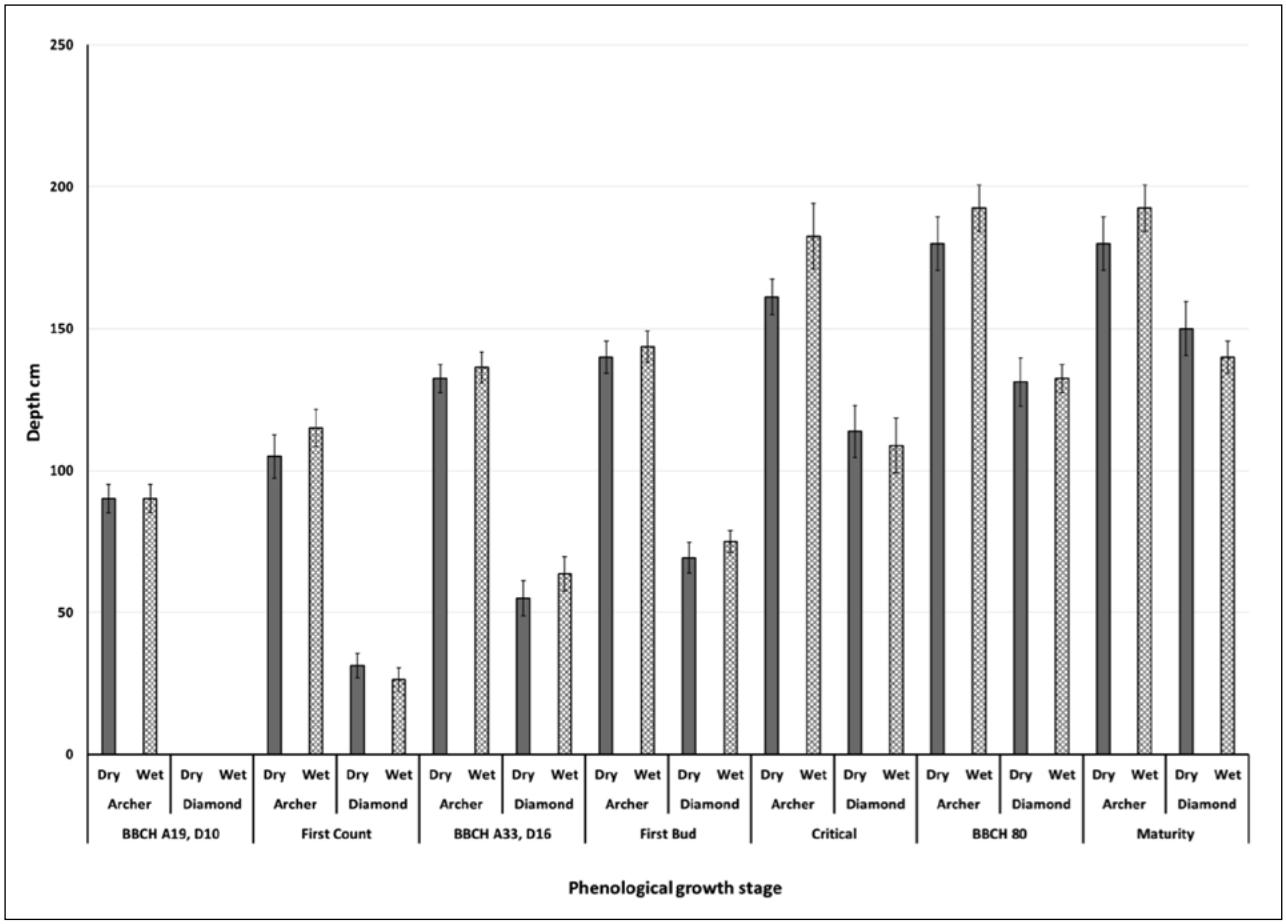

Figure 4. Average maximum rooting depths (cm) of Archer and Nuseed Diamond in irrigated and non-irrigated treatments in the rhizolysimeter trial at Wagga Wagga in 2018. Bars represent standard error of the mean.

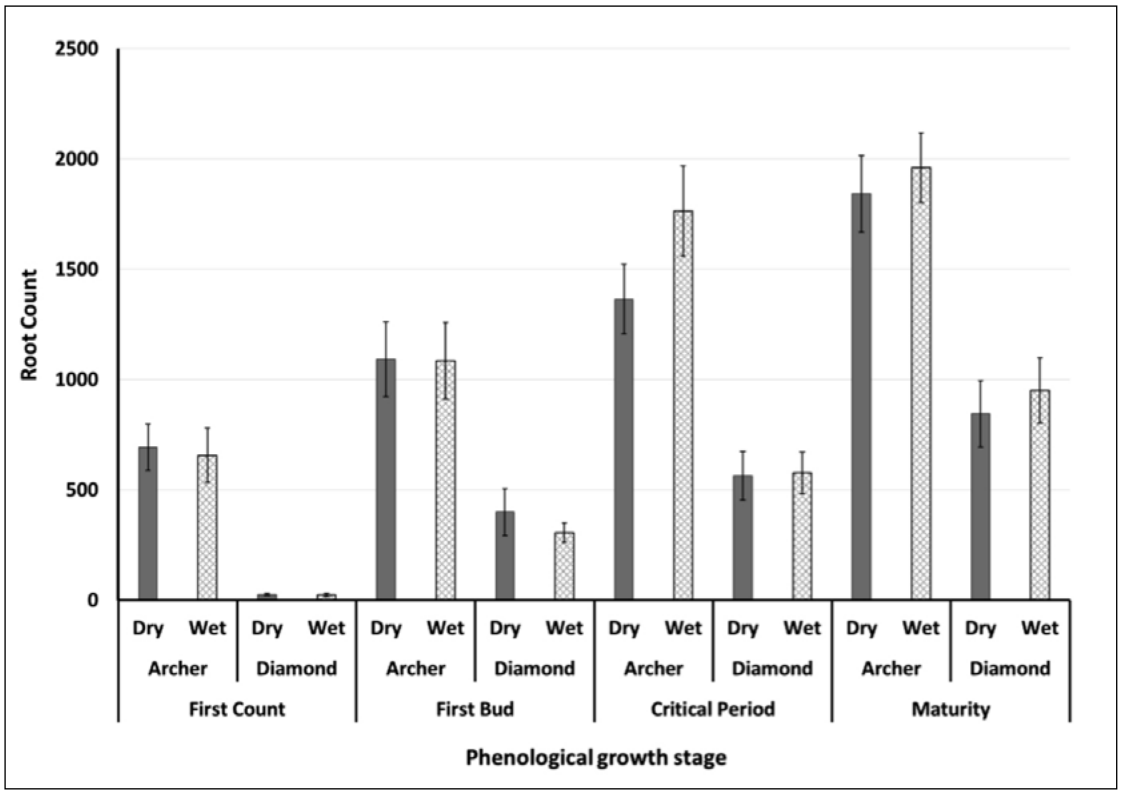

Figure 5. Average root counts of Archer and Nuseed Diamond in irrigated and non-irrigated treatments in the rhizolysimeter trial at Wagga Wagga in 2018. Bars represent standard error of the mean.

additional rainfall with faster maturing, short season varieties seems more likely to result in a yield penalty as a result of a shorter growing season, constrained biomass production, shallower roots and lower water use efficiency.

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Contact details

Wayne Pitt
School of Agriculture and Wine Sciences
Charles Sturt University
Wagga Wagga
02 6933 2933
wpitt@csu.edu.au

Sergio Moroni
School of Agriculture and Wine Sciences
Charles Sturt University
Wagga Wagga
02 6933 2914
smoroni@csu.edu.au

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Dual-purpose crops, forage crops or oversowing pastures – how to manage feed supply post drought

***Jeff McCormick*[1].**

[1]*Graham Centre for Agricultural Innovation, Locked Bag 588, Wagga Wagga.*

Keywords

- Dual-purpose crops, forage crops, pasture lucerne, subterranean clover, density, post drought.

Take home messages

- Using dual purpose crops increases management options to allow post drought recovery.
- Assess pastures on density before the start of season.
- Determine the area of pasture and crops required.

Introduction

Grain producers have become more proficient alt is critical that a whole farm feed budget be created to determine the requirement of feed for the year. This should include dual-purpose crops as they can supply livestock requirements from May to mid-August depending on the season. Environmental stresses such as drought can significantly decrease the density and forage production from existing pasture stands. Assessing a pastures density and its ability to recover from drought is essential for the forage production and long-term viability of the pasture stand. If pastures are degraded dual-purpose crops can provide a good source of feed allowing the existing pastures to recover post drought.

The primary species used in pastures in the mixed farming zone is lucerne and subterranean clover. Lucerne is a perennial legume species that does not recruit seedlings in the field and the population tends to decline over time. Persistence of a lucerne pasture is related to the density of lucerne plants. Environmental stresses such as drought can significantly decrease the density of a lucerne stand. Therefore, a critical density measurement of lucerne can be used to determine if management is required.

In comparison, annual legume species such as subterranean clover rely on the development of a seed bank. As part of the annual cycle, seeds are set each year and the maintenance of the seed bank is essential for maintaining the productivity of the pasture. Determining seed bank levels is difficult but it is likely that following two dry springs that there will have been a severe reduction in the pasture legume seed bank.

Determining a benchmark for lucerne density.

When sufficient soil water is available, lucerne production is limited by the amount of light that is intercepted. These conditions can occur in many dryland areas in spring and it is lucerne density that will limit the amount of light intercepted by the crop, and therefore, limit production. Maximum production under irrigation can be achieved with a lucerne density of 30 plants/m^2 (Palmer and Wynn-Williams 1976). Within the mixed farming zone densities between 20-40 plants/m^2 are sufficient for maximum production (Dear et al 2007; Dolling et al

2011). This may seem low particularly in comparison to the number of plants sown but the population of lucerne declines over time and does not recruit seedlings. When lower lucerne densities occur a companion species such as subterranean clover can intercept light thereby increasing pasture production during periods of adequate soil water. Wolfe and Southwood (1980) suggested that at Wagga Wagga, NSW that 10 lucerne plants/m^2 was adequate when lucerne was sown with a companion species such as subterranean clover.

Under low rainfall conditions the plant density required for maximum production is likely to be lower. Virgona (2003) demonstrated that lucerne density of 12 plants/m^2 could deplete the soil water to equivalent levels as higher densities. Presuming that water use is strongly related to lucerne growth that may indicate that 12 plants/m^2 could produce similar levels of biomass under water limited conditions as that produced with sufficient water. Similarly, at a low rainfall site at Trangie and Condobolin, Bowman et al (2002) demonstrated that 8 plants/m^2 was the critical value for maximum production below which lucerne biomass production decreased.

Mccormick (2017) conducted a paddock survey in the Temora region and measured species' frequency. This was conducted using a 50cm x 50cm quad across a paddock 50 times and a species was observed to be present or absent. This quick assessment demonstrated that a species frequency of 50% limited that species to producing a maximum of 20% of the pasture biomass. The species frequency would need to be at 80% to be able to produce 50% of the biomass. Converting frequency data to density is problematic but if it was assumed there was 1-2 plants at a frequency of 80% (50cm x 50cm quad) that would lead to densities of approximately 3 plants/m^2 to 6.5 plants/m^2. Under this situation companion species would be required to contribute to biomass to meet livestock feed requirements but in degraded pastures it is likely to be weeds.

Companion species in lucerne pastures

Subterranean clover or other annual clovers are the most useful companion species due to the quality of feed produced and their nitrogen fixation ability. Research has indicated that 1000 seedlings/m^2 is sufficient for maximum pasture production from subterranean clover (Silsbury and Fukai, 1977). Environmental conditions and perennial density influence seed production. Drought can lower the seed bank level of companion species. Other species can also be important in lucerne pastures. For example, barley grass can provide important feed early in the season but in spring quality will decrease and animals may be injured due to grass seeds. Consequently, barley grass should be controlled in the winter which will reduce its contribution to pasture production. Annual ryegrass can also be a very useful pasture species in a lucerne stand due to high growth rate and high quality. If the pasture is likely to be returned to annual crops in the next two years, the annual ryegrass should be spray-topped in the spring time to reduce seed set.

Utilising dual-purpose crops in the farming system

Dual-purpose crops are a critical component for feed supply on mixed farms. Dual-purpose crops can support approximately 20-30 dry sheep equivalent (DSE)/ha during the winter period provided there is sufficient soil water. Dove et al (2015) demonstrated in a trial near Canberra that deferred grazing of pasture due to the grazing of dual-purpose crops led to increased pasture production. Not using dual-purpose crops will increase grazing pressure on degraded pastures increasing the requirement for supplementary feed. To offset the requirements for pastures during autumn and winter and also to maximise growth for dual-purpose crops it is essential to follow the best management practices including:

1. Select a paddock with a history of low weed pressure.
2. Ensure paddock has had strict weed control during the fallow period as to ensure greatest soil water storage.
3. Plan to sow early. Earlier sowing increases biomass accumulation. Canola can be sown from late February to April. Wheat can be sown from March to May. Early sowing does increase risk of moisture stress.
4. Select a true winter type cultivar to enable early sowing.
5. Provide sufficient nitrogen.
6. Provide mineral supplements with dual-purpose wheat. Not for canola

Decision making for the year ahead

As sowing time approaches growers will be trying to determine how much pasture to sow as well as what management strategies can be used in existing pastures. Pasture removal should be for those pastures that have degraded over the last season and that are unlikely to be productive in the year ahead. Firstly all pastures should be assessed for lucerne density. This can be done by using a 50cm x 50cm quad randomly placed 30 times across the paddock. Determining actual plant numbers can be difficult in higher density stands as individual plants that are close together cannot be distinguished other than by digging up and counting tap roots. Paddocks should be ranked depending on density.

Companion species can also be assessed. This could be done using residue from last year i.e. grass seed heads or sub clover burrs. Very small areas (<1m^2) could also be wet up from March to determine the number of seedlings that emerge. It is difficult to determine a critical value for subterranean clover seedling density. After the previous two dry springs it is unlikely that any paddocks will reach the critical number of 1000 plants/m^2. Comparing a density to that achieved after a low sowing rate of subterranean clover would result in a critical value of 75 plants/m^2. There would be no point re-sowing subterranean clover if the existing density was already greater than that which could be achieved by re-sowing.

In discussion with the grower determine the area of pasture required. At the most basic level discuss with the manager how many hectares of pasture they normally have to supply sufficient feed for livestock. McCormick et al (2012) calculated an average stocking rate for pasture areas on mixed farms from a survey to be 11 DSE/ha. A simple feed budget could be constructed to determine the livestock requirement for different periods in the season. This could be done with simple online tools such as the Evergraze Feed Calculator (https://www.evergraze.com.au/library-content/feedbase-planning-and-budgeting-tool/) or simple estimation using 3-4% of body weight for growing/lactating animals. Ascertaining the time of season when pasture growth will be most limiting will aid in choosing the most appropriate management strategy. If dual-purpose crops are used extensively on-farm, then animal requirement could be met by these crops from May to mid-August depending on the break of season. Calculate the area required to be sown for dual-purpose crops using the number of ewes on farm and an estimated stocking rate of 20 DSE/ha. Be aware that the DSE rating of a pregnant or lactating ewe can vary from 1.5 – 4 DSE depending on breed and weight of animal. The area required for dual-purpose crops also depends on the timing of the break. An early rainfall event with early sowing accumulates more biomass, and therefore, less area is needed. In comparison a late break would require larger areas of dual-purpose crops to be sown to have the same effect. With the use of dual-purpose crops, it is likely that degraded pastures will be limiting production immediately after the break in season (late autumn) and from August to September after grazing has ceased on the dual-purpose crops. Identifying production limitations will help with selection of the best management option.

The decision tree (Figure 1) outlines different options that are available for paddocks depending on the density of lucerne determined.

Options for pasture renovation

There are a number of options in response to pastures that have a low density of lucerne. It is recommended not to re-sow lucerne back into old lucerne stands due to disease and autotoxicity (Kehr 1983). Pastures could be over sown with subterranean clover or a cereal to increase forage production. Alternatively the pasture could be removed to sow an annual crop.

Using the decision support tree (Figure 1) will lead to the following various options:

- Option 1 - Remove pasture and sow crop for current year.

  If there is no requirement for the pasture, or forage can be supplemented elsewhere with sown cereals (Option 2) then this paddock should be brought back into the cropping phase.

  Opportunities – Moves the paddock into the cropping phase.

  Limitations – If pasture is still present in autumn it is likely that the soil has not stored summer rainfall and the lucerne will be difficult to remove. Crop yield maybe reduced. Does not provide any extra pasture.

- Option 2 - Keep pasture and sow cereal for grazing, hay or grain.

  Cereals can be successfully direct drilled into lucerne stands. Dry sowing can be an option but should not be undertaken too early as lucerne will compete strongly for moisture in

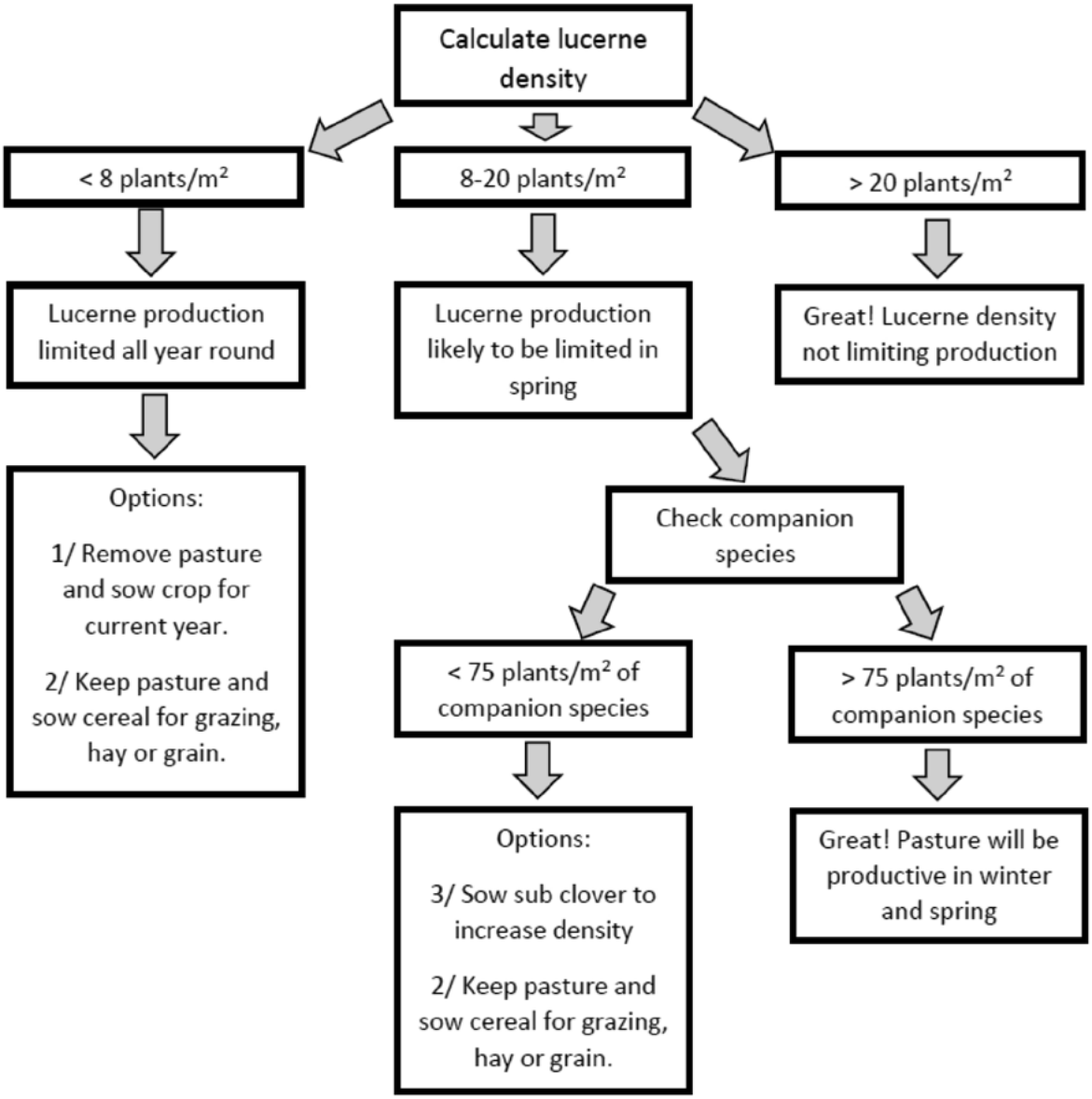

Figure 1. Pasture decision support tree.

the autumn. Cereal species used will depend on what is required. Oats is vigorous and will provide early feed. Barley could be late sown and yet is still vigorous. Winter wheat could be suitable for early sowing with the potential for grain although late grazing may limit significant grain recovery. The opportunity for hay or silage could be high and would enable refilling of haysheds. Decision on cereal species will also depend on seed cost and availability.

Opportunities – High quality forage for autumn, winter and early spring. Potential for hay, silage or grain from dual purpose crops.

Limitations – Cost of sowing operation and seed. One year only. If lucerne density is low, then there is still limited production from the lucerne.

- Option 3 - Oversow sub clover to increase density.

  Ideally high sowing rates will ensure a fast establishment for grazing. Seed should be sown rather than broadcast on the soil as broadcasting success rate is low. Pre-sowing herbicides should be used.

  Opportunities – Should increase the productivity of the pasture for the next few years.

  Limitations – Can be an expensive option. Number of seeds sown is much less than that from an established seed bank, and therefore, growth will be slower.

Conclusion

Pastures on mixed farms will have likely degraded following the drought last year. It is crucial that pastures are assessed to determine their productive potential. Management options can be used to increase forage supply this year to ensure that livestock enterprises are not impacted by poor pastures. Dual-purpose crops can play an important role in filling early season feed gaps giving pastures time to recover and or new pastures to establish.

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Contact details

Jeff McCormick
Charles Sturt University
Wagga Wagga
02 6933 2367
jmccormick@csu.edu.au

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Notes

Biology and control options for wild radish, prickly lettuce and sow thistle

Hanwen Wu and Adam Shephard and Michael Hopwood.

Wagga Wagga Agricultural Institute, NSW Department of Primary Industries.

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Keywords

- weeds, biology, seed dormancy, persistence, management

Take home messages

- Long persistence of wild radish requires management programs of more than six years.
- Wild radish emergence occurred mainly in the second season after fresh seed release from the parent plant, whereas sowthistle and prickly lettuce had their major emergence in the first season.
- Don't let in-crop wild radish patches go to seed.
- Seeds of sowthistle and prickly lettuce are relatively short-lived, therefore prevention of seed set over two years should be effective in running down the seedbank.
- Seeds of sowthistle and prickly lettuce are surface germinators, but prickly lettuce can also emerge beyond 5cm burial depth.
- Good control within paddocks is not the full solution. It is also important to control weeds on fenceline, roadsides and other non-cropping areas, particularly for sowthistle and prickly lettuce due to their wind-dispersal capabilities.
- Seedbank management is critical for the three weeds. It requires a combination of chemical and non-chemical options as there is no single 'silver bullet' available.

Background

Weeds are persistent problems in agriculture, increasing production costs and reducing crop yields. The total cost of weeds to Australian grain growers is estimated at $3,318 million, including $2,573 million for expenditure on control options and $745 million for revenue loss (Llewellyn, 2016). Wild radish (*Raphanus raphanistrum* L.) and common sowthistle (*Sonchus oleraceus* L.) are among the top 10 worst weeds nationally and prickly lettuce (*Lactuca serriola* L.) was ranked number 18 in the southern region (Llewellyn, 2016).

Both sowthistle and prickly lettuce belong to the sunflower family (*Asteraceae*). Seeds of sowthistle and prickly lettuce are enclosed singly in small hard achenes equipped with a pappus, indicating that the spread of the two wind-blown weeds across agricultural landscapes could be very rapid through long distance dissemination via surface runoff and water movement in irrigation channels and waterways.

Control of these three broadleaved weeds relies heavily on herbicides, which has resulted in the rapid development of herbicide resistance to Groups B, C, F, I and M in wild radish, and to

Groups B and M in sowthistle and prickly lettuce. Diversifying control options by incorporating chemical and non-chemical measures is the only way forward if resistant weeds are to be effectively managed. An understanding of weed biology would assist in identifying the weakest link in the weed life cycle and hence contribute to the design of effective control programs. New knowledge on weed biology and management is presented in this paper, with particular focus on prickly lettuce due to the limited information available.

Wild radish biology and management

Wild radish is of Mediterranean origin and is a major weed of winter crops in southern Australia (Murphy et al. 1999). The major source of spread is due to contamination in grain, chaff and hay. It is highly competitive in crops and can cause a yield loss of 10%-90% in cereals, canola and pulses (Storrie, 2014). It germinates in a wide range of temperatures from 5°C to over 35°C, with optimal diurnal fluctuation of 25°C/10°C. Wild radish can therefore emerge at any time of the year given sufficient soil moisture. However, wild radish predominantly emerges in late autumn (May) and early winter, followed by staggered emergence throughout the season (Young, 2001). Deeper burial depths often result in decreased emergence but at the expense of increased persistence. Strong dormancy and long persistence are the two most important features contributing to the difficulty in control. Fresh seeds of wild radish are dormant and many seeds will not germinate until the second season after their formation (about 18 months later) (Storrie, 2014). Wild radish seed has a longevity of more than six years. Two critical steps are required to effectively manage wild radish: (1) prevent seed return to the seedbank (seedset control) and; (2) deplete the existing seedbank (through emergence and seed decay).

Without the new addition of fresh seeds, control measures have to be in place for more than six years in order to exhaust the seedbank (Cheam, 1996), which is supported by results from a long-term rotation trial established in Wagga Wagga, i.e. 2013 field peas ➔ 2014 barley ➔ 2015 triazine tolerant (TT) canola ➔ 2016 wheat ➔ 2017 barley ➔ 2018 wheat.

Over the six year period, the management (Mgt) 1 (treatment pre-emergent (PRE)) had much higher wild radish seeds in the seedbank than Mgt 2 (treatment PRE + post-emergent (POST)) and Mgt 3 (treatment PRE + POST + Seedset) (Figure 1). Mgt 2 and 3 were equally effective, resulting in a rapid decline of wild radish seedbank in the first year, followed by a steady decline over the remaining years. The results indicate that the wild radish seeds persist well in the soil, requiring a long-term approach of more than six years to manage the wild radish problem. Any new seed replenishment will waste the previous management efforts.

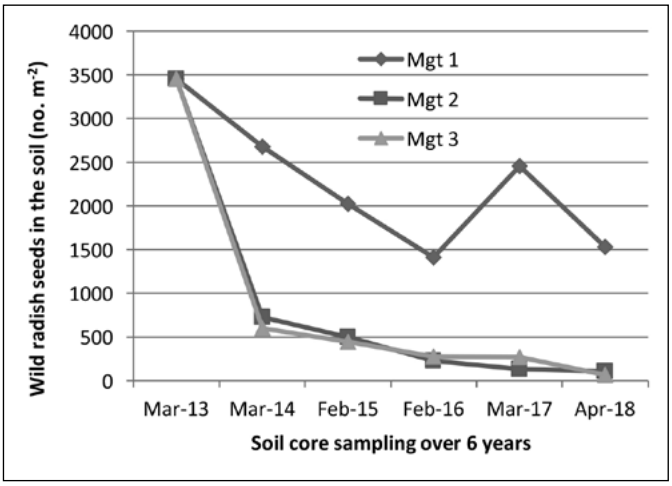

Figure 1. Seedbank dynamics of wild radish between 2013 and 2018 under three management options. Mgt 1– Pre-emergent treatments only (PRE), Mgt 2 – PRE followed by post-emergent treatments (PRE + POST), and Mgt 3 – (PRE + POST) followed by late seedset control (Seedset).

Herbicides are a valuable tool for wild radish control. For effective control, it is necessary to target young and actively-growing weeds with a rosette of less than 5cm in diameter. A two-spray herbicide strategy is recommended for high levels of in-crop control (Storrie, 2014). The 'two-spray' strategy on wild radish was also evaluated in two field trials in southern NSW (Wagga Wagga and Marrar, 2015).

The field had a natural infestation of wild radish at 110 plants/m2and 78 plants/m2 at Wagga Wagga and Marrar sites, respectively. A pre-sowing double-knockdown with glyphosate followed by paraquat was used to control the emerged wild radish. Wheat (cv. Corack) was sowed at Wagga Wagga site on 1 June 15 and oats (a mixture of cv. YiddahA and MitikaA) sowed at Marrar site on 9 May 2015.

The two-spray strategies were highly effective on wild radish control. The 1st spray of Bromicide® MA followed 40 days later by each of the fourteen 2nd spray treatments had 100% control of wild radish (Table 1). However, Bromicide® MA without a follow-up spray only achieved 85% control.

Without the first spray of Bromicide® MA, five 2nd spray treatments Amicide® 700, Jaguar®, Broadside®, Bromicide® MA and a mixture of ParadigmTM + LVE Polo 570 (LVE MCPA) gave poor control of wild radish (<90%). Bromicide® MA applied on 16 September had only 30% control of wild radish

as compared to the same treatment applied on 7 August (85%).

At Marrar site (Table 2), the 1st spray treatments without the 2nd spray were not effective on wild radish (7%-83%). In the untreated 1st spray treatments, only three single knock 2nd sprays of Precept®, Flight® EC and GalleryTM 750 + LVE Polo 570 achieved excellent control of wild radish (98%-100%), while the control for the remaining six 2nd spray treatments was poor (17%-87%).

The combination of either Jaguar® + Sencor® or Tigrex® + Sencor® as the 1st spray treatment, followed 25 days later by any of the nine 2nd spray treatments achieved high level of control (98%-100%). However, the two-spray program using Igran® + Agritone 750 as the 1st spray treatment, even with the follow-up application of nine 2nd sprays, did not achieve consistent control, with the 2nd spray treatments Amicide® 700 and Affinity® Force + Agritone 750 being poorly effective (80%-83%).

Table 1. Two-spray strategy on wild radish control in wheat (Wagga Wagga 2015).

Second spray treatments			First spray treatments			
			Visual rating (%)		Plant density (plant/m^2)	
Treatment	Rate (ml or g/ha)	Rate (g a.i./ha)	Untreated	Bromicide MA	Untreated	Bromicide MA
Amicide 700 + Liase	1400 ml +2 %	980	87	100	0.3	0
Precept + Hasten	2000 ml + 1%	(250 + 50)	100	100	0.0	0
Velocity + Hasten	1000 ml + 1%	(210 + 37.5)	97	100	3.3	0
Tigrex	1000 ml	(250 + 25)	97	100	0.2	0
Jaguar	1000 ml	(250 + 25)	17	100	5.5	0
Broadside	1000 ml	(280 + 140 + 40)	80	100	0.8	0
Flight EC	720 ml	(25.2 + 151.2 + 252)	93	100	0.0	0
Paragon	500 ml	(250 + 25)	98	100	0.0	0
Bromicide MA	1400 ml	(280 + 280)	30	100	0.8	0
Affinity Force + Agritone 750	100 ml + 330 ml	24 + 250	97	100	1.2	0
Paradigm + LVE Polo 570 + Uptake	25 g + 440 ml + 0.5%	(5 + 5) + 250	87	100	1.3	0
Logran 750 WG + Agritone 750 + Uptake	15 g + 330 ml + 1%	11.25 + 250	100	100	0.0	0
Triathlon	1000 ml	(250 + 150 + 25)	99	100	0.3	0
Untreated control			0	85	16.7	0
$Lsd_{0.05}$			8.17		4.35	

Note: 1st spray at 4-5 leaf stage on 7 August using Bromicide MA (200 g/L bromoxynil + 200 g/L MCPA) applied at 1400 ml/ha. 2nd spray treatments on 16 September 40 DAT1 (Days after treatment). Visual rating assessed on 23 October, 37 DAT2 and plant density on 9 November, 54 DAT2.

Table 2. Visual control rating (%) of two-spray strategy on wild radish in forage oats at 60 days after the 2nd spray (Marra 2015).

Second spray treatments			First spray treatments			
Treatment	Rate (ml or g/ha)	Rate (g a.i./ha)	Untreated	Jaguar + Sencor	Tigrex + Sencor	Igran + Agritone 750
Amicide 700 + Liase	1150 ml +2 %	805	40	100	100	83.3
Precept + Hasten	2000 ml + 1%	(250 + 50)	98.3	100	100	100
Velocity + Hasten	1000 ml + 1%	(210 + 37.5)	83.3	98.3	100	93.3
Tigrex	1000 ml	(250 + 25)	80	100	100	96.7
Flight EC	720 ml	(25.2 + 151.2 + 252)	100	100	100	100
Paragon	500 ml	(250 + 25)	86.7	100	100	95
Affinity Force + Agritone 750	100 ml + 330 ml	24 + 250	68.3	100	100	80
LVE Polo 570	440 ml	250	63.3	100	100	98.3
Gallery 750 + LVE Polo 570 + Uptake	100 g + 440 ml + 0.5%	75 + 250	100	100	100	100
Untreated control			0	83.3	80	6.7
$Lsd_{0.05}$			12.19			

Note: 1st spray treatments on wild radish at 5-6 leaf stage on 23 July. 2nd spray treatments on 17 August, 25 DAT1. Visual rating assessed on 16 October, 54 DAT2. Products and formulations applied in the first application include Jaguar® (250 g/L bromoxynil + 25 g/L diflufenican) + Sencor® 480 SC (480 g/L metribuzin) applied at 1000 ml + 100 ml/ha, Tigrex® (250 g/L MCPA and 25 g/L diflufenican) + Sencor® 480 SC (480 g/L metribuzin) at 1000 ml + 100 ml/ha; and Igran® 500 SC (500 g/L terbutryn) + Agritone 750 (750 g/L MCPA) at 500mL + 350mL/ha.

Sowthistle biology and management

Common sowthistle originates in Europe. The weed is not known to compete heavily with cereal crops. However, in a poorly competitive crop, common sowthistle contributes to green matter at harvest and can lead to grain quality problems. It can produce up to 25,000 seeds/plant (Widderick, 2017) and 68,000 seeds/m^2 in a fallow (Storrie, 2014), indicating seedbank can be built up very quickly. The fresh seeds were previously believed to be dormant. However, our recent research showed that seeds from different locations and seasons exhibited variable dormancy based on 38 populations collected in southern NSW, with dormancy ranging from 5.3% to 98.7%.

Sowthistle is a surface germinator, with most emergence occurring from seed on or near the soil surface and no emergence from soil depth of more than 5cm (Chauhan et al. 2018). However, deep burial through cultivation could increase seed persistence. Sowthistle seeds can germinate over a broad range of temperatures from 5°C to 35°C, with maximum germination at alternating day/night temperature of 20/12°C. Sowthistle can therefore grow and flower all year round as long as soil moisture is not limiting. However, majority of plants emerged between April and August in southern NSW, with most emergence in the first year after fresh seed burial on soil surface, and little emergence in the second year. Exception was the samples YAMB01 and COND01 which had some emergence in the second year after burial (Figure 2).

Growing competitive cereals is an effective non-chemical option for sowthistle control (Widderick, 2017). Recently research has shown that high plant population and narrow row spacing are also effective in suppressing sowthistle in the traditionally-believed 'poorly competitive' faba bean and chickpea crops.

Higher faba beans populations resulted in lower plant height and biomass of sowthistle in both narrow- and wide-row spacing treatments (Table 3). Crop population at 60 plants/m^2 reduced the sowthistle seed head/plant, seeds/plant and seeds/m^2 as compared to the crop population at 15 plants/m^2 and the Nil-crop control.

Narrow-row spacing in the faba bean also reduced sowthistle plant height, plant biomass, seed head/plant and seeds/plant by 13%, 52%, 53% and 54%, respectively, when compared to the wide-row spacing treatment.

The impact of chickpea population on sowthistle growth and seed production in the chickpea trial was similar to faba beans. Higher chickpea populations had significantly lower sowthistle plant height, biomass, seeds/plant and seeds/m2 at both row spacing treatments (Table 4).

There were no significant differences between the narrow and wide row spacing treatments.

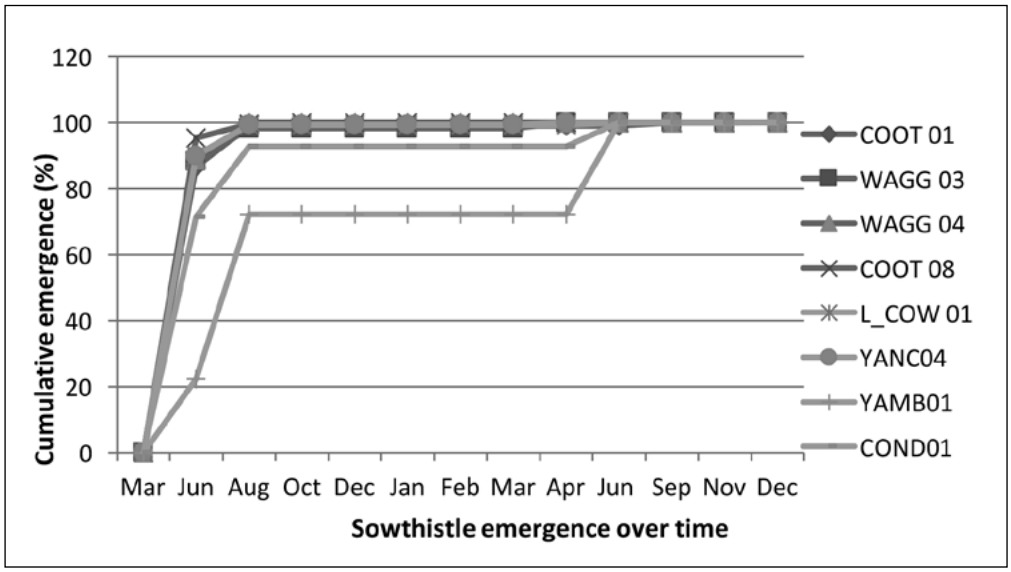

Figure 2. Emergence dynamics of sowthistle collected from different rainfall environments (tested in trays under field conditions in Wagga Wagga from March 2016 to December 2017).

Table 3. Faba beans populations and row spacings on sowthistle growth and seed production.

Faba beans target population (plants m^{-2})	Row spacing (cm)	Plant height cm	Plant biomass (g/plant)	biomass (g/m^2)	Seeds/ plant	Seeds/m^2
15	46	70.0	9.8	46.4	12543.9	56372.1
30	46	66.9	6.7	38.6	7483.4	32675.8
60	46	64.2	5.2	30.3	5253.7	21634.9
Nil-crop	na	73.6	15.1	115.4	9341.5	51442.6
15	23	56.60	4.74	54.86	5522.7	46219.4
30	23	61.19	3.49	28.61	3432.4	22575.9
60	23	56.42	2.22	13.47	2639.8	13010.8
Nil-crop	na	75.56	13.41	120.97	8348.3	78981.6
$Lsd_{0.05}$						
Population		7.73**	3.89**	40.90**	3628.9*	20523.2**
Row spacing		5.47*	2.75*	28.92	2566.0**	14512.1

na: not applicable.

Table 4. Chickpea populations and row spacings on sowthistle growth and seed production.

Chickpea target population (plants m^{-2})	Row spacing (cm)	Plant height (cm)	Biomass (g/plant)	Biomass (g/m^2)	Seeds/plant	Seeds/m^2
20	46	72.4	13.2	132.3	5499.2	29924.4
40	46	62.7	4.1	74.4	2045.0	10914.5
80	46	61.4	4.5	87.2	2267.2	10688.7
Nil crop	na	66.0	16.7	91.8	5618.2	37442.0
20	23	75.4	8.1	79.1	5652.7	22894.6
40	23	66.3	3.3	31.8	4030.9	15534.4
80	23	60.6	2.7	20.1	1734.2	6658.2
Nil crop	na	85.4	16.2	265.1	10160.4	45333.6
$Lsd^{0.05}$						
Population		10.35*	3.11**	85.1*	1545.4**	10791.6**

na: not applicable.

Prickly lettuce biology and management

Prickly lettuce is of Eurasian origin and it was first recorded in 1899 in the Upper Hunter region of NSW. It has recently become an increasing problem in cereals and lucerne pastures in southern NSW. Similar to sowthistle, it did not cause significant yield loss in cereals or grain legumes, but grain quality and harvesting efficiency were severely compromised (Amor 1986a). Flowering buds are cut together with grain during harvest, resulting in grain contamination and reductions in value. Plants are difficult to control with herbicides once the plants start to elongate. Mechanical control is ineffective as it regrows with competitive branches after cutting or harvesting and progresses to set seeds (Amor 1986a).

In Australia, Amor (1986b) estimated that prickly lettuce plant in crop stubble produced 48,000 seeds/plant while it produced 900 seeds/plant in a wheat crop. The seed has been associated with its rapid dispersal over distances of up to 43km (Lu et al. 2007). Prickly lettuce has wide germination temperatures, ranging from less than 5°C to more than 35°C, depending on the species and population (Figure 3). Willow-leaf lettuce (*Lactuca saligna*) had 80% germination even at 5°C. The optimum temperatures for germination were 15 – 25°C for *L. serriola*. Alternating temperature did not improve the germination of *L. serriola* (tall) and *L. saligna*, but reduced the germination of *L. serriola* (short) (Figure 4).

Light stimulated the germination of *L. serriola* for tall and short biotypes, while light was not required for the germination of *L. saligna* (Figure 5).

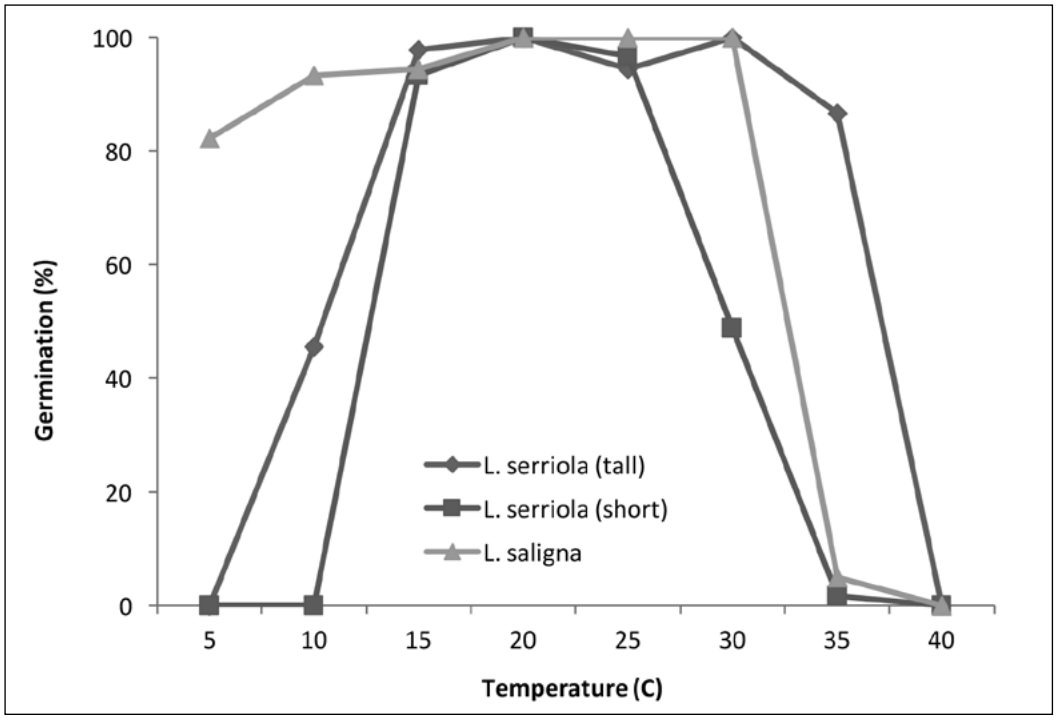

Figure 3. Germination temperature requirements for prickly lettuce.

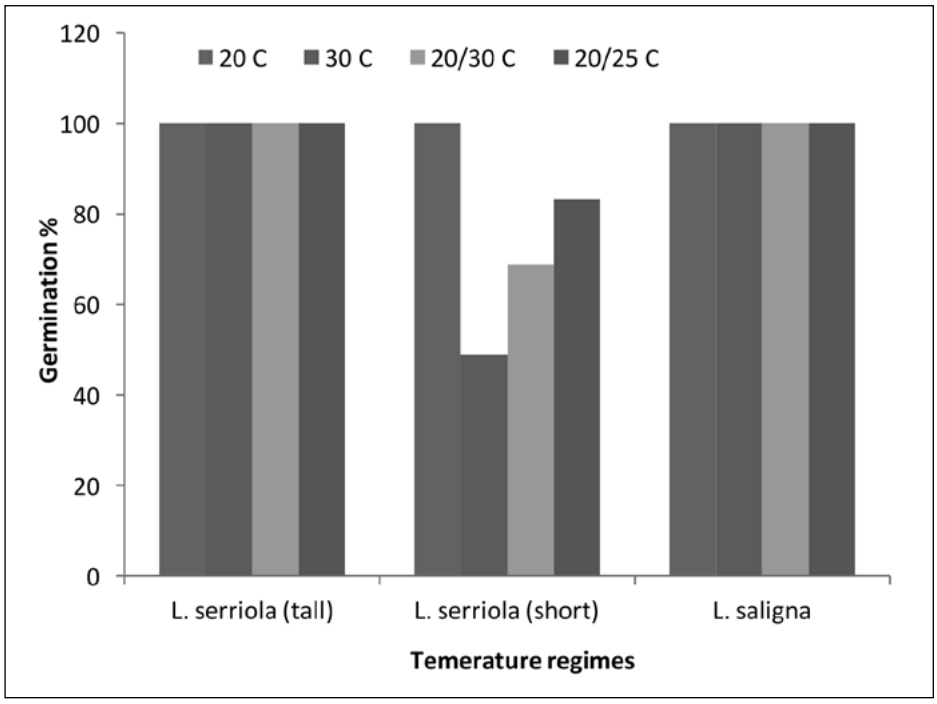

Figure 4. Impact of alternating temperatures on the germination of prickly lettuce.

Higher temperatures induced secondary dormancy in prickly lettuce (Figure 6). *L. serriola* seed (short biotype) underwent induced dormancy at 30 °C, while both biotypes of *L. serriola* as well as the *L. saligna* entered secondary dormancy at 35 and 40 °C.

Prickly lettuce had major emergence (40% to 76%) from the soil surface (0cm), depending on the species and population, with *L. saligna* still having 19% at 2cm burial depth. Both *Lactuca* species can emerge (0.25% to 0.5%) at deeper depths (5cm and 10cm), which is different to sowthistle, indicating cultivation to bury seeds will be less effective in prickly lettuce than sowthistle.

Prickly lettuce populations differed in their final cumulative emergence, ranging from

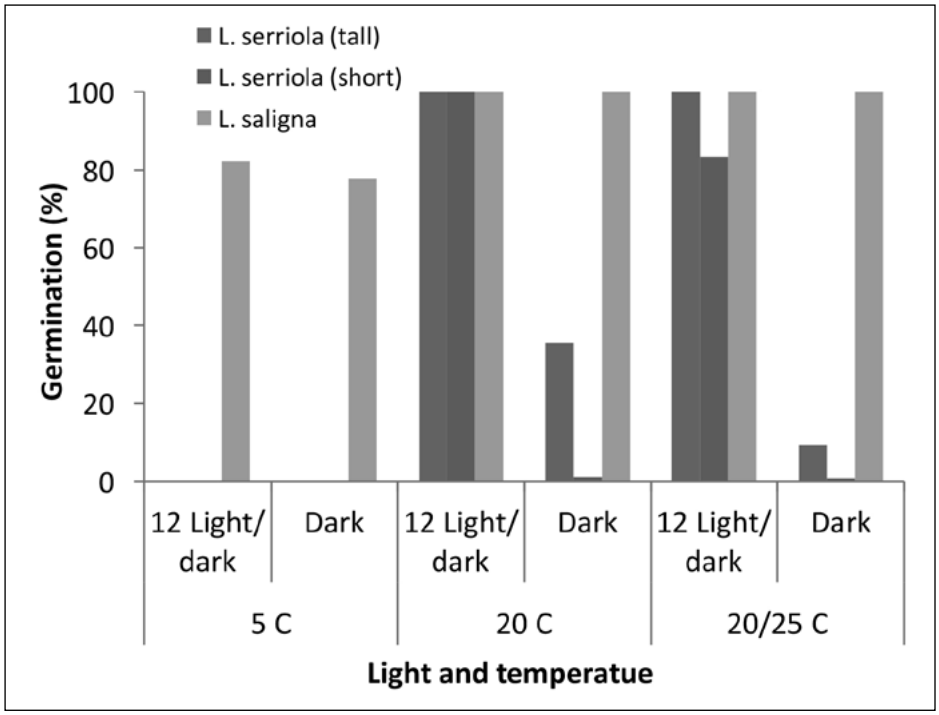

Figure 5. Impact of light on the germination of prickly lettuce.

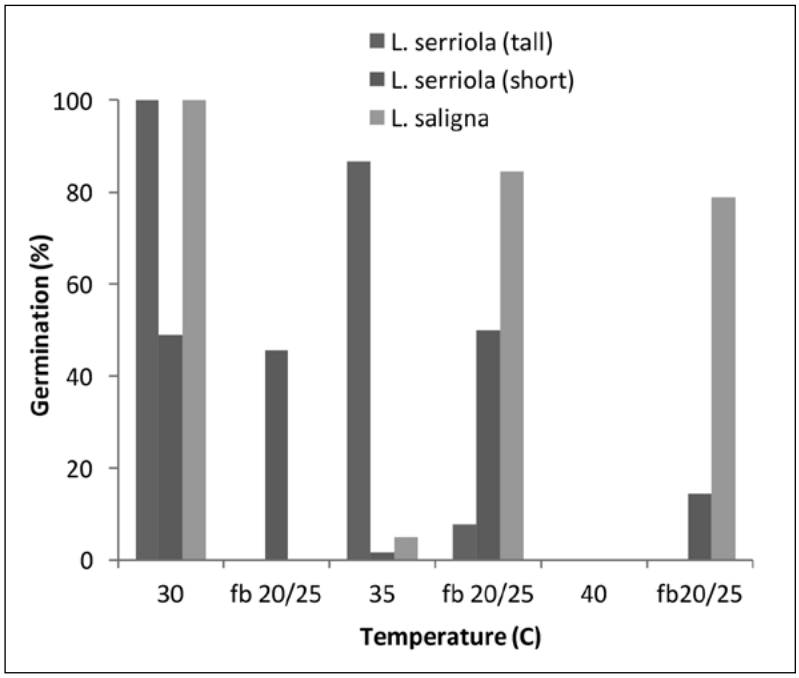

Figure 6. Dormancy of prickly lettuce induced at higher temperatures of 30, 35 and 40 °C.

39 plants/m^2 to 341 plants/m^2 (Figure 8), however, they had similar emergence patterns, with 69% emergence in late autumn and early winter, 27% in later winter, 2.4% in spring in the first year after burial and only 1.6% emergence between autumn and winter in the second year (Wu et al. 2018).

Effective herbicide options are limited on prickly lettuce. A herbicide trial on prickly lettuce in summer fallows identified that five treatments, glyphosate, 2,4-D amine + glyphosate, metsulfuron-methyl + glyphosate, glufosinate ammonium and fluroxypyr achieved good control with more than 90% mortality, while the remaining 11 treatments only controlled 30%–88% of prickly lettuce. The follow-up 'double-knock' treatment with paraquat at 600 g a.i./ha provided 100% control on prickly lettuce, even in the untreated plots which did not have the first knock of herbicide applications (data not shown).

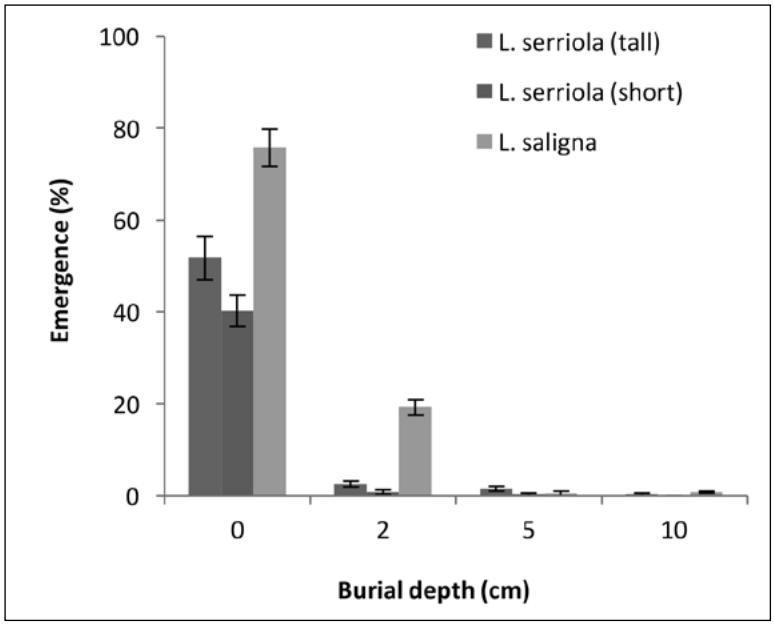

Figure 7. Impact of burial depth on the emergence of prickly lettuce under glasshouse conditions.

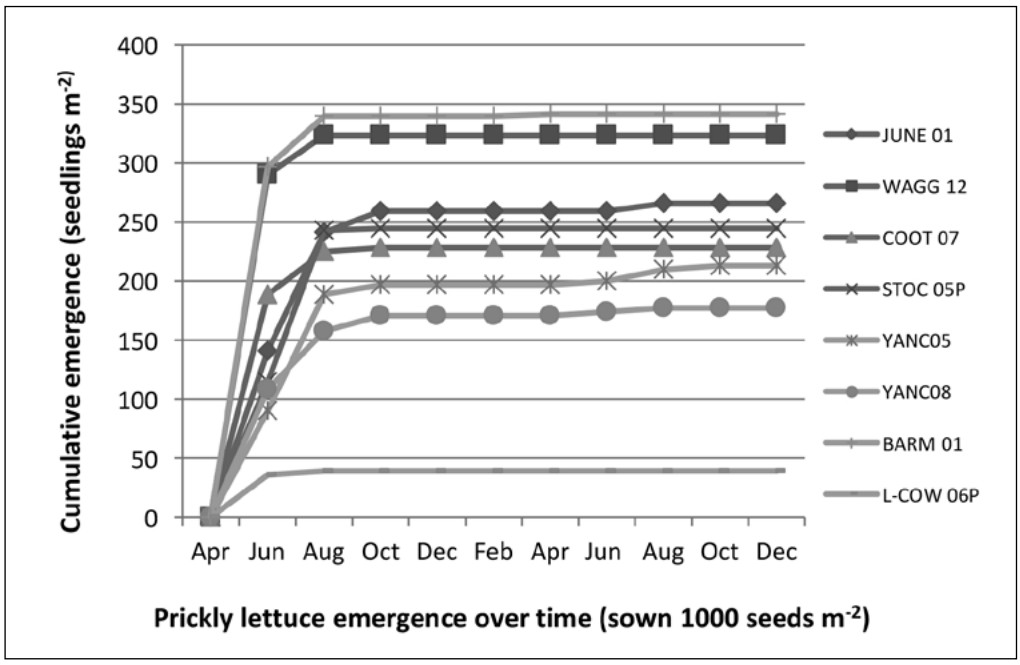

Figure 8. Emergence of prickly lettuce in seedling trays without crop competition under field conditions in Wagga Wagga from April 2016 to December 2017. The number of seeds sown onto each tray was expressed as seeds/m^2.

Table 5. Herbicide control efficacy on mature prickly lettuce plants at Lake Cowal.

Treatment	Rate (ml or g ha^{-1})	Rate (g a.i./ha)	Single_knock[A]	
			Visual rating[A] (%)	Density (plants m^{-2})[B]
Amicide Advance 700 + Liase	1150 ml + 2%	805	30.0	3.7
Amicide 700 Advance + weedmaster ARGO + LI700	515 ml + 1300 ml + 0.3%	360 + 700	93.3	0.6
Weedmaster ARGO + LI700	1300 ml + 0.3%	700	90.0	2.0
Starane Advanced + Uptake	600 ml + 0.5%	200	95.0	0.8
Starane Advanced + Weedmaster ARGO	600 ml + 1300 ml	200 + 700	88.3	2.4
Ally + Weedmaster ARGO	7 g + 1300 ml	4.2 + 700	95.0	1.6
Goal + Weedmaster ARGO + BS1000	75 ml + 1300 ml +1%	18 + 700	86.7	2.1
Kamba + Weedmaster ARGO	240 ml + 1300 ml	120 + 700	85.0	4.5
Basta	4000 ml	800	91.7	1.8
Amitrole T + LI700	5600 ml + 0.3%	(1400 + 1230)	85.0	1.6
Tordon 75D	700 ml	(210 + 53)	53.3	3.9
Tigrex	1000 ml	(250 + 25)	81.7	3.7
Affinity Force + Agritone 750	100 ml + 330 ml	(24 + 250)	76.7	2.5
Lontrel 300+ LVE Agritone 570	150 ml +1000 ml	45 + 570	63.3	2.4
LVE Agritone 570	1000 ml	570	40.0	4.3
Hotshot + LVE Agritone 570	750 ml +1000 ml	(7.5 + 105) + 570	86.7	3.5
Control			0.0	6.2
Lsd0.05			17.93	1.89

[A]Treatments applied on 10 December 2015 and a visual rating was conducted on 8 January 2016, 29 DAT. [B]The surviving prickly lettuce plants were recorded on 2 February 2016, 64 DAT.

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Contact details

Hanwen Wu
Wagga Wagga Agricultural Institute
NSW Department of Primary Industries
Pine Gully Road, Wagga Wagga, NSW 2650
02 6938 1602
hanwen.wu@dpi.nsw.gov.au

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Notes

Understanding the amelioration processes of the subsoil application of amendments

Ehsan Tavakkoli[1,2], Zhe H. Weng[1], Iman Tahmasbian[1], Shihab Uddin[1], Yunying Fang[3], Graeme Poile[1], Albert Oates[1], Binbin Xu[1], Graeme Sandral[1] and Roger Armstrong[4].

[1]New South Wales Department of Primary Industries, Wagga Wagga Agricultural Institute, Wagga Wagga, NSW; [2]Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga, NSW; [3]NSW Department of Primary Industries, Elizabeth Macarthur Agricultural Institute, Menangle, NSW; [4]Agriculture Victoria Research, Department of Economic Development, Jobs, Transport and Resources, Horsham, VIC.

GRDC project code: DAV00149

Keywords

- soil constraints, sodic soils, amendments, amelioration.

Take home messages

- The early results of this project showed great potential in improving soil structure and crop productivity in sodic subsoils using deep placement of organic and inorganic amendments. The increases resulted from improvement in the physical and chemical properties of the clay soil volume around the rip line containing the organic and inorganic amendments, and from increased root growth through the subsurface soil layers adjacent to the rip lines. This improvement was possibly mediated by increased microbial activity that leads to improved soil aggregation.
- In both years of the field experiment, the greatest yield response was achieved in the pea hay + gypsum + nutrients treatment. Given multiple subsoil constraints including high pH, sodicity and poor soil structure that exist in south-east Australia, an amendment with multiple modes of action is required to improve hostile subsoils.
- It is proposed that a reduction in net dispersive charge and pH together with an enhanced microbial biomass carbon (C) resulted in improved soil aggregation. The changes in soil chemicophysical properties correlated with higher crop water uptake from the ameliorated layer.

Background

Approximately 75% of Australian soils have subsoil constraints that limit agricultural productivity. The major constraints to crop growth are poorly structured subsoils that result from high clay content and bulk density, as well as the presence of high subsoil exchangeable sodium (Na) concentrations (resulting in soils with poor subsoil structure, impeded drainage, waterlogging, and high soil strength). These constraints adversely affect soil water and plant available water content (PAWC) by impeding water entry into the soil, restricting water movement within the soil, reducing the soil's ability to store water and nutrients, and reducing the ability of plants to access and extract stored water and nutrients. Soil constraints may be multiple or singular, occurring either near the soil surface, or in the subsoil and they tend to be highly variable across any given paddock or property (McDonald et al. 2013).

A range of practices including deep ripping, subsoil manuring, clay incorporation, applying gypsum, installing underground drainage or use of 'primer-crops' have been tested to overcome

subsoil constraints, usually with unreliable results and often potential financial losses to growers (Gill et al. 2008). For example, despite the fact that gypsum is widely used as the main soil amendment in improving poor structure of sodic soils, it is a sparingly soluble salt and because of this attribute it is hardly possible to deliver adequate calcium (Ca) to correct sodicity issues in the subsoil. In regards to subsoil manuring, despite the demonstrated step change in crop yields that can be achieved by this management strategy, practice change in the grains industry to date has been limited. One constraint to widespread adoption includes the local availability and high cost of suitable organic ameliorants delivered in-paddock. This factor can be significant as research to date in the higher rainfall zones suggests rates of up to 20t/ha are required — transport costs quickly become prohibitive if this material needs to be sourced off-farm (Gill et al. 2008; Sale et al. 2019). Therefore, solutions integrating complementary sources of organic matter materials, such as crop residue and cover crop biomass produced in-situ, need to be investigated, with current project DAV00149 initiating this new area of research.

A series of field and glasshouse experiments was established to understand the amelioration process when various organic and inorganic amendments are placed at depth in dispersive subsoils. This paper will provide results of a GRDC project (DAV00149) aiming to ameliorate subsoil constraints and to understand the amelioration processes of the subsoil application of amendments. It will show how deep incorporation of organic amendments into the clay subsoil provided significant improvements in grain yield, which was associated with changes in subsoil properties and improved root growth.

Method

Field trial

The two-year field experiment was established on a farm in Rand, southern NSW, in February 2017. The site was located in a paddock that had been cropped with a cereal-canola rotation for more than 50 years. Selected soil properties collected from the untreated soil are presented in Table 1. The soil is a Sodosol (Isbell, 2002), with a texture-contrast profile increasing in clay content at depth. The physical and chemical properties indicate that the subsoil condition was unfavourable for root growth. The high clay content in this subsoil layer has a bulk density of 1.55g/cm3 that restricts water movement, and consequently the saturated hydraulic conductivity value is low at 0.03cm/hr (Table 1).

The experimental plots were 2.5m wide and 20m long. There were 14 treatments comprising 1) the control, 2) surface application of gypsum, 3) surface application of chicken manure, 4) surface application of pea hay, 5) deep ripping, 6) deep placement of gypsum, 7) deep placement of manure, 8) deep placement of wheat stubble, 9) deep placement of wheat stubble + nutrients, 10) deep placement of pea hay, 11) deep placement of biochar, 12) deep placement of pea hay + nutrients, 13) deep placement of liquid nutrients, and 14) deep placement of pea hay + gypsum + nutrients. The experiment was a randomised complete block design with four replicates. Ripping and subsoil incorporation treatments were carried out with a 3-D ripping machine (NSW DPI). The machine can deliver inorganic and/or organic amendments at two depths from 10cm to 30cm. The machine is also capable of delivering liquid nutrients/fertilisers at depth. The experiment at Rand was sown to barley (cv. La Trobe(Φ)) on 18 May 2017 and wheat (cv. Lancer(Φ)) on 15 May 2018.

A Geonics EM38® instrument in vertical dipole mode was used to measure the apparent electrical conductivity (EC_a) of the soil. Based on the map of EC_a, the most uniform area of each field was selected for the experiments. The experiment was direct sown using DBS tynes spaced at 250mm. At sowing, 80kg monoammonium phosphate (MAP) (18kgphosphorus (P)/ha and 8kg nitrogen (N)/ha) was added to all plots. Pre-crop weed control was undertaken by applying Roundup® at 1.5L/ha, as well as the pre-emergents Sakura® (pyroxasulfone 850g/L) at 118g/ha and Logran® (triasulfuron 750g/L) at 35g/ha, and was incorporated at sowing. Precautionary disease control was implemented, seed was treated with Hombre ®Ultra imidacloprid (360g/L) and tebuconazole (12.5g/L)] at 200mLs/100kg and Prosaro® (prothioconazole 210g/L and tebuconazole 210g/L) was applied at 300mL/ha at DC 31. The experiment was harvested on 1 December. Grain protein and seed quality were estimated using near infrared (NIR) (Foss Infratec 1241 Grain Analyzer) and seed imaging (SeedCount SC5000R), respectively. At anthesis, about 50 youngest fully mature leaves (YML) were obtained randomly from each replicate plot of each genotype and then dried at 70°C for 48 hours. Dried plant samples were digested in an acid mixture of nitric and perchloric acid and concentrations of ions were measured on inductively coupled plasma (ICP).

Incubation experiment

To provide further insights into the dynamics of C mineralisation and the interactive effects of organic

amendments and gypsum, a laboratory based incubation experiment was conducted. The soil (450g air-dried soil, equivalent to 430g oven-dried soil) was uniformly mixed with organic amendments (i.e. crop stubble) at an application rate of 6.2g C/kg soil with or without gypsum ($CaSO_4 \cdot 2H_2O$) of 7.2g/kg soil or nutrients. The soils were incubated for 90 days and the changes in soil pH, exchangeable Na%, microbial biomass C and aggregate stability were then measured.

Results and discussion

Soil constraints and weather

The depth-wise distribution of physicochemical soil constraints are shown in Figure 1. The profile is characterised by the soil pH ranges from 5.1-9.1 with increasing sodicity (ESP up to 30%) with depth. A dispersion test was performed on several aggregates and indicated significant dispersion in subsoil increasing with depth (Figure 1). A considerable amount of soil water below 60cm was found after harvest which suggests limitations to root growth reduced the ability of the crop to access subsoil water (Rengasamy et al. 2016).

The growing season rainfall in 2017 and 2018 was 329mm and 225mm, respectively. In 2017, rainfall during the April to November growing season was 62.5mm less than the long term average, whereas in 2018, it was 178mm less than the average rainfall. The average rainfall in 2018 was about 40% lower than 2017 (Figure 2).

Yield response to different amendments

This experiment established in 2017 showed consistent, significant ($P<0.05$) effects of amendment

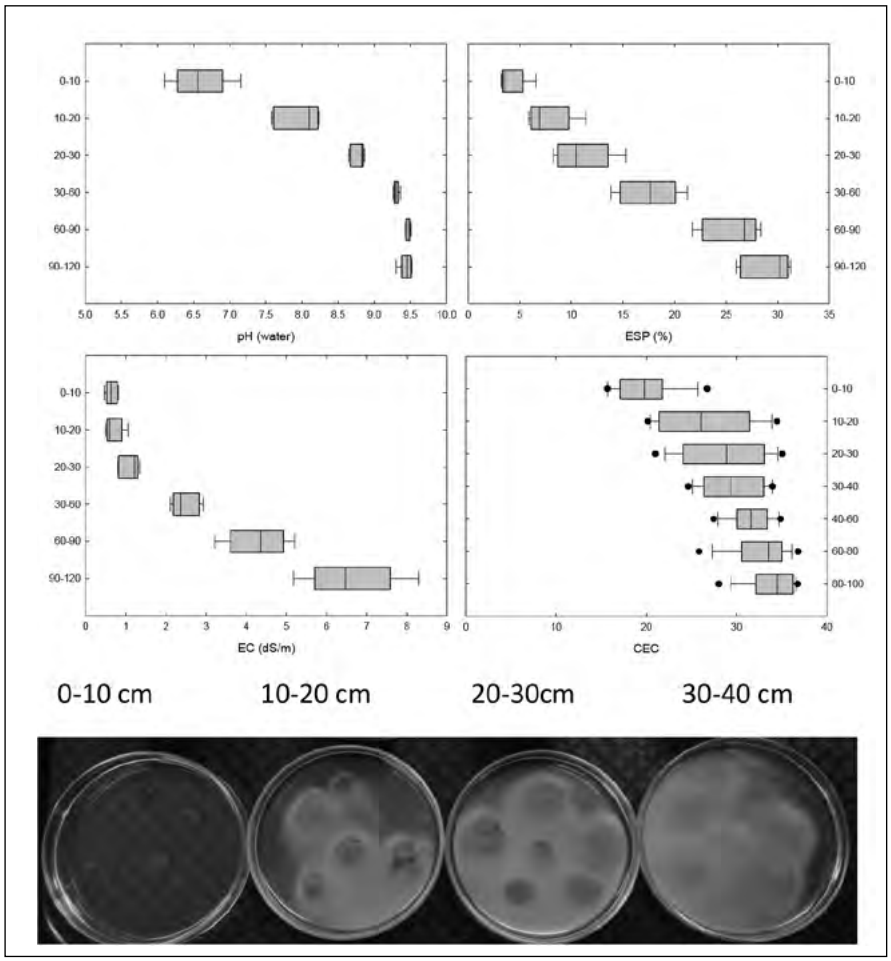

Figure 1. Soil characteristics of sodic site in Rand (southern NSW). Various lines indicate multiple locations across the trial. The picture shows the assessment of soil dispersion at four different depths. The increasing levels of exchangeable Na relative to calcium (Ca) and/or magnesium (Mg) in subsoil result in a decrease in soil structural stability and higher dispersion as shown above. When dispersion occurs, the dispersed clay particles fill up the pores between soil particles and aggregates, and when the soil dries out, the dispersed clay blocks soil pores. This can restrict seedling emergence, water and air movement, and root penetration. Dispersed soils are generally hard-setting and may form a surface crust or concrete-like lump which can also result in waterlogging.

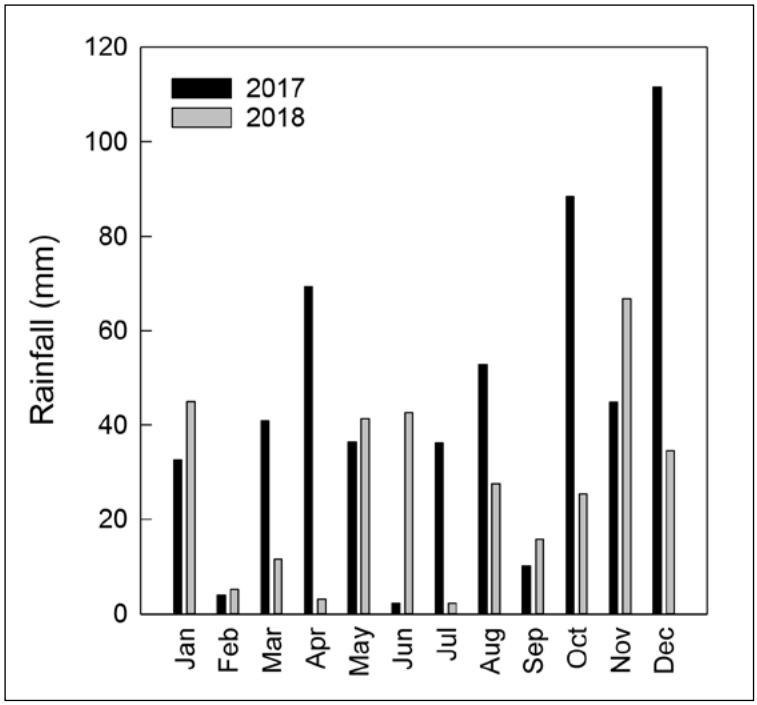

Figure 2. Mean monthly rainfall (histogram) and mean monthly air temperatures at the experimental site (Rand) in southern NSW in 2017 and 2018.

on grain yield in two consecutive years (Figures 3 and 4). In 2017, each plot with deep placement of amendments was harvested in two locations. These were on the amended rip line and off the amended rip line. This approach was undertaken based on the field observations of differential responses between crop rows on and off rip lines. While there was no significant difference (P>0.05) between the control and yield response off the amended rip line, a marked positive response was achieved for crop harvested on the amended rip line. Compared with the control treatment, the highest increase (P<0.05) in grain yield was observed for deep placement of pea hay + gypsum + nutrient (27%), followed by deep placement of manure (22%) and pea hay (20%). As a main effect, rip only, surface gypsum and surface pea hay treatments yielded 6%, 10% and 13% less than control treatments (Figure 3).

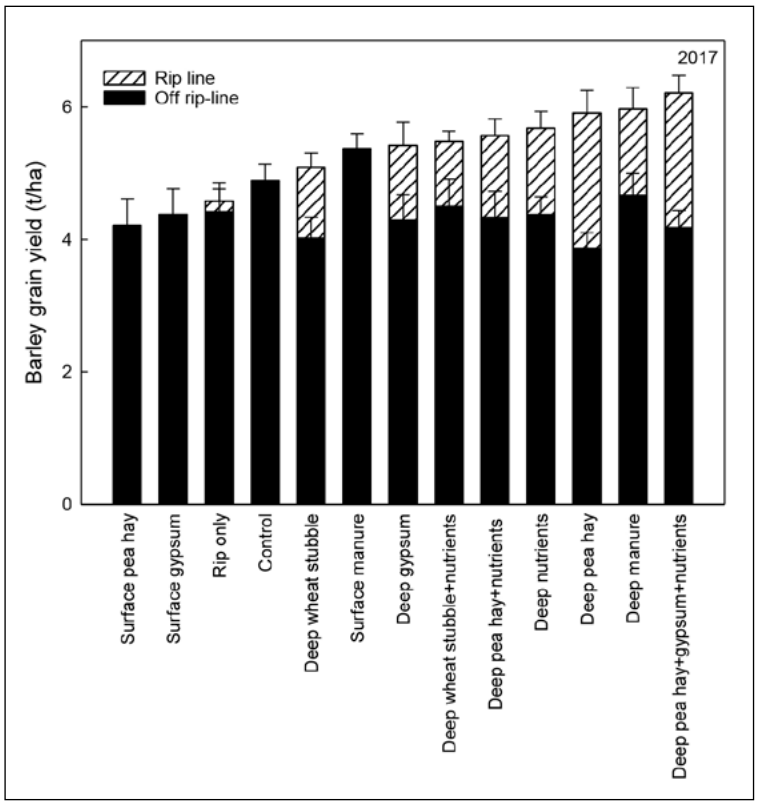

Figure 3. The effects of surface or deep placed amendments on grain yield of La Trobe(1) barley in 2017 at Rand, southern NSW. Plots with deep placement treatments were harvested on amended rip lines (dashed bars, on rip line) and off unamended rip lines (black bars, off-rip line). Values are averages (n = 4).

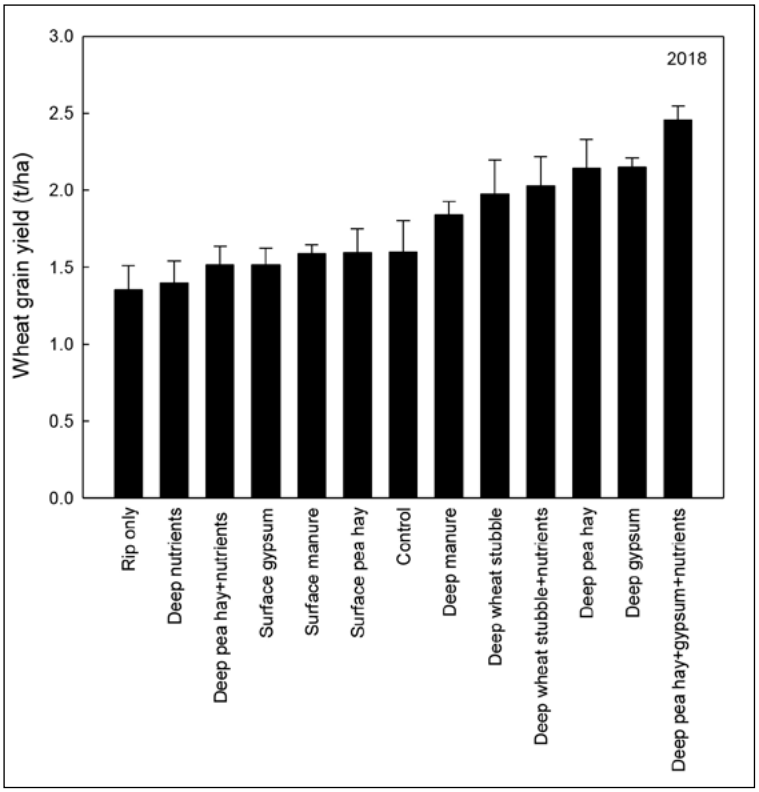

Figure 4. The effects of surface or deep placed amendments on grain yield (whole plot) of Lancer(b) wheat in 2018 at Rand, southern NSW. Values are averages (n = 4).

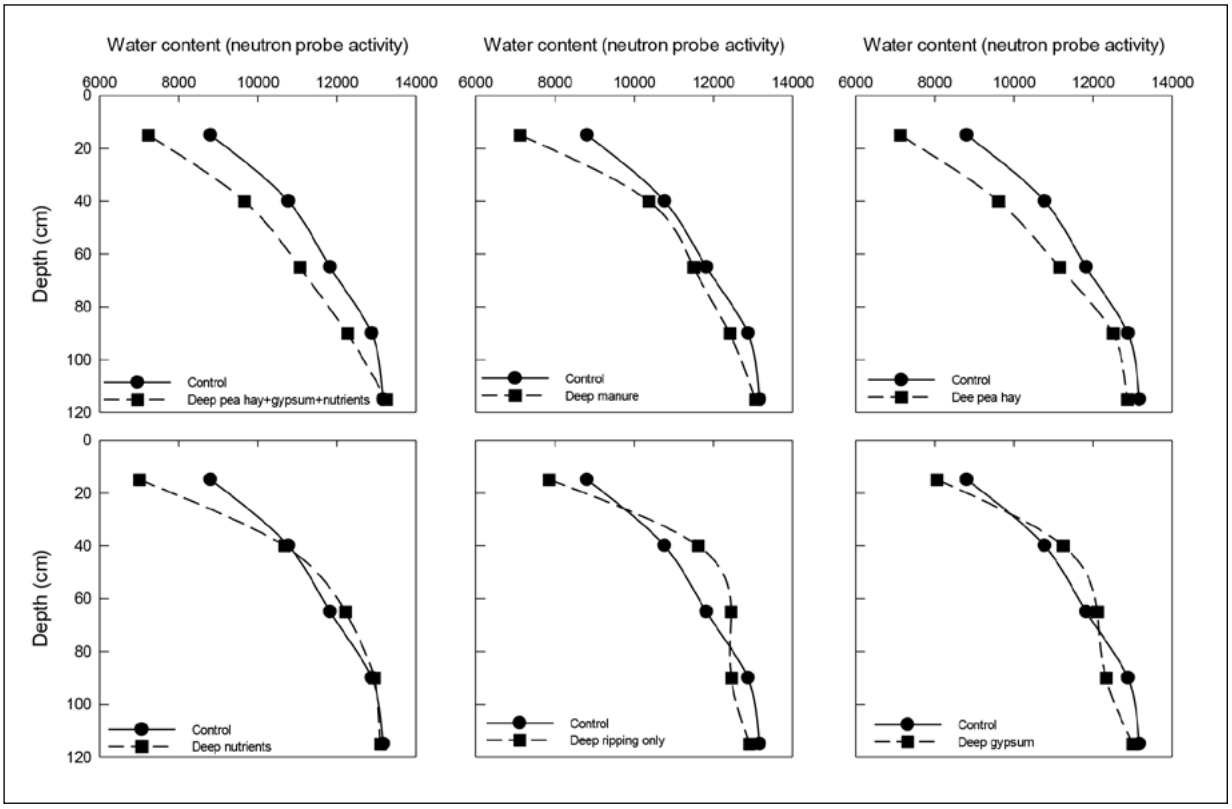

Figure 5. The changes in soil water content in various treatments compared with the control at the Rand site in 2018. Results are based on the neutron activity (raw data), where higher values represent higher water content in the soil profile. Values are averages (n = 4).

Table 1. The changes in soil exchangeable sodium percentage (ESP) and soil pH in selected treatments at the Rand site. Samples were collected in May 2018 pre-sowing. Values are means

	Control	Deep gypsum	Deep nutrients	Deep manure	Deep pea hay	Deep pea+ gyp+ nutrients	rip only
				ESP (%)			
0-10	5.89	7.00	6.43	7.89	6.09	5.13	7.23
10-20	8.47	8.18	9.11	11.41	8.33	6.01	9.69
20-30	13.35	11.70	12.59	16.24	12.91	9.68	14.09
				pH (1:5 water)			
0-10	6.61	6.96	7.04	6.37	6.87	6.89	6.86
10-20	7.98	7.77	7.99	7.66	7.76	7.69	7.91
20-30	8.99	8.13	8.96	8.60	8.87	8.38	8.94

In the 2018 season, wheat grain yield significantly ($P<0.05$) increased 27%-53% (compared with the control) following amendment application in 2017 (Figure 4). The highest increase was observed for deep placement of pea hay + gypsum + nutrient treatment (53%), followed by deep placement of gypsum (34%), pea hay (34%) and deep wheat stubble + nutrients (27%). As a main effect, surface pea hay, surface manure, surface gypsum, deep pea hay + nutrients, deep nutrients and rip only treatments yielded 0.1%-15% less than the control. These differences were not significant ($P>0.05$).

The volumetric water content in the soil declined in all layers of the profile as the wheat crop matured some 200 days after sowing (2018 growing season). A number of variations in the pattern of the decline in soil water were observed in different subsoil amelioration treatments. The most notable result occurred with the deep pea hay + gypsum + nutrients treatment followed by deep manure and deep pea hay, where there was a marked drying of the ameliorated layers as the crop matured (Figure 5). The effect was observed in the 40cm-60cm (amended layer). The neutron probe values in this layer were significantly lower ($P<0.05$) for the organic amendment treatments at crop maturity than for all other treatments including the control, the deep ripped, deep nutrients and the deep gypsum treatments (Figure 5).

Table 1 shows the effect of various amendments on soil ESP and pH at three depths. The deep placement of amendments at a depth of 15-40cm had a marked impact on the physicochemical properties in the subsoil layers. The 20-30cm deep subsoil layer in the control treatment had a pH of 9 and ESP of 13.4%. Deep placement of gypsum, pea hay + gypsum + nutrients and deep manure reduced the soil pH by 0.86, 0.61 and 0.39 unit, respectively ($P<0.05$). Compared with the control, the deep placement of gypsum and pea hay + gypsum + nutrients treatments also reduced the ESPby 12% and 27%.

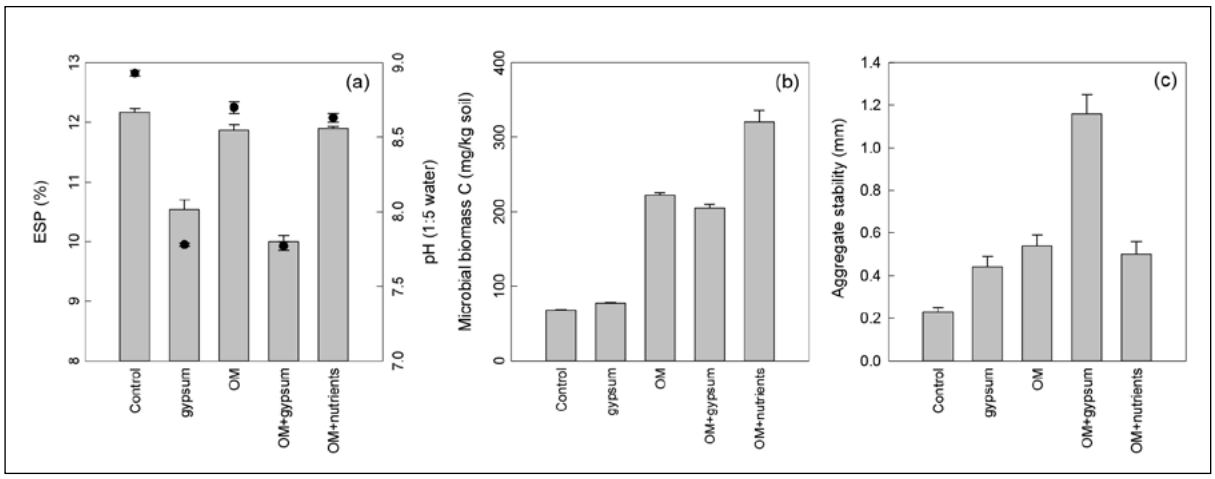

Figure 6. The effect of gypsum, OM, OM + gypsum and OM + nutrients on (a) soil ESP (bars) and pH (●), (b) microbial biomass C (mg/kg soil) and (c) aggregate stability (mm) over the 90-day incubation period. Error bars represent ± standard errors of the mean (n = 4).

To further explore the changes that organic amendments have on subsoil physical and chemical properties, primarily the effects on water-stable aggregates, an incubation experiment was conducted to investigate how the physical condition of the sodic clay soil may benefit from the addition of organic amendments that are able to benefit biological activity in the soil. Figure 6 shows the effects of gypsum, organic matter (crop stubble), organic matter + gypsum and organic matter + nutrients after an incubation of 90 days on the formation of water-stable aggregates. Similar to data from field trials, gypsum had a significant effect ($P<0.05$) on reducing soil pH (1.15 unit) and ESP (13%-17%) compared with the control. The addition of organic matter with or without nutrients had no influence on soil pH or ESP. However, the input of organic matter and organic matter + nutrient increased total microbial biomass C by 3-fold and 4.7-fold, respectively ($P<0.05$). Combined application of organic matter (OM) and gypsum had the greatest influence on the proportion of stable aggregates in the poorly structured sodic alkaline subsoil used in this study. While separate application of gypsum and OM increased the aggregate stability, the much greater improvement in soil aggregation in OM + gypsum treatment suggests that their co-application has an additive and/or interactive effect.

Discussion

This study provides early but significant indications that soil amelioration of alkaline-sodic subsoils with organic and inorganic amendments can provide significant grain yield increases that are associated with both improved soil chemicophysical properties and water use.

The extent of the changes in soil chemical and physical properties in the 15cm-40cm layers of this alkaline sodic soil, with the deep incorporation of organic and inorganic amendments, was remarkable. The changes occurred over the 14-month period between the incorporation of the amendments in late February 2017, and the taking of soil samples in May 2018. The key changes were a reduction in subsoil pH and ESP (Table 1) and an increase in soil porosity (data not shown) and higher water uptake by the crop (Figure 5). While the soil analysis is still in progress, it is suggested that this is resulted from improved soil aggregation, as incubation studies using this clay subsoil and similar organic amendments, led to a rapid improved aggregation in the clay matrix over three months (Figure 6).

The results demonstrated that amelioration of multiple soil constraints (high pH, sodicity and poorly structured aggregates) requires amendments and strategies with various modes of action and independent mechanisms. The suggested improvement in subsoil aggregation with OM + gypsum and the resulting significant increases in grain yield in this study can be attributed to several causes. The first was that application of gypsum resulted in a reduction in pH of 0.86-1.15 unit (Table 1, Figure 5). Tavakkoli et al. (2015) showed that carbonate salts of Na and potassium (K) dominate above pH 8.5 of many sodic subsoils in south-east Australia and a reduction in pH below 8.5 can decrease the net dispersive charge and ESP by changing the speciation of carbonate salts (Rengasamy et al. 2016). The second reason for the suggested improvement in subsoil aggregation was that the organic amendments provide a substrate for greatly enhanced microbial activity in and around the rip lines. The incubation study discussed above also found that the addition of OM to alkaline sodic, clay subsoil increased microbial biomass C over the 90 day of incubation period which in turn led to rapid improvement in aggregation (Clark et al. 2007; Gill et al. 2008; Fang et al. 2018).

Conclusions

The findings from this study demonstrate early results for amelioration of alkaline sodic subsoils in southern NSW. Deep application of organic and inorganic amendments resulted in significant yield increases in 2017 and 2018. The increases resulted from the improvement in the chemical and physical properties of the subsoil around the rip line containing the organic and inorganic amendments. This improvement was mediated by a reduction in soil pH and ESP and an increased microbial activity that leads to improved soil aggregation. This led to considerable water extraction from the deeper clay layers.

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Contact details

Ehsan Tavakkoli
NSW DPI, Wagga Wagga Agricultural Institute
02 6938 1992
Ehsan.tavakkoli@dpi.nsw.gov.au
@EhsanTavakkoli

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Fixing more N – improving the performance of rhizobial inoculants in suboptimal conditions

Ross Ballard[1], Elizabeth Farquharson[1], Maarten Ryder[2], Matthew Denton[2], Judith Rathjen[2], Frank Henry[3], Jason Brand[3], Rachael Whitworth[4], Barry Haskins[4], Mark Seymour[5] and Ron Yates[5].

[1]South Australian Research and Development Institute; [2]University of Adelaide; [3]DEDJTR Agriculture Victoria; [4]Ag Grow Agronomy and Research; [5]WA Department of Primary Industries and Regional Development.

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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.

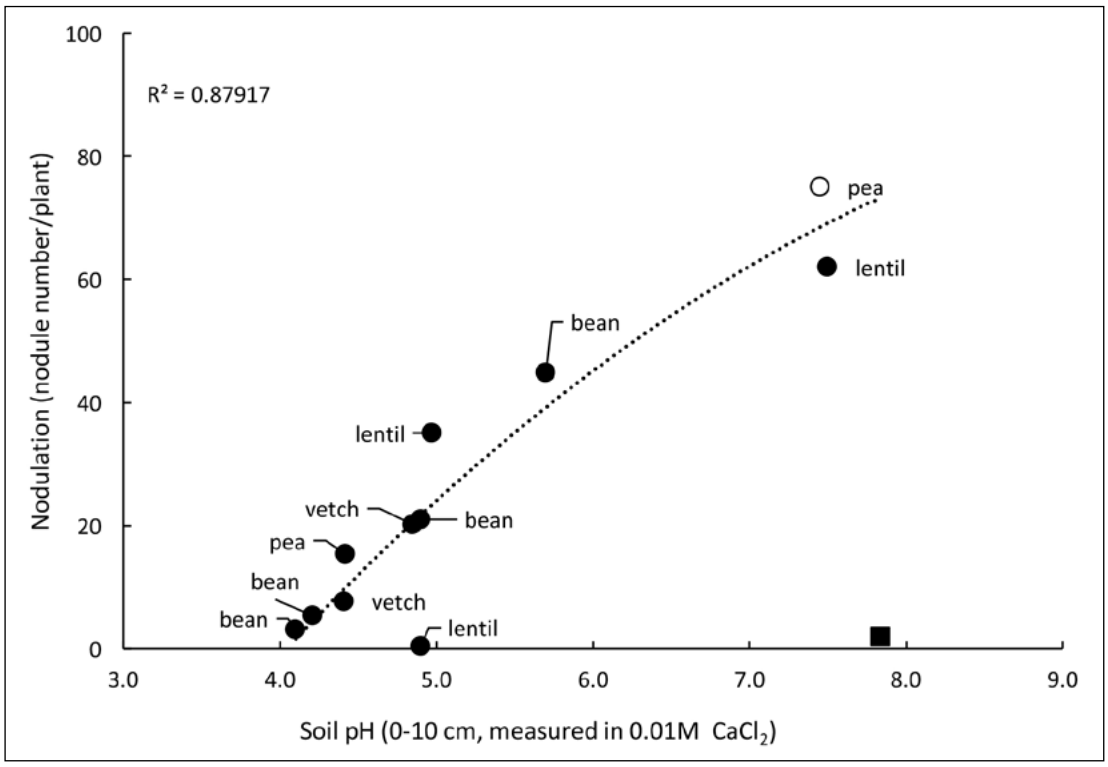

Figure 1. Relationship between soil pH_{Ca} (0-10cm) between pH 4.0 and pH 8.0 and the field nodulation (number of nodules per plant) of legumes inoculated with rhizobia strain WSM-1455. Value for pea at pH 7.5 (open circle) is an average of data collected from 12 sites with background rhizobia. All 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.

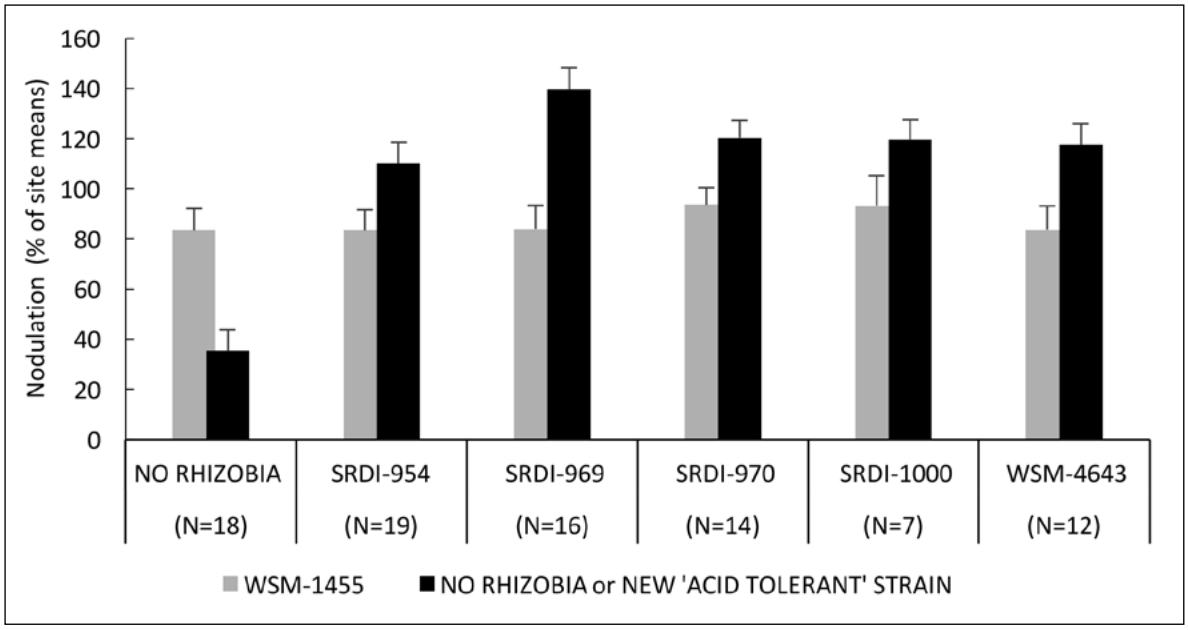

Figure 2. Nodulation of bean/lentil/pea/vetch at acidic field sites. Pairwise comparison (expressed as a % mean nodulation at sites) of new rhizobia strains against Group E inoculant strain WSM-1455. Number of sites included in each pairwise comparison shown in parentheses. Bars on columns indicate inter-site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

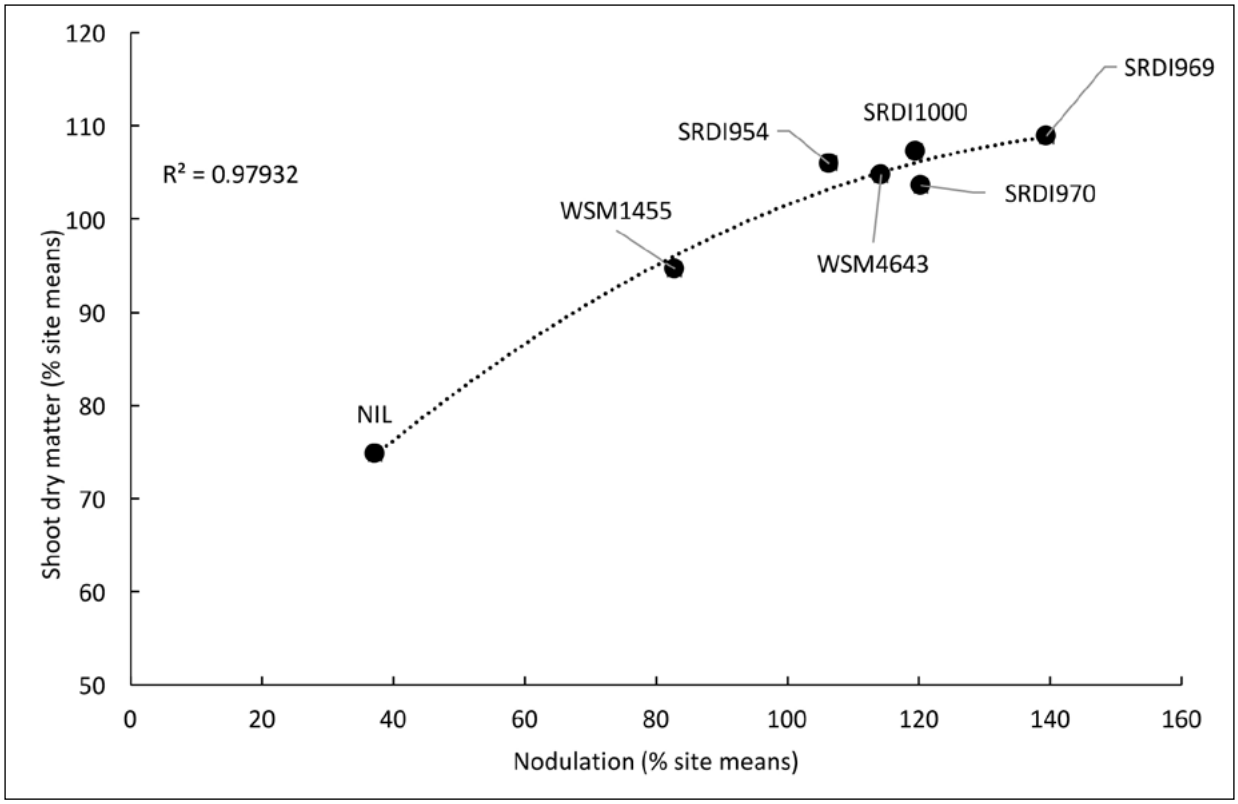

Figure 3. Relationship between nodulation by the different rhizobia strains and total above ground dry matter production (at mid pod fill) of legumes at acidic field sites.

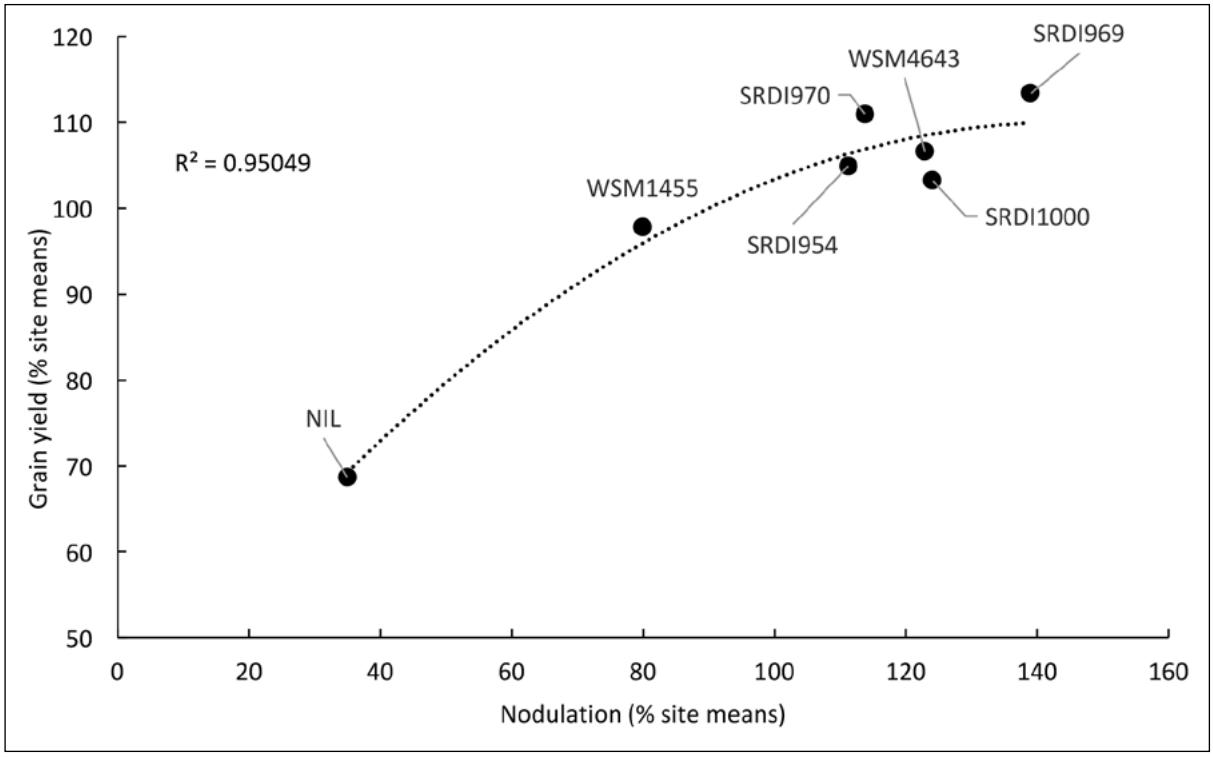

Figure 4. Relationship between nodulation by the different inoculant strains and grain yield.

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

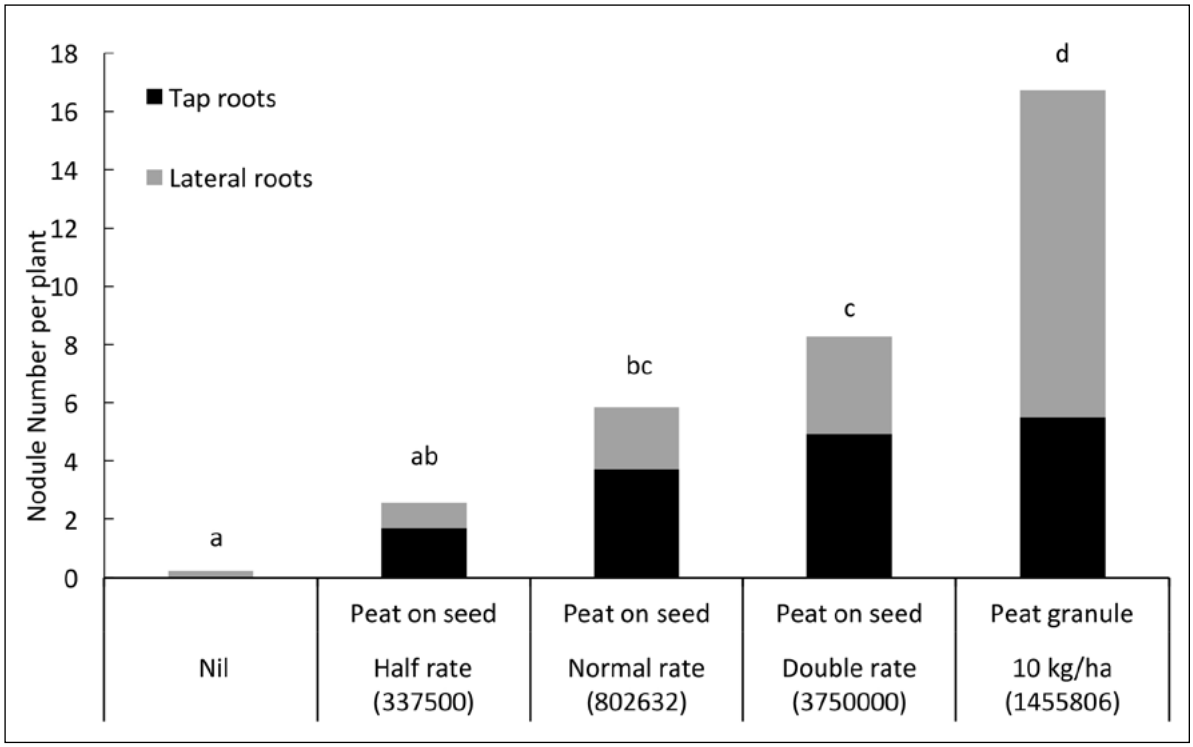

Figure 5. Effect of inoculation rate and formulation on chickpea nodulation (nodule number per plant) at Lameroo, SA. Number of rhizobia per seed indicated in parentheses under inoculation rate. Commercial inoculants at manufacture, applied at normal rate deliver about 600,000 rhizobia per chickpea seed.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

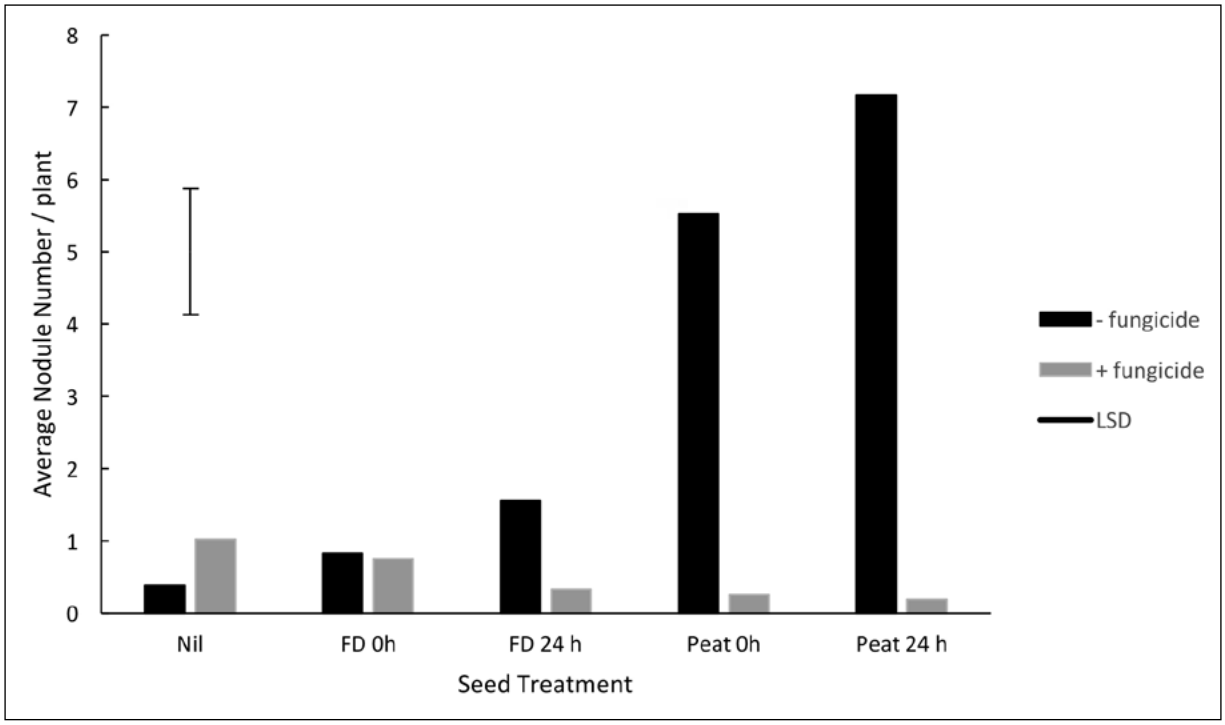

Figure 6. Effect of P-Pickel T® fungicide, formulation type (FD = freeze-dried, and peat) and time between inoculation and sowing (0hr or 24hr) on the nodulation of pea cv. Oura(ϕ), Minnipa, SA, 2018. LSD is the least significant difference at P<0.05.

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(ϕ)) 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.

mproved 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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Contact details

Ross Ballard
SARDI Soil Biology and Diagnostics
GPO Box 397, Adelaide SA, 5001
8429 2217
ross.ballard@sa.gov.au

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Notes

How did barley fare in a dry season?

Felicity Harris[1], David Burch[2], Kenton Porker[3], Hugh Kanaley[1], Hayden Petty[4] and Nick Moody[2].

[1]NSW Department of Primary Industries, Wagga Wagga; [2]NSW Department of Primary Industries, Condobolin; [3]SARDI; [4]NSW Department of Primary Industries, Yanco.

GRDC project code: DAN00213

Keywords

- phasic development, sowing time, flowering time, photoperiod, vernalisation.

Take home messages

- Barley is capable of maintaining a yield advantage over wheat in southern NSW across yield environments.
- New barley varieties such as RGT Planet$^{\Phi}$ and Banks$^{\Phi}$ offer alternative phenology patterns compared to the benchmark fast spring type La Trobe$^{\Phi}$.
- In southern NSW, most spring barley types are still suited to traditional May sowing dates, and earlier sowing options are limited by suitable winter varieties.

Background

Compared to wheat, barley is considered to be more widely adapted, has superior frost tolerance, and offers higher yield potential across environments of southern Australia. A comparative analysis of the best performing barley and wheat genotypes (defined as highest yielding treatment), where experiments were co-located in southern NSW from 2015-2018, indicated that barley maintained a constant yield advantage over wheat at all yield levels, including in low yield potential seasons such as 2018 (Figure 1).

Matching varietal phenology and sowing date to achieve an optimal flowering time for each growing environment is the most effective management strategy in minimising effects of abiotic stresses, whilst maximising grain yield in all seasons. Recent yield improvements in barley varieties have been achieved through direct selection of yield based on traditional May sowing dates and suitable flowering dates, achieved through indirect selection of phenology types with photoperiod sensitivity and without vernalisation responses (Porker et al. 2017). However, a recent trend towards the earlier sowing of cereals (and canola), as well as European long-season spring barley introductions such as RGT Planet$^{\Phi}$ has highlighted differences in barley phenology in southern NSW. This paper presents phenology and grain yield responses of some diverse barley genotypes with respect to sowing date across three environments in southern NSW in 2018, and discusses options for early sowing opportunities.

Phenology and grain yield responses to sowing date – Condobolin and Wagga Wagga, 2018

Field experiments were conducted at Condobolin and Wagga Wagga to determine optimal sowing date and phenology to maximise grain yield. A range of genotypes with varied development (through different responses to vernalisation and photoperiod) were sown across sowing dates from mid-April to late May. In 2018, grain yield and

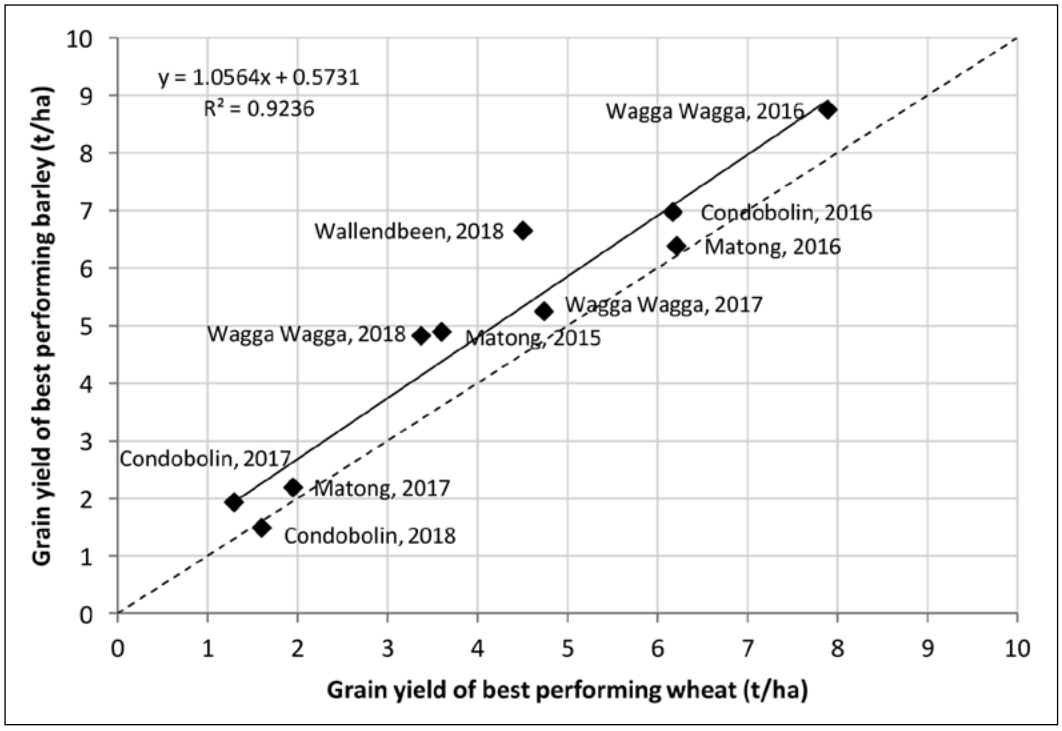

Figure 1. The relationship between the best performing wheat variety and the best performing barley variety across a range of sowing dates (mid-April to late-May) at co-located field experiments at Condobolin (2016-2018), Matong (2015-2017), Wagga Wagga (2016-2018) and Wallendbeen (2018). Dotted line indicates 1:1 relationship.

phenology responses were significantly influenced by below average rainfall and frost at both sites, with growing season rainfall (April to October) recording of 91 mm at Condobolin (long term average – 246 mm) and 135 mm at Wagga Wagga (long term average – 355 mm). Eleven extreme frost events (<-2°C) were recorded at both sites, including -4.9°C (28 August), -6.3°C (29 August), -5.4°C (30 August) and -3.9°C (17 September) at Wagga Wagga. Sowing dates were achieved by supplementary irrigation to ensure establishment due to lack of reliable autumn rainfall. The Condobolin site received 30 mm prior to all sowing dates and a final irrigation of 20 mm in early September, whilst at the Wagga Wagga site, the first two sowing dates were established with 15 mm via drippers at sowing, and the site was rainfed thereafter.

Generally, flowering date is a strong predictor of yield, with genotype and sowing date combinations that flower in early-mid September at Condobolin, and in late September- early October in Wagga Wagga capable of achieving the highest yields. In 2018, there was significant variation in grain yields for genotype x sowing date combinations which flowered within the optimal period at both sites. (Figure 2 and 3). At both sites, optimal flowering time and similar grain yields were achieved by both fast winter type Urambie$^{\phi}$ sown mid-late April and the best performing spring type sown mid-May, whilst novel French winter genotypes, characterised as having a strong vernalisation and photoperiod response flowered too late and suffered a significant yield penalty as grain filling occurred under terminal drought conditions (Table 1).

Differences in phasic development – Wagga Wagga, 2018

Genotypes varied significantly in phasic development in addition to flowering time as shown for the Wagga Wagga site in Figure 4. Experiments conducted from 2014-2018 indicate many spring varieties achieve optimal flowering times and greatest grain yields when sown mid-May in southern NSW. Faster developing spring types (with minimal responses to vernalisation), sown early (when temperatures are warmer and days longer), progressed quickly and had a shorter vegetative phase, and flowered earlier in comparison to slower spring and winter types. For example, La Trobe$^{\phi}$ sown 16 April 2018 at Wagga Wagga, started stem elongation (GS30) on 2 June. However, winter type Urambie$^{\phi}$ sown on the same day (16 April), had a prolonged vegetative phase, due to its vernalisation requirement and reached GS30 four weeks later

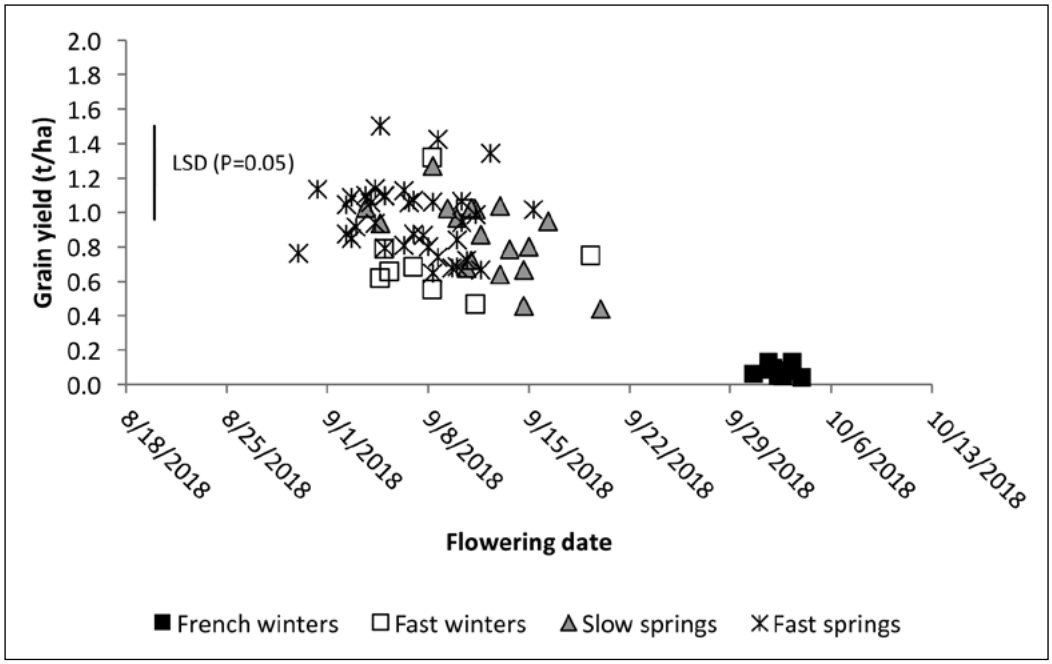

Figure 2. The relationship between flowering date and grain yield of genotypes with varied phenology patterns sown 23 April, 5 May and 28 May at Condobolin in 2018.

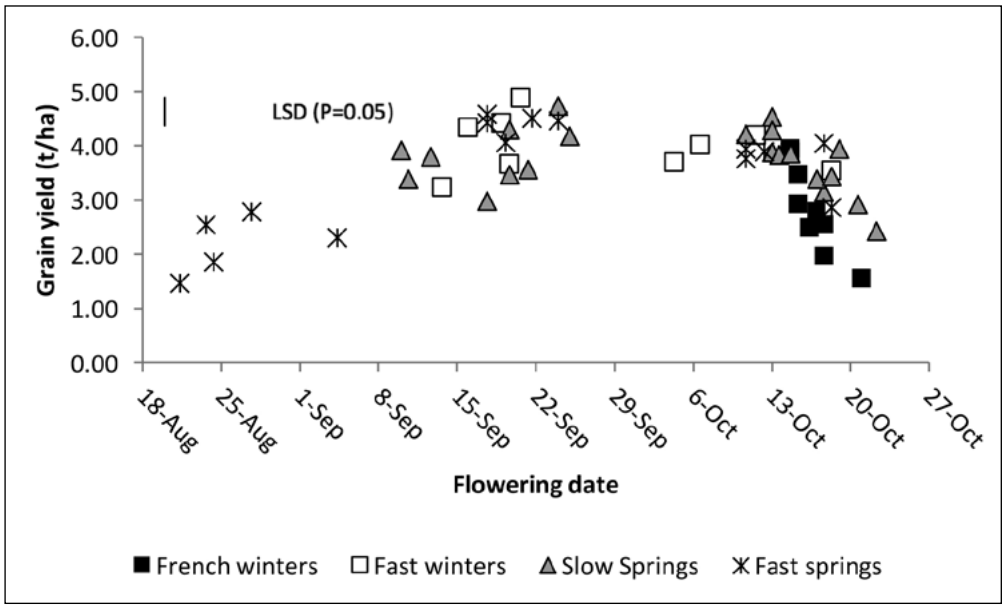

Figure 3. The relationship between flowering date and grain yield of genotypes with varied phenology patterns sown 16 April, 8 May and 28 May at Wagga Wagga in 2018.

on 6 July. It also had a relatively stable flowering response across sowing dates.

Increased photoperiod requirements of Commander$^{\Phi}$ and Banks$^{\Phi}$ resulted in slightly slower development comparative to La Trobe$^{\Phi}$, however, despite this they still achieved greatest grain yields from the mid-May sowing (Table 1). RGT Planet$^{\Phi}$ is also a longer- season spring genotype, though via a different phenology pattern (minimal vernalisation response coupled with weak photoperiod response), and is characterised as having only a slightly longer vegetative phase than La Trobe$^{\Phi}$, with an extended reproductive phase. RGT Planet$^{\Phi}$ has shown some flexibility across sowing dates, and is capable of being sown earlier in May than La Trobe$^{\Phi}$, however, in frost prone environments, due to its lack of vernalisation response, it is not suited to April sowing dates.

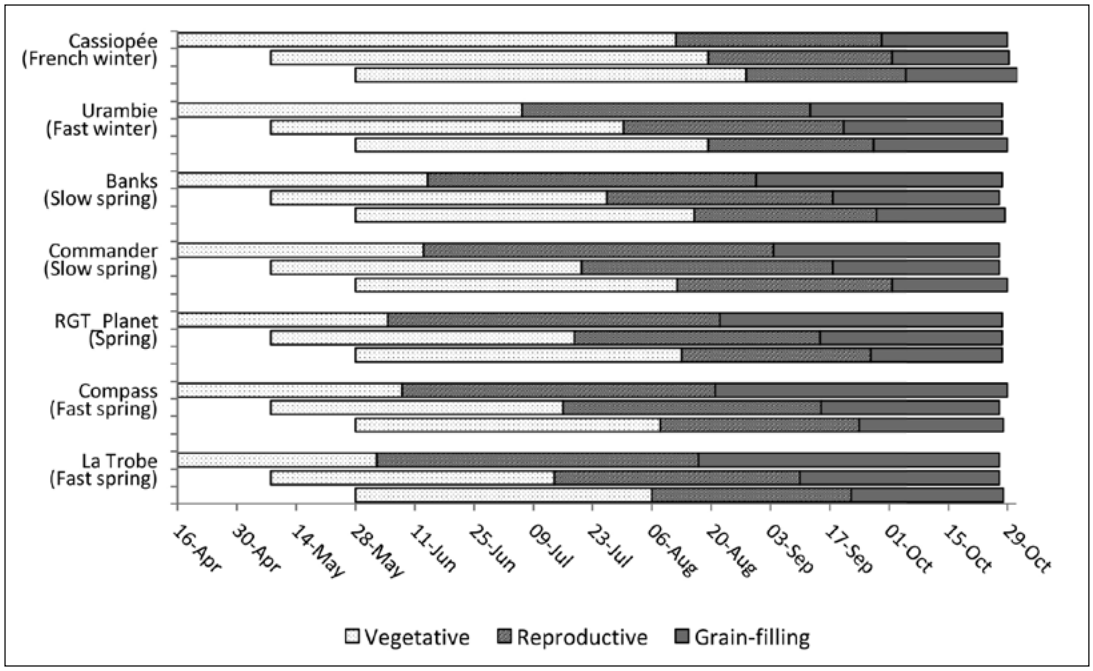

Figure 4. Influence of sowing date on phasic development of selected genotypes sown 16 April (SD1), 8 May (SD2) and 28 May (SD3) at Wagga Wagga, 2018. Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-filling stage (flowering to maturity).

Table 1. Grain yield of genotypes across three sowing dates (SD) at Condobolin and Wagga Wagga in 2018.

Genotype	Condobolin			Wagga Wagga		
	SD1: 23-Apr	SD2: 5-May	SD3: 28-May	SD1: 16-Apr	SD2: 8-May	SD3: 28-May
Banks$^{\Phi}$ (Slow spring)	1.27	0.87	0.95	3.57	4.53	3.94
Biere$^{\Phi}$ (Fast spring)	0.76	1.14	0.88			
Bottler$^{\Phi}$ (Fast spring)	0.81	0.87	0.99			
Cassiopée (French winter)	0.06	0.13	0.08	3.47	2.93	2.49
Commander$^{\Phi}$ (Spring)	0.97	0.67	0.46	3.81	4.21	3.38
Compass$^{\Phi}$ (Fast spring)	0.94	1.42	1.34	2.31	4.47	4.05
CSIROB1 (Fast winter)	0.66	0.62	0.47	3.24	3.66	3.7
CSIROB10 (Spring)	0.79	1.13	0.74	2.79	4.58	3.89
CSIROB2 (Fast winter)	0.78	0.68	0.55	4.33	4.42	4.01
CSIROB5 (Spring)	1.06	0.65	0.68	2.55	4.51	3.95
Fathom$^{\Phi}$ (Fast spring)	1.5	1.06	0.72	3.39	4.18	3.86
La Trobe$^{\Phi}$ (Fast spring)	0.85	0.92	0.68	1.86	4.43	3.77
Maltesse (French winter)	0.05	0.09	0.04	3.89	2.55	1.57
Oxford$^{\Phi}$ (Slow spring)	0.68	0.64	0.44	4.3	3.16	2.43
RGT Planet$^{\Phi}$ (Spring)	1.03	0.94	1.03	3.92	4.73	3.83
Rosalind$^{\Phi}$ (Fast spring)	1.1	1.05	0.8	1.48	4.06	2.87
Salamandre (French winter)	0.09	0.05	0.13	3.94	2.79	1.98
Scope CL$^{\Phi}$ (Fast spring)	0.87	1.07	1.06			
Spartacus CL$^{\Phi}$ (Fast spring)	1.09	1.14	0.84			
Traveler (Slow spring)	1.02	1.02	0.79	2.99	4.29	3.44
Urambie$^{\Phi}$ (Fast winter)	1.32	1.02	0.75	4.88	4.19	3.54
Westminster$^{\Phi}$ (Slow spring)	0.72	1.04	0.8	3.47	3.88	2.93
Mean	*0.96*	*0.94*	*0.79*	*3.34*	*3.98*	*3.31*
LSD (Genotype)	*0.31*			*0.06*		
LSD (SD)	*0.11*			*0.12*		
LSD (Genotype x SD)	*0.54*			*0.51*		

Opportunities for early sown barley – Wallendbeen, 2018

A third field experiment was conducted at Wallendbeen to determine suitability of novel winter genotypes to early sowing in a higher rainfall environment. Genotypes including Australian winter barley - Urambie$^{\phi}$ (fast winter), European winter types (strong vernalisation and photoperiod responses), and some spring types with varied development patterns were sown on 13 April 2018. In 2018, the Wallendbeen site also recorded below average rainfall, with growing season rainfall (April to October) recording 219 mm (long term average – 460 mm). Wallendbeen recorded considerably less frost (number and severity), with three frost events <-2°C, including -2.4°C (14 July), -2.3°C (16 July), and -2.1°C (17 September), which influenced phenology and grain yield responses. Following sowing (13 April), the site received 6mm rain, though additional 7mm irrigation via drippers was applied 2 May to assist establishment.

Highest yields were achieved by genotypes which flowered late September-early October, with a yield penalty associated with the delayed flowering of European winter types beyond the optimal window (Figure 5). The yield penalty commonly experienced for early sowing of fast developing types (resulting in flowering earlier than optimal) was not as severe as for Condobolin (Figure 2) and Wagga Wagga (Figure 3) at Wallendbeen (Figure 5) in 2018. This is likely due to reduced early frost risk, and timely grain filling prior to significant moisture stress experienced by slower winter types.

An analysis comparing the best performing spring types (sown at optimal time for each environment, typically traditional May dates), with the best performing fast winter and slow winter types was conducted across nine experiments in southern NSW and SA in 2017-2018. This indicated that the fast winter types (typically Urambie$^{\phi}$) were capable of comparable high yields when sown early, and both offered a constant significant yield advantage over slow winter types at seven out of nine sites (Figure 6). This suggests that a fast winter genotype is capable of achieving high yields when sown earlier than traditional May sowing dates. The strong vernalisation requirements of the European winter types consistently resulted in later flowering than optimal at all sites and were not able to maintain grain yield even in high rainfall environments. Further research investigating options for early sowing in southern NSW, requires suitable germplasm which combines a vernalisation requirement capable of early sowing.

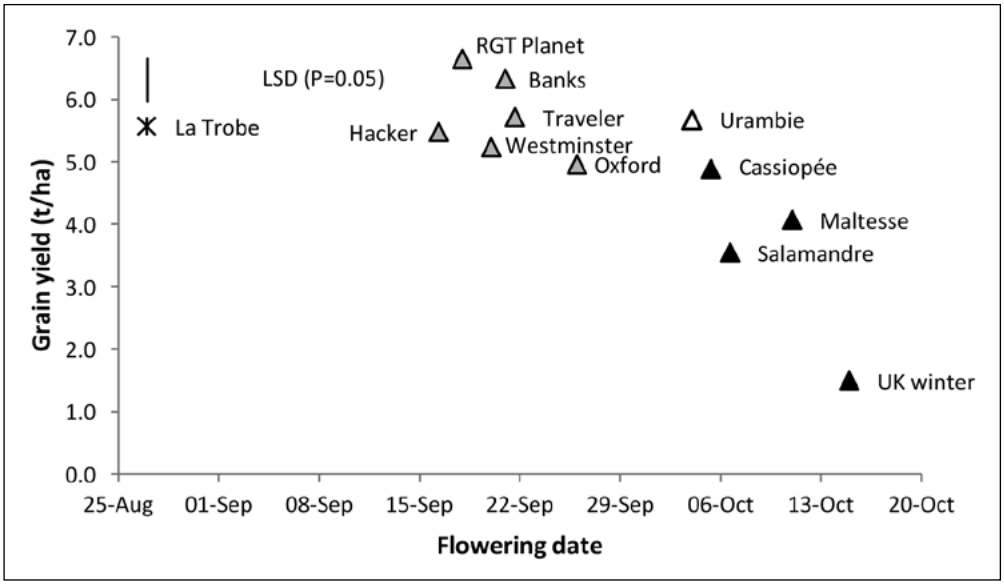

Figure 5. The relationship between flowering date and grain yield of barley genotypes sown 13 April at Wallendbeen in 2018.

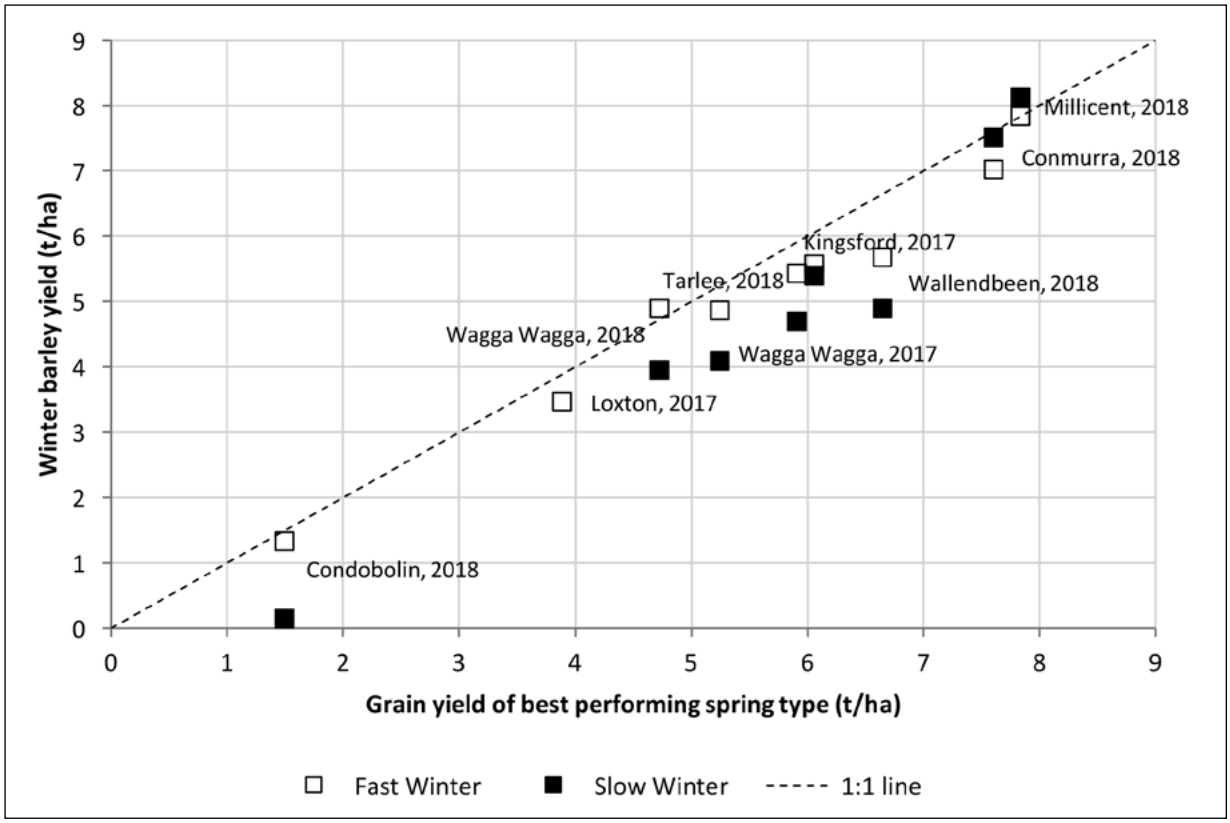

Figure 6. The relationship between the best performing spring barley types (sown at optimal time) with fast winter and slow winter genotypes (sown mid-late April) at field experiments in NSW: Condobolin, 2018; Wagga Wagga 2017, 2018; Wallendbeen, 2018; and South Australia: Conmurra, 2018; Kingsford, 2017; Loxton, 2017; Millicent, 2018 and Tarlee, 2018.

Summary

Despite the seasonal conditions experienced in 2018, barley was able to achieve stable grain yields across a range of yield environments comparative to wheat. High yields were achieved through varied genotype x sowing time combinations, however in southern NSW, many barley varieties are still suited to traditional May sowing dates. Recent European introductions of longer season spring types such as RGT Planet$^{\phi}$ offer opportunities for slightly earlier sowing (early May) and slower spring types such as Banks$^{\phi}$ and Commander$^{\phi}$ have alternative phenology patterns compared with benchmark fast spring types such as La Trobe$^{\phi}$. Recent research has evaluated novel European winter types to provide options for early sowing; however these did not offer a yield advantage over Australian fast winter types such as Urambie$^{\phi}$. Whilst new spring types have displayed some alternative phenology patterns, early sowing options in frost prone environments of southern NSW are currently limited by suitable winter genotypes.

Acknowledgements

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

Sincere thank you for the technical assistance of Cameron Copeland, Dean Maccallum, Mary Matthews and Jordan Bathgate at the Wagga Wagga site; and Leisl O'Halloran, Karen Brangwin and Daryl Reardon at the Condobolin site.

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Porker, K., Coventry, S., Trevaskis, B., Fettell, N. (2017) Is Vrn-H1 a missed opportunity for southern Australian barley growers? Proceedings of the 18th Australian Society of Agronomy Conference, 24-28 September 2017, Ballarat Australia.

Contact details

Felicity Harris
NSW Department of Primary Industries,
Wagga Wagga
0458 243 350
felicity.harris@dpi.nsw.gov.au
@NSWDPI_Agronomy

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

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

[1]CSIRO Agriculture & Food, Canberra, ACT; [2]Marcroft Grains Pathology, Horsham, VIC; [3]School of BioSciences, University of Melbourne, VIC; [4]SARDI, Port Lincoln, SA; [5]NSWDPI, Wagga Wagga, NSW.

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.
- Sclerotinia stem rot in high risk situations can be controlled by fungicide application at 30% bloom (14-20 flowers on main raceme).
- 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 loss 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 areas with high disease risk.
- Fungicides applied for Sclerotinia stem rot control (~30% bloom) can reduce upper canopy blackleg on stems but does not protect the pods from lesions. More work is required to determine robust 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 stem rot (Sclerotinia sclerotiorum)

Sclerotinia stem rot disease 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 require chemical control. If sclerotinia stem rot 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. Consider rainfall predictions for spring and 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.

Yield loss from sclerotinia is greatest 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 - 30% bloom stage (20% bloom is 14 – 16 flowers on the main stem, 30% bloom is approximately 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. Use high water rates and fine droplet sizes for good canopy penetration and coverage.

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 also reduces yield albeit to a lesser extent.

A decision support tool, *SclerotiniaCM*, will be available in late-February (for ipad and Android tablets) to assist crop managers in making spray decisions during flowering. Managers can input variables for each paddock to determine the most likely economic return for their situation.

Blackleg (Leptosphaeria maculans)

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 but are not available for phones. The tool is interactive, allowing growers/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 a foliar fungicide.

Blackleg upper canopy infection

Blackleg is able to infect all parts of the canola plant. Upper canopy infection is a collective term that describes infection of flowers, peduncles, pods, upper main stem and branches (Figure 1). Upper canopy infection 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 spores in stubble-retained systems and increased intensity of canola production. While blackleg crown canker is well understood, the factors contributing to upper canopy infection and possible control strategies are currently under investigation. An outline of findings to date are presented here.

Upper canopy blackleg infection research results

In field experiments, upper canopy infection 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/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, facilitate 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 upper canopy infection symptoms on main stems and pods.

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

It is now thought that upper canopy infections are also systemic causing damage to the plant's vascular tissue, similar to traditional blackleg crown infections. The issue for growers is that external symptoms may appear insignificant but internal vascular damage may significantly reduce yield. 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 (Figure 2).

Figure 2. Blackened branches caused by internal vascular damage. Symptoms become visible post 100% seed colour change.

Upper canopy blackleg infection control strategies

Genetic resistance

Effective major gene resistance prevents infection of all canola plant parts (cotyledons, leaves, stems, branches, flowers, pods), thereby preventing both crown canker and upper canopy blackleg infections. 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 identify which major genes are effective or have been overcome in each growing region and to understand the implications for all aspects of blackleg disease.

Commencement of flowering

There is a strong relationship between the earlier onset of flowering and increased yield loss caused by upper canopy infection. Canola plants are particularly susceptible to stress during the early stages of flowering (Kirkegaard et al. 2018). Evidence from controlled environment and field experiments indicate that plants infected by blackleg on the upper main stems and branches during the early flowering period results in the greatest reduction in 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/m^2. Oil content can also be reduced. In regions with a high blackleg disease risk, target start of flowering towards the end of the optimal start of flowering range suggested in the GRDC guide – *Ten Tips to Early Sown Canola* (https://grdc.com.au/resources-and-publications/all-publications/publications/2018/ten-tips-to-early-sown-canola)

Fungicides

There are no products registered for control of upper canopy blackleg infection. Application of Prosaro®/Aviator®Xpro for Sclerotinia control around 30% bloom may reduce the severity of upper canopy infection on flowers, peduncles, stems and branches if it occurs, but is unlikely to provide pod protection. High levels of pod infection tends 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).

Fungicide resistance in blackleg populations

Reliance on fungicides can increase the risk of fungicide resistance developing. In 2018, 107 blackleg populations from across the Australian canola-growing regions were screened for resistance to commercially available and soon-to-be released fungicides for blackleg control. The results are that 22% and 28% of populations tested are highly resistant to the DMI fungicides fluquinconazole and flutriafol, respectively, compared to 7% of populations screened against the tebuconazole + priothioconazole mixture. No resistance was detected to any of the SDHI or QoI fungicides, which are to be commercially released for blackleg control. We will continue to screen populations in 2019 and 2020 to monitor changes in the frequency of resistance to both the DMI chemistries and the new SDHI and QoI chemistries.

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

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

White leaf spot (Mycosphaerella capsellae)

White leaf spot 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 white leaf spot.

White leaf spot 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 advisors is that there is no knowledge on how to predict if white leaf spot will occur as there has been no work 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 white leaf spot will continue to flourish. If no (or few) lesions are present and weather is forecast to be dry it is highly unlikely that new leaves will become infected.

Interestingly a number of experiments to assess fungicide efficacy for blackleg control have also produced excellent control of white leaf spot. Both Prosaro® and Miravis® applied for blackleg control at 4-6 leaf growth stage have provided excellent control of white leaf spot. Miravis® is registered for white leaf spot control whilst Prosaro® is not registered for white leaf spot control. Other experiments show that fluquinconazole applied to seed and fertiliser amended with flutriafol for blackleg control may also provide some control of white leaf spot (Van de Wouw *et al.* 2016). Fluquinconazole and flutriafol are not registered for white leaf spot.

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. There is limited data available on the effect of disease on yield. Powdery mildew is often present in northern NSW and is thought to reduce yield in some seasons. Powdery mildew typically occurs post-flowering and can affect all plant parts. Powdery mildew first appears as small whitish patches on the upper and lower surfaces of leaves. These spots consist of mycelia and conidia (spores), which allows 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. Resistance has been identified in some current and historic commercial canola varieties (Uloth *et al* 2016), although varieties are not routinely screened. Overseas management of powdery mildew is achieved through application of foliar fungicides but in experiments in northern NSW, powdery mildew control with fungicides was not achieved.

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. Some historic and commercial canola varieties differ in resistance (Mohammed et al. 2019) but varieties are not formally screened.

Alternaria leaf and pod spot (Alternaria brassicae and other spp)

Alternaria occurs with prolonged wet weather, especially post-flowering when conditions are humid with mild temperatures. 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 unknown whether f lutriafol or SDHI seed treatments control Alternaria seedling blight.

Fungicide resistance screening sample submission

If you would like to be involved in the fungicide resistance screen, please send 30 pieces of stubble from a 2018 canola crop. Please email Angela Van de Wouw (angela@grainspathology.com.au) for

a stubble collect protocol. You will be provided with results indicating the level of resistance in your blackleg population to current DMI blackleg fungicides and the new SDHIs. The service is free to growers/advisors. Costs are covered by an Australian Research Council/industry investment.

Useful resources

BlacklegCM App for iPad and android tablets

The Blackleg Management Guide (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)

Ten Tips to Early Sown Canola (https://grdc.com.au/resources-and-publications/groundcover/groundcover-133-march-april-2018/ten-tactics-for-early-sown-canola)

Scientific papers (please email the authors of this paper for copies):

Kirkegaard et al. (2018) *Field Crops Research* 222: 180-188

Mohammed et al. (2019) *European Journal of Plant Pathology* 153: 67-81

Uloth et al. (2016) *Crop and Pasture Science* 67: 1179-1187

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

Current status of major resistance genes for blackleg at >30 sites throughout the canola-growing regions of Australia - www.nvt.com.au

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Contact details

Susie Sprague
CSIRO Agriculture and Food, Clunies Ross Street, Canberra, ACT 2600
(02) 6246 5387, 0466 643 227
Susan.Sprague@csiro.au

Steve Marcroft
Marcroft Grains Pathology, Grains Innovation Park, Natimuk Rd, Horsham, VIC 3400
(03) 5381 2294, 0409 978 941
Steve@grainspathology.com.au

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Final session
Day 1

Can wheat be vernalised during grain development?

Ramon Javier Atayde[1], Sergio Moroni[1], Felicity Harris[2] and Ben Trevaskis[3].

[1]School of Agricultural and Wine Science, Charles Sturt University, Wagga Wagga; [2]NSW Department of Primary Industries, Wagga Wagga; [3]CSIRO Agriculture and Food, Canberra.

Keywords

- cold temperature, apical development, flowering time.

Take home messages

- Cold temperature during grain development altered phenology in the subsequent generation of vernalisation-sensitive genotypes when seed was retained and grown under controlled conditions.
- The effect of cold temperature during grain development was evident in accelerated early reproductive development and earlier flowering in winter and intermediate spring types.
- Exposure to cold temperature during early vegetative growth was more effective at stimulating development in vernalisation-sensitive genotypes than cold exposure during grain development.

Background

The productivity of wheat is largely influenced by environmental conditions at flowering, with temperature and moisture stress during this period causing significant reductions to yield. The flowering requirements of vernalisation *(VRN)*, photoperiod *(Ppd)* and earliness per se *(EPS)* regulate wheat development in response to environmental stimuli, increasing the likelihood of flowering within the optimal window (late September to mid-October in southern NSW). Growers increase the likelihood of coordinating flowering with the optimal window by matching sowing time to variety phenology (Harris et al. 2017).

Literature suggests vernalisation in wheat involves the acceleration of reproductive development in response to cold temperature exposure during early vegetative growth. There is evidence to suggest, however, that cold temperature during grain development may also stimulate a vernalisation response and accelerate development in the subsequent generation (Dobovy et al. 1998; Sharma & Mascia, 1987). The purpose of this honours study was to therefore investigate the effects of cold temperature during grain development on flowering time in the subsequent generation.

Method

Eight near isogenic lines (NILS) derived from cv. Sunstate (developed by Ben Trevaskis, CSIRO) and three winter varieties (Marombi$^{\phi}$, EGA Wedgetail$^{\phi}$ and Wylah$^{\phi}$) with a variety of sensitivities to photoperiod and vernalisation were used in the study (Table 1) (Eagles et al. 2010; Trevaskis, 2010). This paper presents results from the wheat NILS W7, W29 and W77 (cv. Sunstate), encompassing treatment responses from winter, intermediate spring and fast spring genotypes.

Seed from of all eleven genotypes was sown and initially grown for six weeks at 4°C under short day conditions (8-hour light period @ 200µmols/m2) to saturate any vernalisation requirements and synchronise development. Seedlings were then transferred into a growth chamber (Conviron PGW40) set to a constant 23°C under 16-hour light periods @ 800µmols/m^2, where they remained

Table 1. Genotype, flowering requirements (vernalisation and photoperiod) and associated phenology type of wheat used in the study.

Genotype	Photoperiod response	Vernalisation response	Phenology type
W34	None	None	Fast spring
W77	None	None	Fast spring
W40	Weak	None	Spring
W29	None	Weak	Intermediate spring
W71	None	Weak	Intermediate spring
W7	None	Strong	Winter
W8	None	Strong	Winter
W46	Moderate	Strong	Slow winter
EGA Wedgetail[Φ]	Weak	Strong	Winter
Wylah[Φ]	None	Strong	Winter
Marombi[Φ]	Weak	Very strong	Slow winter

until the detection of flowering. Fourteen days after flowering was observed, mother plants and developing grains were exposed to cold treatments.

Treatments consisted of exposure to constant cold temperature (4°C) for 0, 21, 28, 35 and 42 calendar days. Post-treatment, mother plants and developing grains were transferred to a chamber set to 23°C day/15°C night temperatures under 16-hour light periods @ 800µmols/m^2 and allowed to mature prior to harvest.

To determine treatment effects on development in the subsequent generation, harvested seed was sown into a temperature-controlled glasshouse (23°C day/18°C night temperatures ±3°C) under long days (16-hour light periods) to saturate photoperiod requirements. A fully-vernalised (FV) treatment was also included to determine whether cold temperature during grain development had a similar effect on phasic development as cold temperature during early vegetative growth.

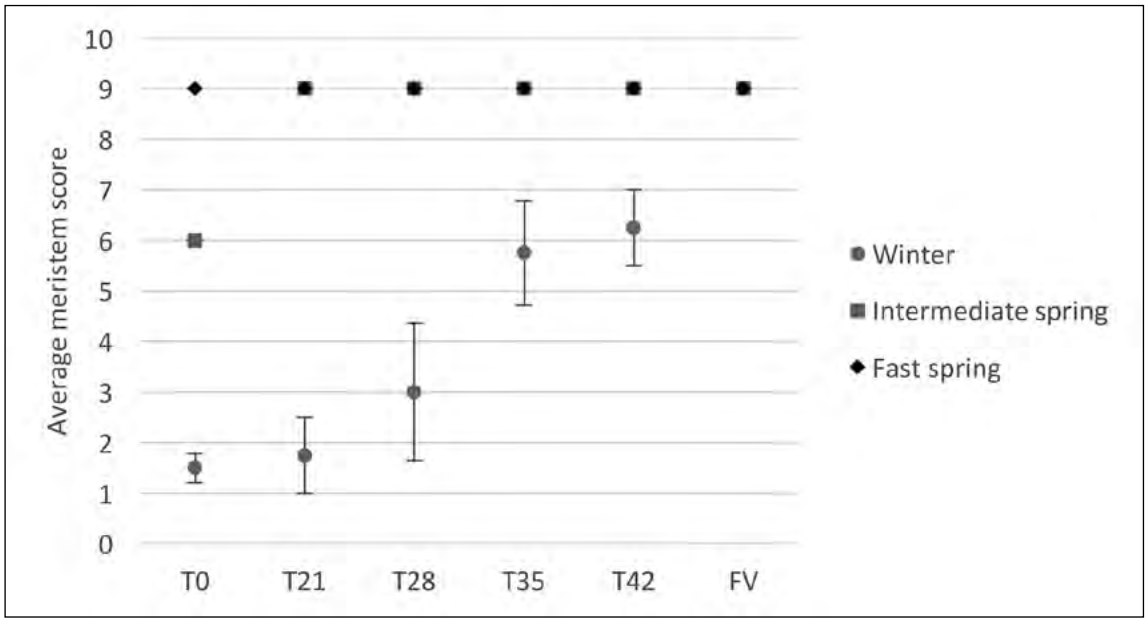

Figure 1. The effect of cold temperature during grain development on the timing of reproductive development in apical meristems of winter, intermediate spring and fast spring wheats. Wheat apical meristem scoring system adapted from Bonnett et al. (1966). 1. Vegetative shoot apex with leaf primordia; 2. Vegetative shoot apex with leaf primordia; 3. Elongated shoot apex; 4. Beginning of spikelet formation shown by double ridges; 5. Early stages of spikelet formation; 6. Spikelet-forming branches just before differentiation of spikelet parts; 7. Beginning of differentiation of the empty glumes; 8. Basal florets initiated in the middle spike; 9. Florets of all the spikelets have been initiated.

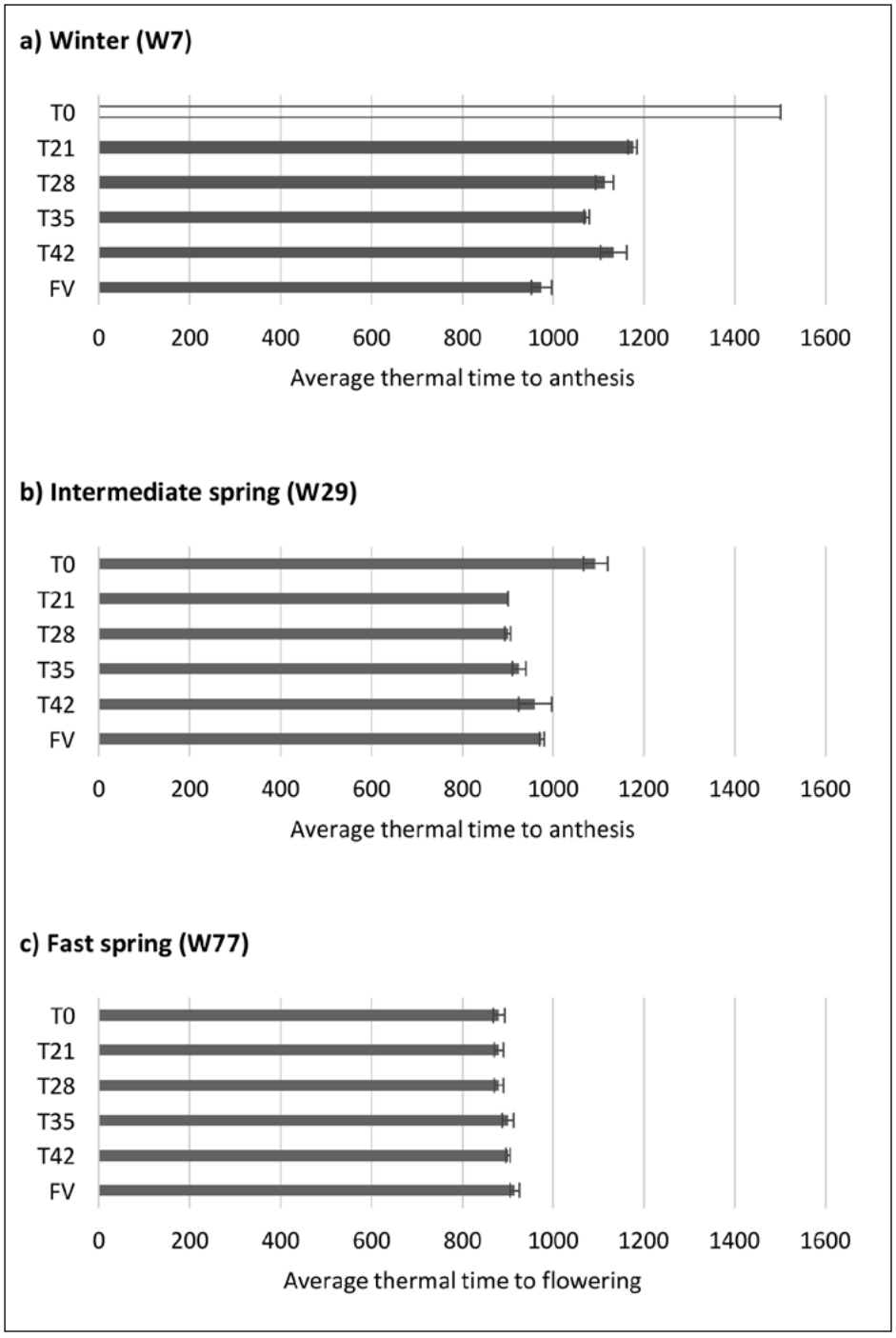

Figure 2. The effect of cold temperature during grain development on average thermal time to flowering for a) winter, b) intermediate spring, and c) fast spring wheats.

The FV treatment involved exposing untreated (T0) seed to cold treatment (4°C under short days/8-hour light periods @ 200µmols/m^2) from sowing. FV plants remained under cold treatment for 42 days to fully saturate vernalisation requirements in the winter genotypes used.

Phenological measurements were recorded every second day ±1 between sowing and flowering (Z65), with growth stage scored using the Zadoks scale (Zadoks et al. 1974). A subset of plants was also sampled at Z14 to observe treatment effects on early reproductive development. Plants were dissected and apical meristems observed under a microscope before being allocated a score using a modified scale from Bonnett (1966).

Effects on early apical development

Plants of intermediate spring types (weak vernalisation requirement) and winter types (strong vernalisation requirement) grown from cold-treated seed were significantly more advanced than untreated plants. Differences in apical development between treatments suggested a dose response, whereby longer periods of cold treatment (>21

days) resulted in faster apical development (higher meristem score) (Figure 1).

The winter type (W7) had the greatest response to cold treatment, which is understandable given its obligate vernalisation requirement. The intermediate spring type (W29) also responded to cold treatment due to its facultative vernalisation requirement. Progression to early reproductive development was not dependent on cold treatment as apices from the T0 treatment were also reproductive (meristem score 6 – indicative of spikelet forming branches). At the time of sampling, apices from all treatments of the fast spring type (W77) had progressed to terminal spikelet (Z30), reflective of its insensitivity to vernalisation.

It was also noted that the apices of plants exposed to cold temperatures during early vegetative growth (FV) were more reproductive (meristem score 9 – terminal spikelet) than apices from the T42 treatment, despite similar periods of cold exposure. This suggests that cold temperature during early vegetative development has a greater impact on apical developmental rate.

Effects on flowering time

Differences in the average thermal time to flowering were consistent with observations on early apical development, whereby cold treated plants flowered earlier than untreated plants in both the winter and intermediate spring types. Again, the fast spring type flowered at a similar time regardless of treatment (Figure 2). Results also indicated a dose response, whereby progressively longer periods of cold temperature exposure (>21 days) resulted in faster flowering times (Figure 4). Faster flowering in the FV plants compared to the T42 treatment agrees with the suggestion that cold temperature during early vegetative growth has a greater effect on phasic development than cold temperature during grain development.

In southern NSW, the chances of experiencing 21 to 42 days of cold temperatures (4°C) during grain development are unlikely. However, it is not uncommon for temperatures to fall within the vernalising range (0°C - 15°C) during late September to early October for short periods of time (<21 days). It is, therefore, feasible that the observations from this experiment will have relevance in the field, particularly for intermediate spring types with a weak vernalisation requirement.

Conclusion

The results of this study have shown that the effects of cold temperature during grain development can persist in the developing and mature grain and have an effect on phasic development in the subsequent generation. Specifically, it is possible to saturate the vernalisation requirements of intermediate spring and winter types through prolonged exposure to cold temperature during grain development. This results in accelerated reproductive development at the apical meristem and an earlier flowering time. Results also suggest that a) the effect of cold temperature treatment is dose responsive, whereby prolonged exposure to cold temperatures resulted in more rapid development, and b) that vernalisation responses are saturated more effectively during early vegetative development than during grain development. While this study has been conducted under controlled environments, future research should focus on the implications of this phenomenon under field conditions in southern NSW.

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Contact details

Ramon Javier Atayde
0449 933 309
javi.atayde@gmail.com

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Effects of surface incorporation of organic matter (lucerne pellets) on subsurface soil acidity and wheat growth

H. H. Nguyen[1, 2], J.S. Moroni[1, 2], J.R. Condon[1, 2], A. Zander[1, 2] and G. Li[1, 3].

[1]Graham Centre for Agricultural Innovation (Charles Sturt University and NSW Department of Primary Industries); [2]School of Agricultural and Wine Sciences, Charles Sturt University; [3]NSW Department of Primary Industries, Wagga Wagga Agriculture Institute.

GRDC project code: DAN00206

Keywords

- organic amendment, lucerne pellets, subsurface soil acidity, movement of alkalinity.

Take home messages

- Results from glasshouse experiments indicated that the surface incorporation of an organic matter, such as lucerne pellets, can increase subsurface soil pH.
- The combined incorporation of lucerne pellets with lime could improve the ameliorating effect of the organic amendment on subsurface soil acidity.
- However, in a first-year field experiment, the incorporation of lucerne pellets with lime only affected the pH in soil layer 5cm below the incorporated layer and did not improve grain yield.

Background

In Australia, acidic soil affects many major crops such as wheat, barley, canola and pulses. Surface incorporation of lime can increase the pH of the 10-20cm subsurface soil layer, but the rate of change is very slow (0.04 pH units per year) (Li et al. 2019). Subsurface soil acidity can also be ameliorated by the incorporation of organic amendments (Butterly et al. 2013). The pH increases by the addition of organic matter is a consequence of the association reactions between hydrogen ions and organic anions, decarboxylation of organic anions and ammonification of organic nitrogen (N) compounds. Moreover, organic matter is able to detoxify the Al^{3+} by forming organic acid-Al complexes. The aim of this research was to study the effects of surface incorporation of organic matter on subsurface soil pH and plant growth.

Glasshouse Experiment 1

This experiment was conducted at Charles Sturt University, Wagga Wagga, in November 2015. Soil samples were collected from the top 40cm in layers (i.e. 0-10cm, 10-20cm, 20-30cm and 30-40cm) near Holbrook, NSW. The soil was classified as Yellow Chromosol (Isbell, 1996). The initial pH was 4.54, 4.15, 4.46 and 5.15 in the soil layer 0-10cm, 10-20cm, 20-30cm and 30-40cm, respectively. The soil profile was reconstructed into a pot which was built from PVC pipe (10cm diameter and 50cm length), maintaining the order and thickness of each layer, except for the 30-40cm layer which occupied 17cm at the bottom of the pot. Fine ground lucerne or lime was incorporated in layers from 0-30cm by single or double or triple layers. The acid soil sensitive wheat variety Axe® (Australian Grain Technologies Pty Ltd, Glen Osmond, SA) was grown and the shoot and

roots dry biomass and soil pH of each layer were determined at 31 days after sowing.

Key results from Glasshouse Experiment 1

No improvement on either shoot or root biomass was detected in any of the treatments, even though the wheat variety Axe(Φ) is considered sensitive to soil acidity. Lucerne incorporation resulted in a significant (P<0.05) reduction of shoot and root growth compared to the lime treatment and this effect was exacerbated if the lucerne was placed in the top soil layers.

However, the incorporation of lucerne or lime significantly increased pH (*P*<0.05) (Table 1). The lime treatment increased pH where lime was placed, whereas lucerne treatments raised pH not only at the depth where it was placed, but also below the incorporated layers (Table 1). The more depths to which lucerne were incorporated, the greater the pH increased below the depths where amendment was placed (Table 1).

Glasshouse Experiment 2

Soil samples were collected at the Ferndale site at Dirnaseer, west of Cootamundra, NSW. The soil was classified as red chromosol (Isbell, 1996). The initial pH was 4.83, 4.18, 4.12 and 4.62 in soil layer 0-10cm, 10-20cm, 20-30cm and 30-40cm, respectively. The soil profile was reconstructed as described in Experiment 1. The lucerne pellets were cut into ~2cm (LP1), ~1cm (LP2), ~0.5cm (LP3) and 0.1-0.2cm (LP4) and incorporated into the top 5cm of soil column, whereas lime was incorporated into the top 10cm. For treatments with the combination of lucerne pellets and lime, the incorporated depths were kept the same. An acid soil resistant wheat variety Dart(Φ) (LongReach Plant Breeders Management Pty Ltd, VIC, SA) was used in this experiment. Shoot, root dry weight and soil pH were measured at 14, 21, 28 and 35 days after sowing.

Key results from Glasshouse Experiment 2

The incorporation of lucerne pellet into the top 5cm soil layer significantly increased soil pH throughout the soil column (downward to 40cm), particularly in the fine cut lucerne treatments, whereas the incorporation of lime alone only increased pH at the incorporated layer (0-10cm — Figure 1a). Furthermore, the combination of lucerne with lime raised the pH more than lucerne alone (Figure 1b). The pH of the soil layer from 0-15cm in lucerne pellets + lime treatment increased by 0.47-0.76 pH unit compared to lucerne pellets treatment alone (Figure 1b). Lime might have reacted with acidity in the incorporated layer, which provided more available alkali from the lucerne pellets to move downward.

The incorporation of the lucerne pellets had a negative effect on plant growth up to 28 days after sowing, but no significant differences were observed at 35 days after sowing. Both shoot and root dry weight of the treatments with addition of the amendments were significantly lower than the control (nil) treatment after 14 days of sowing (Figure 2). The ground lucerne pellets ~0.1-0.2cm (LP4) had adverse effects on both shoot and root growth compared with the other lucerne pellets sizes (Figure 2). Shoot and root dry weight in LP4 treatment decreased by 37.5% and 43.3% compared with shoot and root dry weight in the LP3 treatment, respectively. The results of this experiment were similar to those found in Experiment 1.

Field experiment

A field experiment was established in 2018 at a Ferndale site at Dirnaseer, west of Cootamundra, NSW, (34o38'S, 147°49'E). The experiment was a split-plot design with two wheat varieties as main plots and four soil amendment treatments as subplots, replicated four times. The four treatments were no addition of the amendment (Nil); addition

Table 1. Effect of placement of lime and ground lucerne pellet (LP) amendments on mean pH in $CaCl_2$ of soil layers of reconstructed soil columns of acidic soil at 31 days of the experiment.

Soil layer (cm)	Control	Soil layer placement of lime or ground lucerne pellet (LP)													
		1st layer		2nd layer		3rd layer		1st and 2nd layers		1st and 3rd layers		2nd and 3rd layers		1st, 2nd and 3rd layers	
	None	lime	LP	lime	LP	lime	LP	lime	LP	lime	LP	lime	LP	Lime	LP
1st (0-10)	4.6	5.2*	5.1*	4.6	4.6	4.6	4.6	5.1*	5.5*	5.1*	5.2*	4.6	4.6	5.2*	5.5*
2nd (10-20)	4.2	4.2	4.5*	5.4*	5.5*	4.2	4.2	5.4*	5.7*	4.2	4.8*	5.4*	5.7*	5.4*	5.8*
3rd (20-30)	4.2	4.2	4.4	4.2	4.5*	4.7*	5.4*	4.2	4.9*	4.6*	6.0*	4.7*	6.0*	4.7*	6.2*
4th (30-40)	4.4	4.4	4.6*	4.4	4.6*	4.4	4.6	4.4	4.9*	4.4	4.9*	4.4	4.9*	4.5	5.5*

** = indicates significant differences (LSD = 0.196, at P<0.05) of a pairwise means comparison of the pH between the layer of the control pot (unamended layers pot) and the corresponding layer of the amended pots — where not indicated, it is not significantly different. This LSD value is a conservative statistic for pairwise means comparisons across soil layers and treatment combinations.*

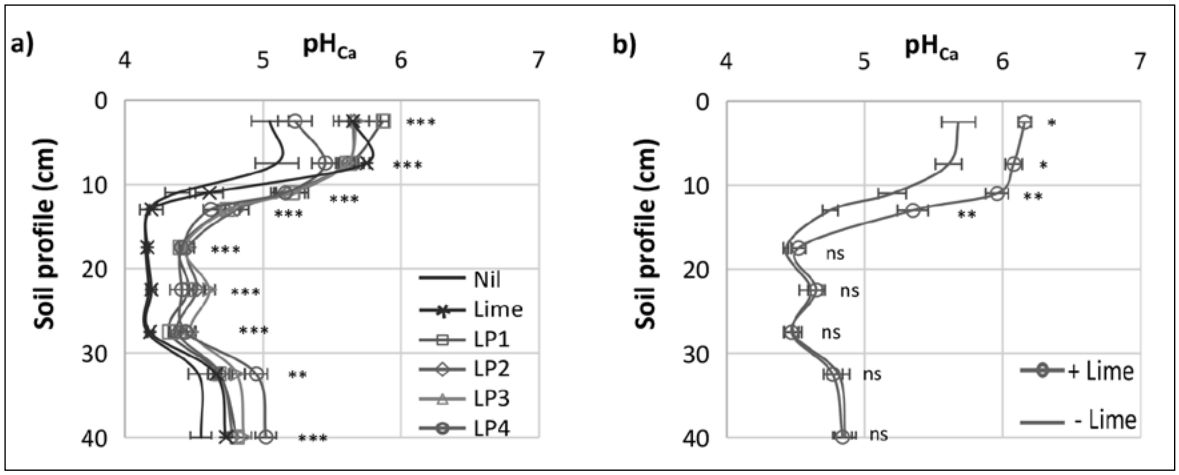

Figure 1. The pH profile at 14 days after sowing - (a) the pH of the soil incorporated with no addition of amendment (Nil); lime; lucerne pellets ~2cm, ~1cm, ~0.5cm, and 0.1-0.2cm (LP1, LP2, LP3, and LP4, respectively); (b) the pH of the soil incorporated with LP3 in combination with (+Lime) and without (-Lime) lime; *** = *P*<0.001; **= *P*<0.01; * = *P*<0.05; ns = not significant (*P*>0.05); closed vertical bars indicated standard error (n=4)

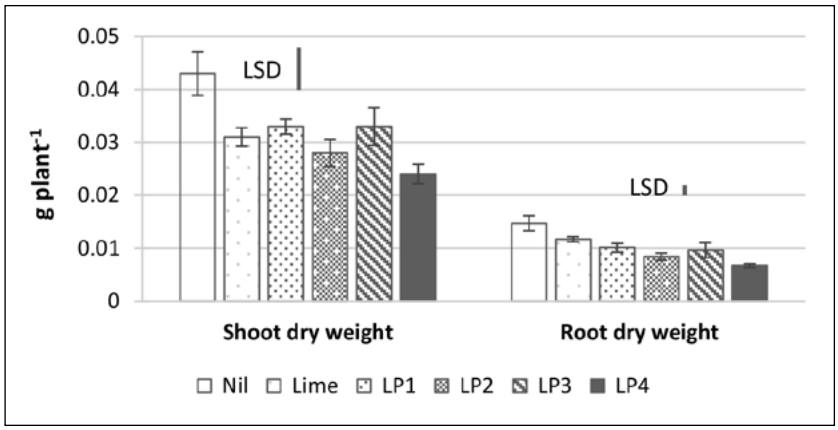

Figure 2. Shoot and root dry weight of single plant at 14 days after sowing. Closed horizontal bars indicated standard error (n=4); opened horizontal bar indicated the least significant difference (LSD) at *P*=0.05.

of 2.5t/ha lime (Lime); addition of 15.0t/ha lucerne pellets ~0.5cm (LP) and, addition of 15.0t/ha lucerne pellets ~0.5cm in combination 2.5t/ha lime (LP+L). The amendments were incorporated into ~5cm of the soil profile. The two wheat varieties were an acid soil sensitive variety, Lancer$^{\phi}$ (LongReach Plant Breeders Management Pty Ltd, VIC, SA) and the acid soil resistant variety Gregory$^{\phi}$ (Queensland Department of Primary Industries and Fisheries (DPI&F) within the Enterprise Grains Australia (EGA)). Soil pH was measured before, at three months, six months after incorporation and at harvest time at depths of 0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-30cm and 30-40cm. Grain yield was measured with quadrat cut.

Key results from field experiment

The incorporation of the amendments significantly increased pH at the incorporated layer, however it had no effect on pH of the layer below 5cm of the soil profile three months after incorporation. At harvest, however, the pH in the 5-10cm layer of the soil profile significantly increased following treatment with lime and LP+L (Figure 3). No pH change was detected below 10cm of the soil profile.

Grain yield did not increase from any soil amendment for either acid soil sensitive or resistant wheat varieties in the first year of the experiment (Figure 4). However, on average across the treatments, the grain yield of the acid soil sensitive variety was significantly higher than the grain yield of the resistant variety (Figure 4).

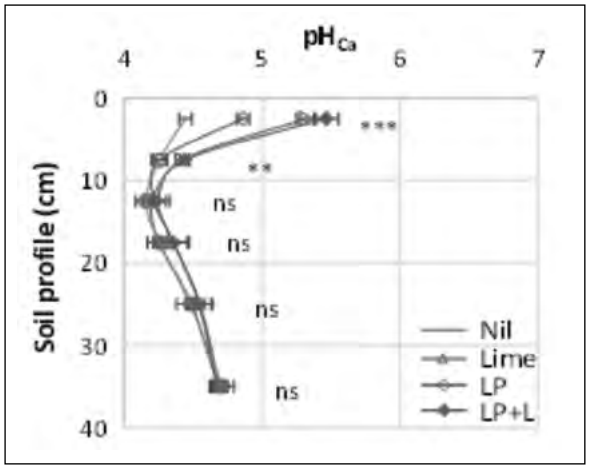

Figure 3. The pH profile at harvest (eight months after incorporation). *** = $P<0.001$, ** = $P<0.01$ and ns = not significant ($P>0.05$). Nil = control treatment with no addition of the amendment, Lime = treatment with lime, LP = treatment with lucerne pellets, and LP+L = treatment with lucerne pellets in combination with lime. Closed vertical bars indicated standard error (n=8).

Conclusions

Surface incorporation of lucerne pellets ameliorated subsurface acidity under controlled glasshouse conditions. The pH of the subsurface layers increased higher with the surface incorporation of organic matter in combination with lime. Although the incorporation of the amendments increased soil pH, plant growth in the glasshouse and field grain yield did not significantly improve in the short term.

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Contact details

Hoang Han Nguyen
School of Agriculture and Wine Sciences, Charles Sturt University, Wagga Wagga NSW
0468 462 014
hnguyen@csu.edu.au

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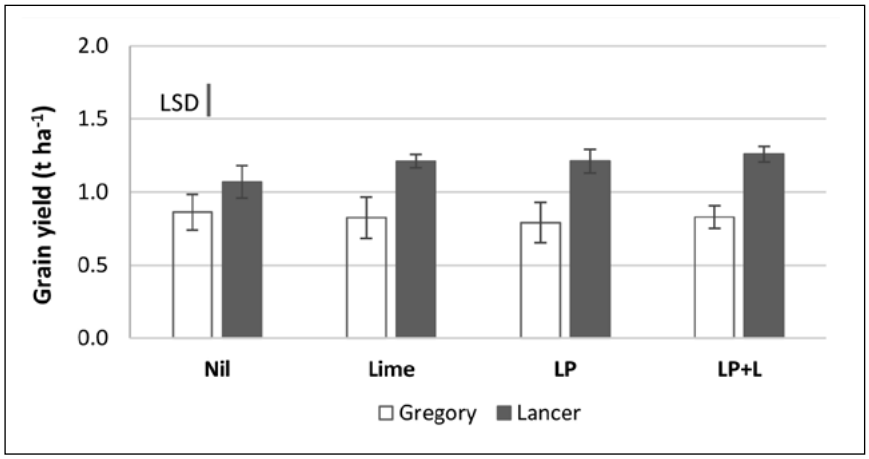

Figure 4. The field grain yield of acid soil resistant and sensitive varieties, Gregory[Φ] and Lancer[Φ], respectively. Closed horizontal bars indicated standard error (n=4); opened horizontal bar indicated the least significant difference (LSD) at $P=0.05$.

Notes

Notes

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/

Contact details

Gordon Cumming
Grains Research and Development Corporation (GRDC)
0428 637 642
gordon.cumming@grdc.com.au

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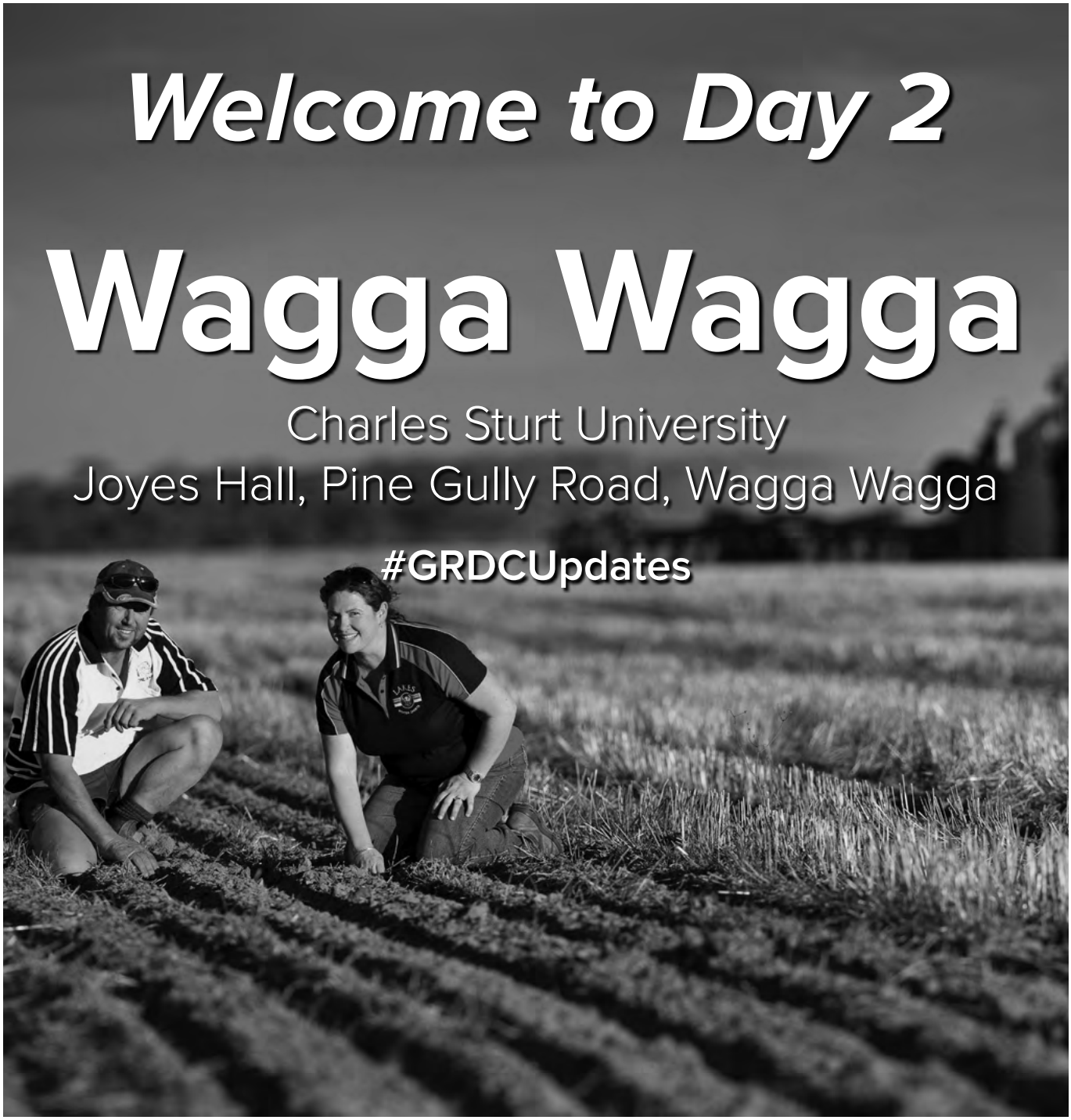
Notes

Notes

GRAINS RESEARCH UPDATE

BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION



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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.

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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.

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Contents — DAY 2

CONCURRENT SESSION

FINAL SESSION

FURTHER INFORMATION

BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

PROGRAM DAY 2 - FEBRUARY 20th

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

	Joyes Hall	Room 229/182	Room 229/178	SAVS Green Room
9.00 am	**Emerging management tips for early sown winter wheats (R)** – P159 ***Felicity Harris,*** *NSW DPI*	**Assessing key pulse crops including lentils and chick peas (R)** – P167 ***Mark Richards,*** *NSW DPI*	**Pest patrol – RWA under the spotlight (R)** – P173 ***Jessica Lye,*** *cesar*	**Super high oleic oil safflower - a future crop option for southern NSW** – P185 ***Rosemary Richards,*** *Go Resources*
9.40 am	**Sustaining our herbicides into the future (R)** – P193 ***Chris Preston,*** *University of Adelaide*	**Utilising precision agriculture for better agronomic decisions (R)** – P199 ***Quenten Knight,*** *Agronomy Focus*	**Phosphorus stratification - affects on utilisation and access (R)** – P203 ***Graeme Sandral,*** *NSW DPI*	**Companion cropping - should we be considering it? (R)** – P215 ***John Kirkegaard,*** *CSIRO and* ***Greg Condon,*** *Grassroots Agronomy*
10.20 am	**MORNING TEA**			
10.50 am	**Phosphorus stratification - affects on utilisation and access** – P203 **Graeme Sandral, NSW DPI**	**Integrated weed management round up forum** **Overview of current adoption of HWSC, impact of chaff lining and stripper fronts on weed seed management and IWM technology based solutions** – P221 ***Mike Walsh,*** *Uni of Sydney,* ***Greg Condon,*** *AHRI, and* ***John Broster,*** *CSU*	**Utilising precision agriculture for better agronomic decisions** – P199 ***Quenten Knight,*** *Agronomy Focus*	**Canola establishment - learnings around precision planting, sowing depth and density (R)** – P229 ***Col McMaster,*** *NSW DPI*
11.30 am	**Assessing key pulse crops including lentils and chick peas** – P167 ***Mark Richards,*** *NSW DPI*		**Sustaining our herbicides into the future** – P193 ***Chris Preston,*** *University of Adelaide*	**Pest patrol – RWA under the spotlight** – P173 ***Jessica Lye,*** *cesar*

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

	Joyes Hall	Room 229/182	Room 229/178	SAVS Green Room
12.10 pm	**Applying R&D to help drive farm business profitability** – P237 ***Jordan Lindgren,*** *2018 Saskatchewan Young Farmer of the Year*	**Emerging management tips for early sown winter wheats** – P159 ***Felicity Harris,*** *NSW DPI*	**Canola establishment - learnings around precision planting, sowing depth and density** – P229 ***Col McMaster,*** *NSW DPI*	**Companion cropping - should we be considering it?** – P215 ***John Kirkegaard,*** *CSIRO and* ***Greg Condon,*** *Grassroots Agronomy*

12.50 pm **LUNCH**

1.30 pm **Served with a side of science - building community trust in food production** – P241 — ***Heather Bray,*** *The University of Western Australia*

2.10 pm **Herbicide residues in soil -what is the scale and significance?** – P247 — ***Mick Rose,*** *NSW DPI*

2.50 pm **CLOSE AND EVALUATION**

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Concurrent session
Day 2

Emerging management tips for early sown winter wheats

Kenton Porker, Dylan Bruce, Brenton Spriggs and Sue Buderick[1]; James Hunt[2]; Felicity Harris and Greg Brooke[3]; Sarah Noack[4]; Michael Moodie, Mick Brady and Todd McDonald[5]; Michael Straight[6]; Neil Fettell, Helen McMillan and Barry Haskins[7]; Genevieve Clarke and Kelly Angel[8].

[1]SARDI; [2]La Trobe University; [3]NSW DPI; [4]Hart Field-Site; [5]Moodie Agronomy; [6]FAR; [7]CWFS; [8]BCG.

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$^{\phi}$ 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$^{\Phi}$, Kittyhawk$^{\Phi}$ and DS Bennett$^{\Phi}$.
- 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$^{\Phi}$, Kittyhawk$^{\Phi}$ and DS Bennett$^{\Phi}$.
- 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$^{\Phi}$	2016	LRPB	Mid winter	AH	MR	MR	R	MRMS
Longsword$^{\Phi}$	2017	AGT	Fast winter	Feed	RMR	MSS	MR	MRMS
Illabo$^{\Phi}$	2018	AGT	Mid-fast winter	AH/APH*	RMR	S	MRMS	MRMS
DS Bennett$^{\Phi}$	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$^{\Phi}$	2015	AGT	Mid spring	APW/AH*	MS	RMR	R	MSS
Trojan$^{\Phi}$	2013	LRPB	Mid-fast spring	APW	MR	MRMS	MRMS	MSS
Scepter$^{\Phi}$	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

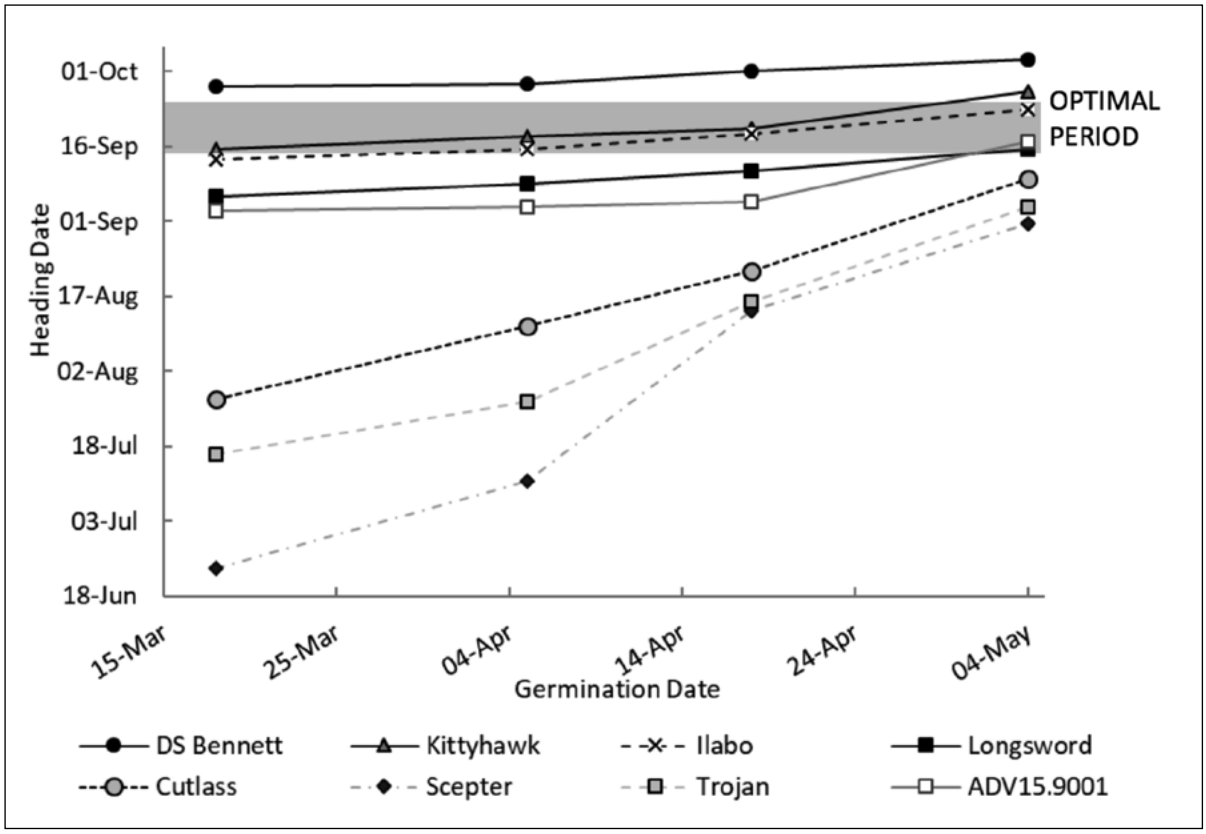

Figure 1. Mean heading date responses from winter and spring varieties at Hart in 2017 and 2018 across all sowing times — grey box indicates the optimal period for heading at Hart.

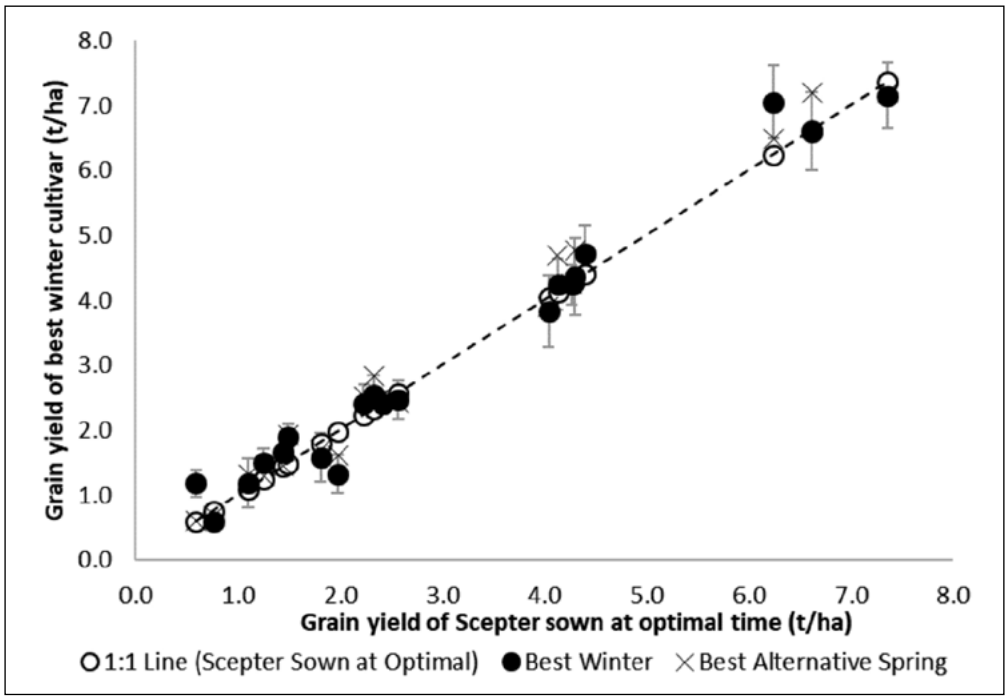

Figure 2. Grain yield performance of Scepter$^{\Phi}$ wheat sown at its optimal time (late April-early May) in 20 environments compared to the best performing winter wheat and best alternative spring wheat. Error bars indicate LSD ($P<0.05$).

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[Φ] and Kittyhawk[Φ] 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[Φ] 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[Φ] 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[Φ] sown at the optimum time (late April-early May). Different letters within a site indicate significant differences in grain yield.

Site		Year	Scepter[Φ] 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[Φ]	16-Apr	0.61 a	Cutlass[Φ]	16-Apr
Booleroo	SA	2018	0.77 a	0.59 a	Longsword[Φ]	4-Apr	0.69 a	Trojan[Φ]	2-May
Loxton	SA	2018	1.10 a	1.19 a	Longsword[Φ]	19-Mar	1.32 a	Cutlass[Φ]	3-May
Minnipa	SA	2018	1.25 a	1.50 b	Longsword[Φ]	3-May	1.29 a	Trojan[Φ]	3-May
Mildura*	Vic	2018	1.44 a	1.66 b	DS Bennett[Φ]	1-May	1.46 a	LPB14-0293	1-May
Mildura	Vic	2017	1.49 a	1.90 b	Longsword[Φ]	13-Apr	1.93 b	Cutlass[Φ]	28-Apr
Horsham*	Vic	2018	1.81 a	1.58 a	DS Bennett[Φ]	6-Apr	1.70 a	Trojan[Φ]	2-May
Booleroo	SA	2017	1.98 a	1.33 b	DS Bennett[Φ]	4-May	1.61 b	Cutlass[Φ]	4-May
Minnipa	SA	2017	2.23 a	2.42 a	Longsword[Φ]	18-Apr	2.52 a	Cutlass[Φ]	5-May
Loxton	SA	2017	2.33 a	2.55 a	Longsword[Φ]	3-Apr	2.83 b	LPB14-0293	3-Apr
Hart	SA	2018	2.41 a	2.42 a	Illabo[Φ]	17-Apr	2.52 a	LPB14-0293	17-Apr
Rankins Springs	NSW	2018	2.57 a	2.47 a	DS Bennett[Φ]	19-Apr	2.42 a	Trojan[Φ]	7-May
Birchip	Vic	2018	4.04 a	3.83 a	Longsword[Φ]	30-Apr	3.90 a	Trojan[Φ]	30-Apr
Hart	SA	2017	4.13 a	4.25 a	Illabo[Φ]	18-Apr	4.70 b	LPB14-0293	18-Apr
Yarrawonga	Vic	2017	4.27 a	4.24 a	DS Bennett[Φ]	3-Apr	4.26 a	Cutlass[Φ]	26-Apr
Wongarbon	NSW	2017	4.30 a	4.37 a	DS Bennett[Φ]	28-Apr	4.77 a	Trojan[Φ]	13-Apr
Tarlee	SA	2018	4.40 a	4.71 a	Illabo[Φ]	17-Apr	4.62 a	LPB14-0293	17-Apr
Wallendbeen	NSW	2017	6.24 a	7.05 b	DS Bennett[Φ]	28-Mar	6.49 a	Cutlass[Φ]	1-May
Birchip	Vic	2017	6.62 a	6.60 a	DS Bennett[Φ]	15-Apr	7.20 a	Trojan[Φ]	15-Apr
Horsham	Vic	2017	7.36 a	7.15 a	DS Bennett[Φ]	16-Mar	7.19 a	Trojan[Φ]	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$^{\Phi}$ 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$^{\Phi}$ was generally favoured (Table 2, Figure 3).
- In environments greater than 2.5t/ha the mid to slow developing varieties were favoured — Illabo$^{\Phi}$ in the Mid North of SA, and DS Bennett$^{\Phi}$ at the Victorian and NSW sites (Table 2, Figure 4).

The poor relative performance of Longsword$^{\Phi}$ 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$^{\Phi}$ 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

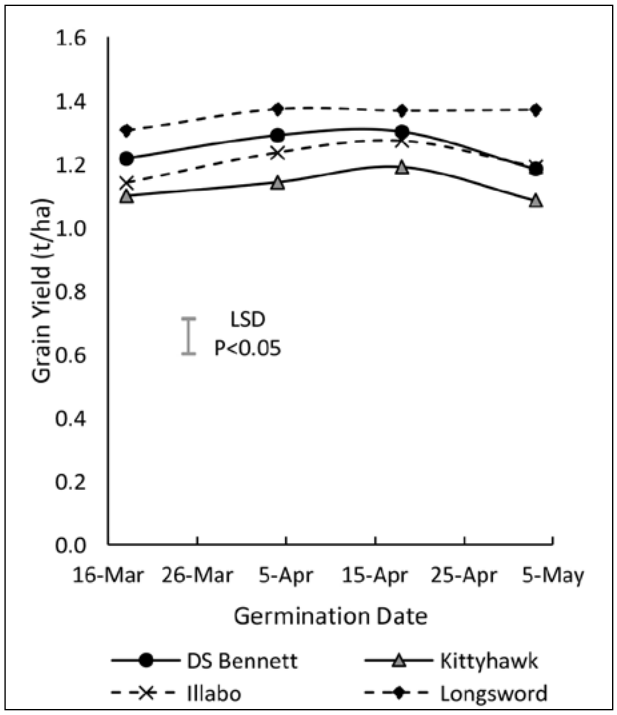

Figure 3. Mean yield performance of winter wheat in yield environments less than 2.5t/ha (11 sites in SA/Victoria)

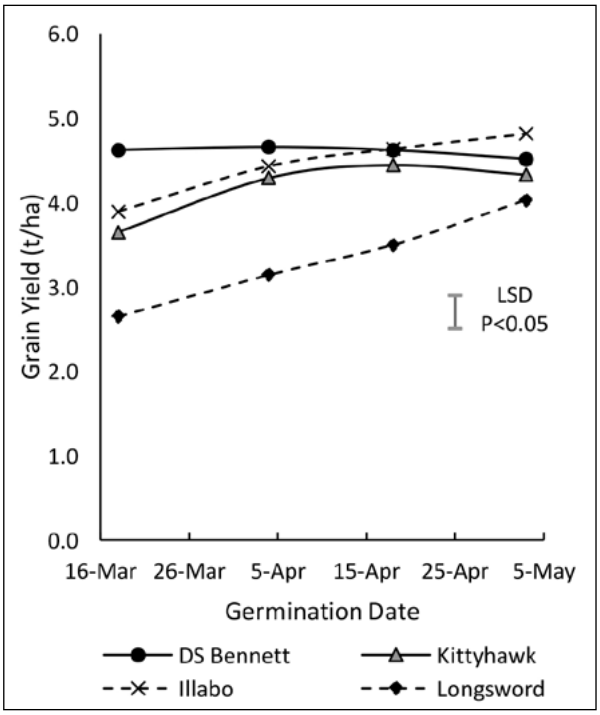

Figure 4. Mean yield performance of winter wheat in yield environments greater than 2.5t/ha (five sites in SA/Victoria)

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.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC — the authors would like to thank them for their continued support. The project is led by La Trobe University in partnership with SARDI, Hart Field-Site Group, Moodie Agronomy, Birchip Cropping Group, Agriculture Victoria, FAR Australia and Mallee Sustainable Farming. Collaboration is with NSW DPI, Central West Farming Systems and AgGrow Agronomy & Research.

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.*

Contact details

Kenton Porker
SARDI
GPO Box 397, Adelaide SA 5001
0403 617 501
Kenton.porker@sa.gov.au
@kentonp_ag

James Hunt
La Trobe University – AgriBio Centre for AgriBiosciences
5 Ring Rd, Bundoora VIC 3086
0428 636 391
j.hunt@latrobe.edu.au
@agronomeiste

Felicity Harris
NSW DPI
Pine Gully Road, Wagga Wagga NSW 2650
0458 243 350
felicity.harris@dpi.nsw.gov.au
@FelicityHarris6

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Pulses 2018 — an update for southern NSW

Mark Richards.

NSW DPI, Wagga Wagga Agricultural Institute, Wagga Wagga.

GRDC project codes: BLG112, DAN00212, DAV00154, UA00163

Keywords

- pulse crops, pulse breeding, variety evaluation, chickpea, faba bean, lentil.

Take home messages

- Three new pulse varieties were released by the Pulse Breeding Australia (PBA) programs
- Poor seasonal conditions throughout the 2018 growing season in southern NSW limited yield potential.
- Disease incidence and severity were low during 2018.
- Where sub-surface acidity is detected, incorporate lime to a depth of 10cm, at least 12 months before sowing pulses (18 months in drier environments).
- Biosecurity alert – keep lupin anthracnose out of NSW.

2018 seasonal snapshot

- Three new pulse varieties were released by the Pulse Breeding Australia (PBA) programs — a lentil, PBA Hallmark XT$^{\phi}$, and two faba bean, PBA Bendoc$^{\phi}$ and PBA Marne$^{\phi}$. All varieties were released in the Southern Region in 2018 for grower availability in 2019. The pulse area sown in southern NSW was generally down on previous seasons due to the subdued price outlook combined with the dry autumn and late seasonal break. However, due to the resulting supply shortages, growers who persisted with their rotations have been able to take advantage of favourable market conditions across most of the pulse species, in particular faba bean, field pea and lupin.
- Poor seasonal conditions throughout the 2018 growing season in southern NSW limited yield potential. Low autumn rainfall delayed sowing and establishment of most species. With growing season rainfall at Wagga Wagga of 153mm or 52% below the long-term average of 322mm, low soil moisture restricted crop growth throughout the growing season (Figure 1). In addition, a number of severe frost events during winter and spring impacted on crop growth and pod set in some situations. The flowering and grain filling period of September-October was also extreme with below average rainfall and above average temperatures limiting yield potential.
- Disease incidence and severity were low across all species due to the dry seasonal conditions.
- Most southern NSW pulse crops are grown in soils where pH stratification and sub-surface acidity can affect root growth, nodulation, crop vigour and yield potential. Field observations show that severely acidic layers (pHCa < 4.5) are common at depths of 5–10cm and 10–15cm in the main cropping soils of central and southern NSW, but are not detected in soil samples collected at the standard sampling depths of 0–10cm and 10–20cm. Check for the presence of acidic layers by sampling soils at 5cm intervals to a depth of 20cm two years before sowing acid-sensitive pulses.

- Where sub-surface acidity is detected, the most rapid method to increase pH is to incorporate appropriate rates of fine grade lime to a depth of 10cm, at least 12 months before sowing pulses (18 months in drier environments). This will allow time for the lime to react and increase pH to the depth of incorporation.
- Biosecurity alert – keep lupin anthracnose out of NSW. Growers and processors buying hay and grain originating from WA or SA should ask for a vendor declaration that states it does not contain any lupin material. If not sure of the origin of the grain or hay, ask your supplier to confirm the origin. For advice on managing biosecurity risks and understanding entry requirements for NSW visit https://www.dpi.nsw.gov.au/biosecurity/feed-and-fodder

Pulse overview

Pulse crop research based at the Wagga Wagga Agricultural Institute occurs with co-investment from NSW DPI and GRDC, covering all aspects of pulse growing, from breeding and variety evaluation, to applied agronomy research. The aim is to improve yield, adaptation, disease resistance and seed quality of five winter pulses — field pea, lupin, chickpea, faba bean and lentil.

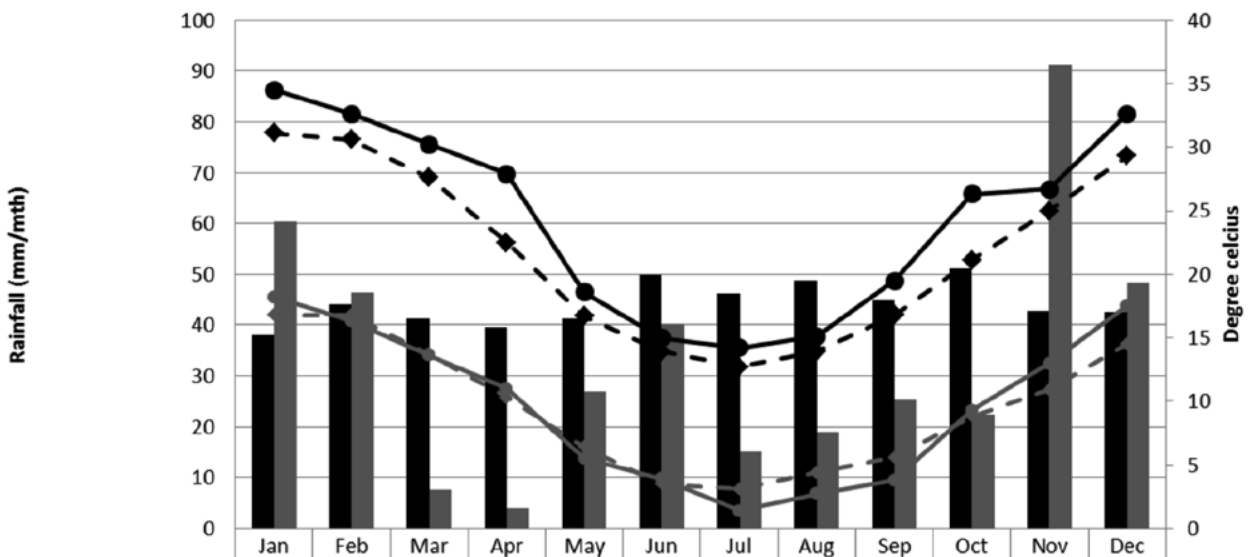
Current research

'The adaptation of profitable pulses in the central and southern zones of the Northern Grains Region' (project code BLG112). This is a new pulse agronomy project funded through the NSW DPI Grains & Pathology Partnership (GAPP).

Unfortunately, results from 2018 were not available at the time of writing. These results will be presented at the 2019 Wagga Update and experiment reports will be published in the 2019 NSW DPI Southern Research Results.

This project aims to quantify and understand the phenological drivers of high value pulses in the central and southern environments of the Northern Grain Region (NGR). Research will focus on the Genotype x Environment x Management (GxExM) interactions of each species, examining three climatic environments at Wagga Wagga, Trangie and Yanco, and two high value pulses, chickpea and lentil. This project will quantify the effects of selected abiotic factors on plant phasic development, principally focusing on photoperiod and temperature effects.

This project aims to identify which phenotypes are best adapted to each of three agro-ecological environments and characterise crop phenology for current chickpea and lentil genotypes.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LTA rainfall	38.1	44	41.3	39.5	41.2	49.9	46.1	48.7	45	51.2	42.8	42.6
2018 rainfall	60.3	46.5	7.7	3.9	26.8	40.1	15.2	19.0	25.3	22.3	91.3	48.4
LTA min temp	16.8	16.8	13.7	10.3	6.4	3.5	3.1	4.4	5.6	8.8	10.9	14.5
2018 min temp	18.2	16.3	13.6	11.0	5.5	3.9	1.4	2.7	3.8	9.3	13.0	17.5
LTA max temp	31.1	30.6	27.6	22.5	16.7	13.9	12.7	13.9	16.8	21.1	25	29.3
2018 max temp	34.5	32.6	30.2	27.9	18.6	15.0	14.2	15.1	19.5	26.3	26.7	32.6

Figure 1. Wagga Wagga Agricultural Institute climate 2018.
Source - Patched Point Data, http://www.longpaddock.qld.gov.au/, LTA – long term average.

The first step is to conduct experiments in the three environments over multiple years, using the same genotypes, and to collect detailed crop phenology data. This data can be used to identify the key phenology traits driving adaptation across environments.

New information from this project will assist growers to make informed choices when selecting lentil and chickpea variety sowing dates so that the critical growth period occurs under optimal environment conditions. The project aims to deliver greater yield stability and improve confidence, adoption and profitability of these crops in central and southern NSW.

New pulse variety releases for 2019

Lentil - PBA Hallmark XT$^{\phi}$

PBA Hallmark XT$^{\phi}$ builds on the success of the other herbicide tolerant red lentils, PBA Herald XT$^{\phi}$ and PBA Hurricane XT$^{\phi}$. It is broadly adapted with 10% higher yields than PBA Hurricane XT$^{\phi}$ across lentil growing areas of southern NSW (Table 1 and 2).

It incorporates the same tolerance to some Group B herbicides, but with higher grain yields than PBA Hurricane XT$^{\phi}$ and improved agronomic characteristics. PBA Hallmark XT$^{\phi}$ has greater early vigour, similar ratings for ascochyta blight and improved ratings for botrytis grey mould (BGM) compared with PBA Hurricane XT$^{\phi}$. These features, combined with its herbicide tolerance, will make PBA Hallmark XT$^{\phi}$ a preferred variety in cropping systems in southern NSW.

PBA Hallmark XT$^{\phi}$ is a medium red lentil so this variety can provide an alternative market class option to the popular small red lentil PBA Hurricane XT$^{\phi}$.

PBA Hallmark XT$^{\phi}$ and PBA Hurricane XT$^{\phi}$ have similar herbicide tolerance including:

- tolerance to applied imazethapyr at label rates*,
- improved tolerance to applied flumetsulam*, and
- improved tolerance to residual levels of sulfonylurea and imidazolinone herbicide from prior crops*.

** Note that permits, product label rates, plant back periods and all label directions for use must be adhered to.*

Seed protection and royalties

PBA Hallmark XT$^{\phi}$ is protected under Plant Breeder's Rights (PBR) legislation. A PBR bag licence applies to the seed. Authorised growers can retain seed from production of PBA Hallmark XT$^{\phi}$for their own seed use. An End Point Royalty (EPR) of $5.94/t (including GST) applies to this variety when delivered to authorised EPR collectors, which includes breeder royalties and also the $0.44/t (including GST) herbicide technology royalty to Agriculture Victoria Services Pty Ltd. Seed is commercialised by PBSeeds and available from 2019.

Further details www.pbseeds.com.au

National Variety Trial (NVT) yield data

Table 1. NVT long term results (2013–2017) for lentil in the south east (Wagga Wagga) of the southern NSW cropping zone. Yields are presented as a percentage of the site mean yield.

Variety	Year	2013	2014	2015	2016	2017
	Site mean yield	1.41t/ha	1.57t/ha	1.28t/ha	2.80t/ha	0.88t/ha
PBA Jumbo 2$^{\phi}$		108	110	112	131	103
PBA Hallmark XT$^{\phi}$		-	111	111	113	105
PBA Ace$^{\phi}$		107	114	109	97	116
PBA Greenfield$^{\phi}$		100	107	104	122	101
PBA Hurricane XT$^{\phi}$		100	101	98	98	104

Table 2. NVT long term results (2013–2017) for lentil in the south west (Rankins Springs and Methul) of the southern NSW cropping zone. Yields are presented as a percentage of the site mean yield.

Variety	Year	2013	2014	2015	2016	2017
	Site mean yield	1.28t/ha	0.52t/ha	0.78t/ha	2.94t/ha	0.48t/ha
PBA Jumbo 2$^{\phi}$		117	124	119	86	130
PBA Hallmark XT$^{\phi}$		117	116	116	96	122
PBA Ace$^{\phi}$		118	116	116	112	111
PBA Greenfield$^{\phi}$		-	100	100	105	112
PBA Hurricane XT$^{\phi}$		98	91	89	101	99

Faba bean – PBA Bendoc$^{\Phi}$

PBA Bendoc$^{\Phi}$ 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 Group B (including the sulfonylureas) herbicide residues persist from applications to the previous crop.

PBA Bendoc$^{\Phi}$ is similar in time of flowering and maturity to Nura$^{\Phi}$ and PBA Samira$^{\Phi}$, and has similar resistance to both pathotypes of ascochyta blight as these two varieties. It is susceptible to chocolate spot, which will have to be managed in higher rainfall and high biomass situations.

PBA Bendoc$^{\Phi}$ has similar yields to the major faba bean varieties grown in southern Australia and is resistant to ascochyta blight. Seed is small/medium in size and suited to the Middle East markets.

PBA Bendoc$^{\Phi}$ was only tested at three sites in southern NSW in 2016-2017 (Table 3), so results must be considered in a limited context. Two further sites were undertaken in 2018, however the NVT multi-environment trial (MET) analysis was not available at the time of writing. Individual site results for 2018 are available on www.nvtonline.com.au

Herbicide tolerance

PBA Bendoc$^{\Phi}$ is tolerant to some imidazoline herbicides when applied post crop emergence, up to the 6-node growth stage.

- Growers must adhere to all product label and current permit directions for use including rates, timing of application and plant back periods.
- Minor Use Permit PER14726 is available for post-emergence application of imazamox to faba bean crops.
- PBA Bendoc$^{\Phi}$ shows reduced sensitivity to some sulfonylurea herbicide residues from previous crop applications.

Seed protection and royalties

PBA Bendoc$^{\Phi}$ is protected by PBR legislation. Growers can only retain seed from production of PBA Bendoc$^{\Phi}$ for their own seed use.

An EPR of $4.29 per tonne (GST inclusive), which includes breeder royalty, applies upon delivery of this variety.

Further details www.seednet.com.au

Faba bean – PBA Marne$^{\Phi}$

PBA Marne$^{\Phi}$ is an early flowering, high yielding faba bean that has shown adaptation to the lower rainfall and short season areas throughout southern Australia, generally yielding more than current varieties. PBA Marne$^{\Phi}$ 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. Further validation of the performance of PBA Marne$^{\Phi}$ in the low to medium rainfall zones of central and southern NSW, across a range of soil types, is required to have confidence in its adaptability. The current Griffith NVT site is an irrigated site; therefore the only dryland site is the Stage 3 breeder's trial at Wagga Wagga, which is in a medium rainfall area. 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.

Key features:

- Highest yielding faba bean available for short growing season areas in the Southern Region.
- Early flowering, particularly when sown early.
- Medium height plant with good standing ability.
- Resistant to pathotype 1 of ascochyta blight, but only moderately susceptible to the new pathotype 2 of ascochyta blight.
- Improved resistance to rust compared to other Southern Region varieties.
- Medium size seed, similar to PBA Samira$^{\Phi}$ and suited to the Middle East markets.

Seed protection and royalties

PBA Marne$^{\Phi}$ is protected by PBR legislation. Growers can only retain seed from production of PBA Marne$^{\Phi}$ for their own seed use.

An EPR of $3.85 per tonne (GST inclusive), which includes breeder royalty, applies upon delivery of this variety.

Further details www.seednet.com.au

Table 3. NVT long term results (2013–2017) for selected faba bean varieties in southern NSW dryland sites. Yields are presented as a percentage of the site mean yield.

Variety	Year	2013	2014	2015	2016	2017
	Site mean yield	2.24t/ha	2.67t/ha	2.17t/ha	4.73t/ha	1.39t/ha
	Number of sites	3	4	3	1	1
PBA Nasma$^{\phi}$		-	110	114	105	105
PBA Zahra$^{\phi}$		104	104	99	99	107
PBA Samira$^{\phi}$		110	99	98	97	101
PBA Marne$^{\phi}$		97	101	106	116	86
Farah$^{\phi}$		91	106	103	83	104
Fiesta VF		94	103	100	84	104
PBA Bendoc$^{\phi}$		-	-	-	82	89

Further Information

www.dpi.nsw.gov.au

NSW DPI & GRDC Bulletin: Legumes in acidic soils – maximising production potential in south eastern Australia, Burns H & Norton M

NSW DPI Winter crop variety sowing guide 2018

NSW DPI Weed control in winter crops 2018

Insect and mite control in field crops

Pulses: putting life into the farming system (case studies)

NSW DPI Southern NSW Research Results 2014

NSW DPI Southern NSW Research Results 2015

NSW DPI Southern NSW Research Results 2017

Various NSW DPI Crop Agfacts

www.pulseaus.com.au

Pulse Australia information on growing pulses including:

- Crop specific production guides.

www.nvtonline.com.au

Detailed NVT trial results and links to variety information.

www.grdc.com.au

Inoculating legumes: A practical guide - GRDC GRDC GrowNotes™

References

PBA Hallmark XT$^{\phi}$ variety brochure (Sept. 2018)

PBA Bendoc$^{\phi}$ variety brochure (Sept. 2018).

PBA Marne$^{\phi}$ variety brochure (Sept. 2018).

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Contact details

Mark Richards
NSW Department of Primary Industries
Wagga Wagga Agricultural Institute
Pine Gully Road, Wagga Wagga 2650
0269 381 831
mark.richards@dpi.nsw.gov.au

NSW Department of Primary Industries
@NSWDPI_Agronomy

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Russian wheat aphid - current investigations and recent findings

Lisa Kirkland[1], Elia Pirtle[1], James Maino[1], Julia Severi[1], Jessica Lye[1], Paul Umina[1], Thomas Heddle[2] and Maarten van Helden[2].

[1]cesar Pty Ltd; [2]South Australian Research and Development Institute.

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

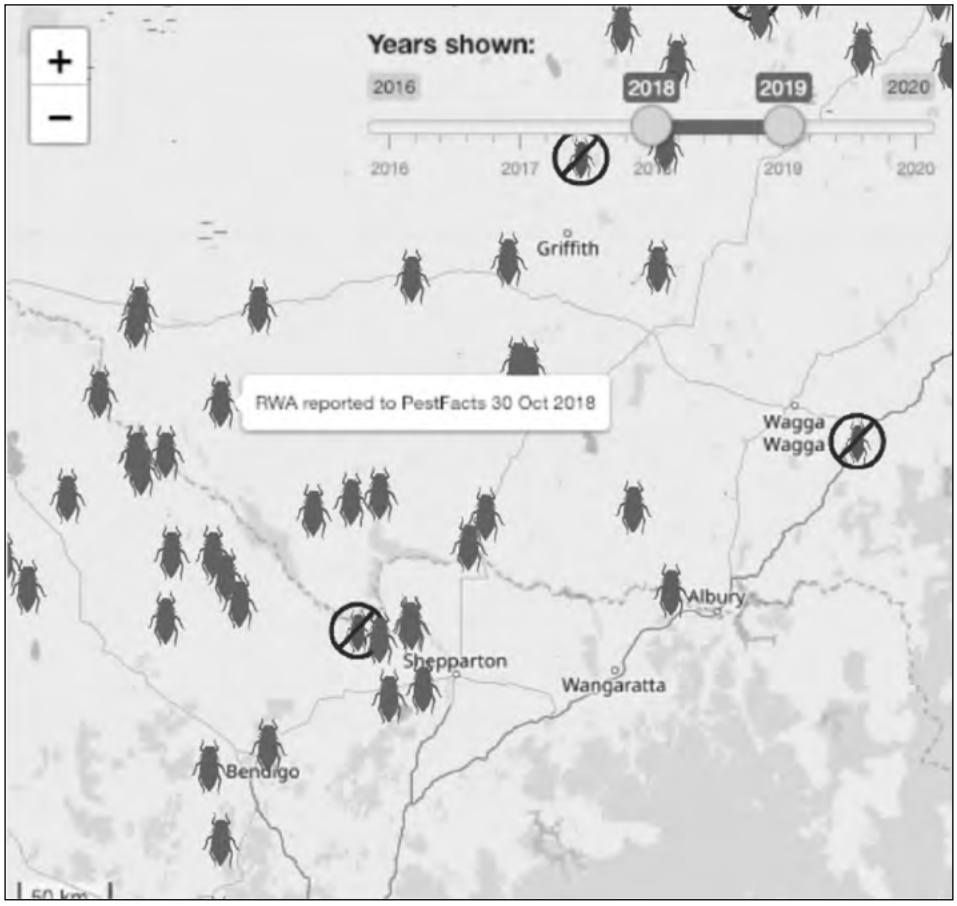

Figure 1. RWA Interactive Map. Detections span 2016-2018 and with data sourced from 2018 green bridge surveillance and adviser reports to PestFacts. Red (light) icon indicates RWA detection in that area. Green (dark) icon with cross out denotes no RWA found during summer surveillance (map developer –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

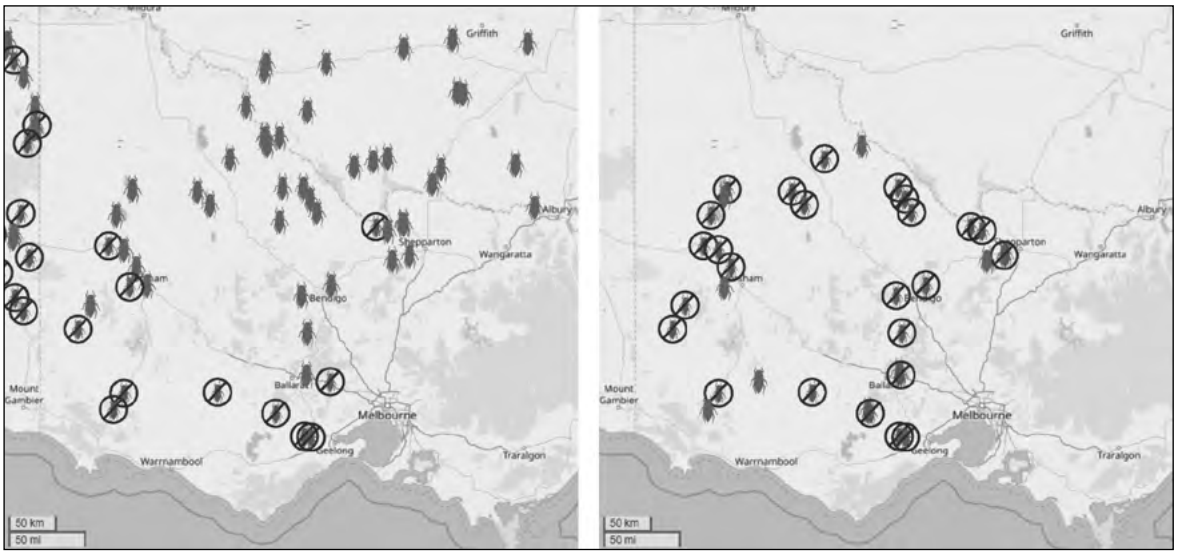

Figure 2. RWA population distribution and abundances across Victoria in the spring (left) compared to summer (right). Presences are represented by red (light) aphids, and absences by green (light) aphids with cross out.

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

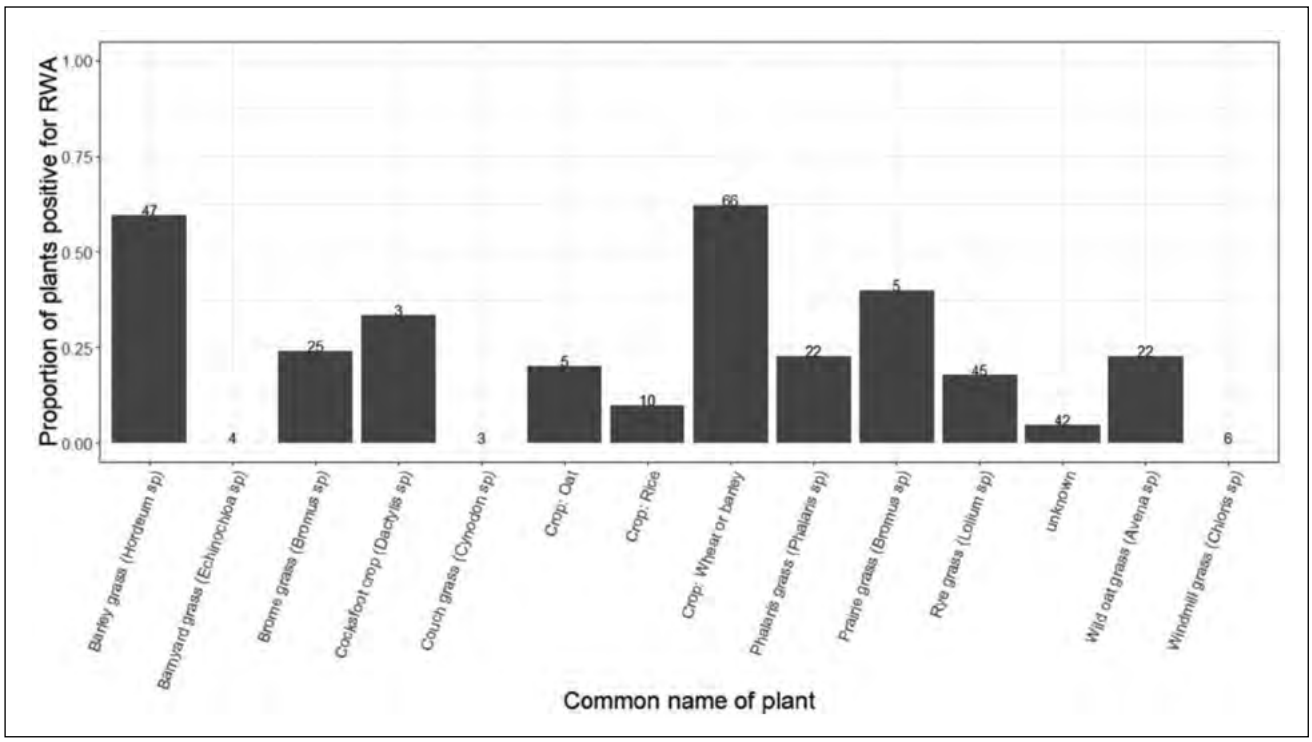

Figure 3. The proportion of individuals within each host plant represented during random plant searches that were positive for RWA (the number of plants searched per species is displayed above the bar). Please note these are preliminary data from Victoria, NSW and Tasmania during the spring sampling – 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$^{\Phi}$) 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.

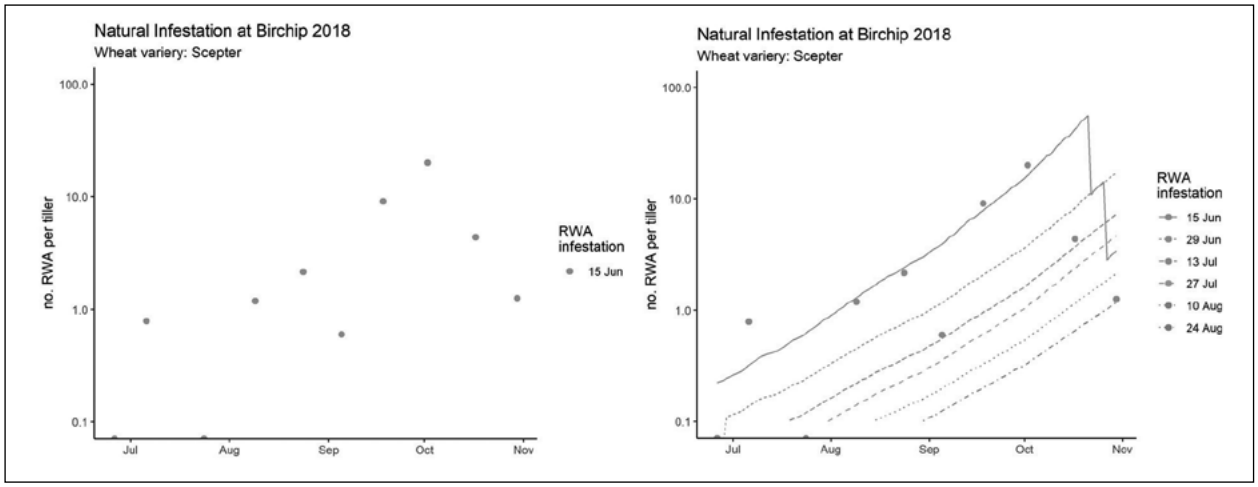

Figure 6. Actual RWA abundance data collected from the 2018 Birchip trial site (left) and RWA population growth as predicted by the new RWA-APSIM module based on variable colonisation dates (right) (module developer: Dr James Maino, **cesar**)

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(ᵇ)) 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

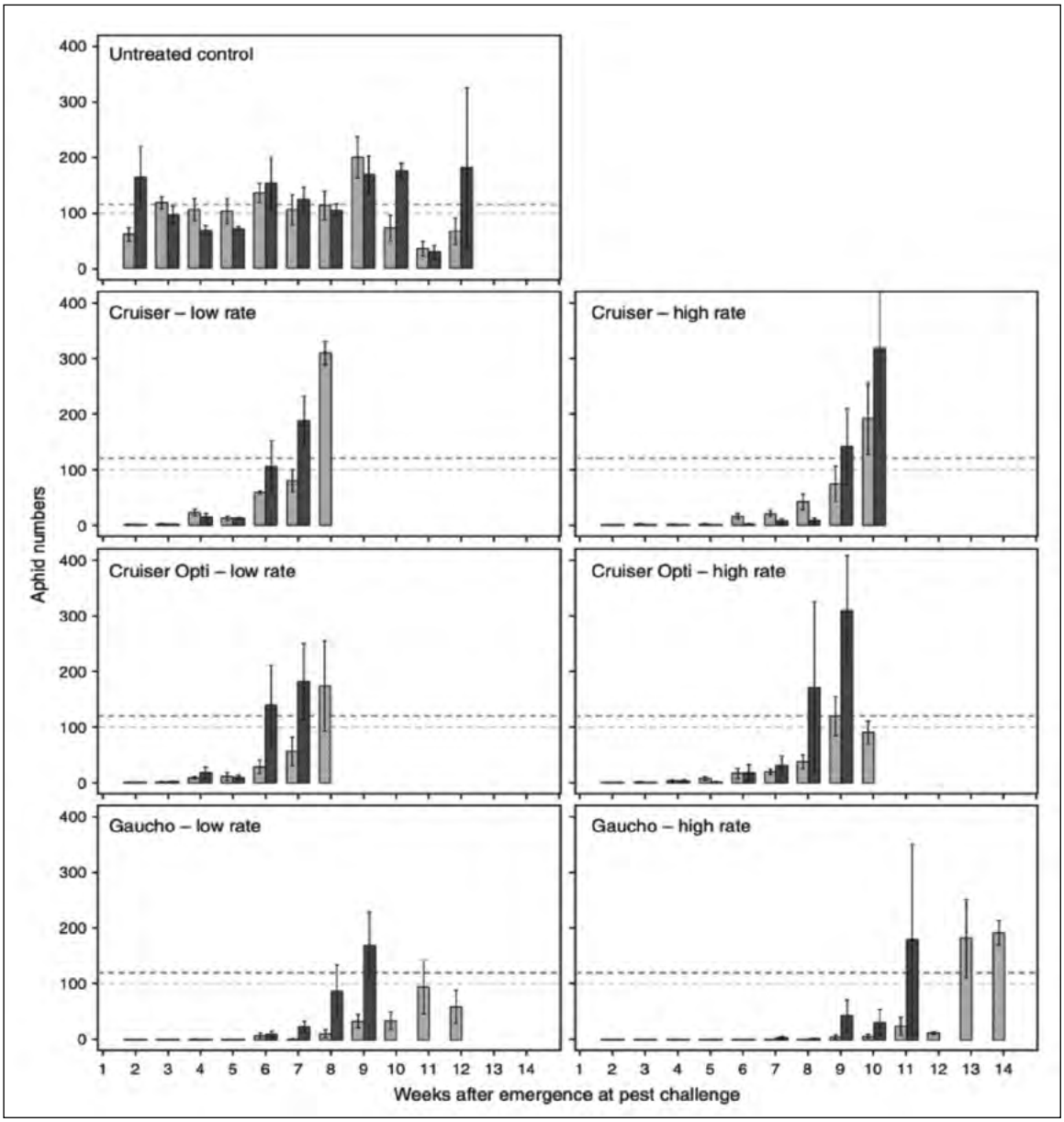

Figure 8. Average numbers of RWA (pale grey bars) and oat aphid (dark grey bars) at weekly intervals after wheat emergence for each chemical treatment. Counts are plotted against the week when aphids were introduced to tubs *(Source: Kirkland et al. 2018)*.

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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Contact details

Jessica Lye
cesar Pty Ltd, 293 Royal Parade, Parkville Vic
03 9349 4723
jlye@cesaraustralia.com
@cesaraustralia

Elia Pirtle
cesar Pty Ltd, 293 Royal Parade, Parkville VIC
03 9349 4723
epirtle@cesaraustralia.com
@cesaraustralia

Maarten van Helden
South Australian Research and Development Institute
08 8429 0642
Maarten.VanHelden@sa.gov.au

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Super high oleic oil - a game changer for the oleochemical industry

Rosemary Richards.

GO Resources.

Keywords

- safflower, super high oleic oil, cropping rotations.

Take home messages

- Safflower varieties have been bred to produce super high oleic oil which provides superior thermal properties and functionality, and therefore, many applications are available for its use including bio-lubricants, bioplastics, cosmetics and pharmaceuticals.

About safflower

Safflower is a winter/spring growing crop. It is:

- Heat and drought tolerant,
- suited to both dryland and irrigation farming systems,
- low input, low maintenance and easy to grow, and;
- crop inputs and machinery requirements similar to cereal /canola production

Rotation benefits include:

- Late autumn/early winter or early spring crop option.
- Potential to double crop out of sorghum.
- Heat and drought tolerant suited to lower rainfall areas.
- Broadleaf crop option – break crop for cereal diseases (e.g. Crown rot, Common root rot, Yellow leaf spot).
- Improve soil structure when used strategically in crop rotations.
- Utilises soil water deep in the soil profile/lowers the water table.
- Sodic soils/salt tolerance

Table 1. Summary of key safflower characteristics.

Sowing time	June to September
Flowering	End October /November - December
Harvest	Matures in 110 – 170 days Mid December – January northern NSW
Yield - dryland	1.0 – 1.5 t/ha
Yield - irrigated	2.0 – 3.0 t/ha
Disease	Alternaria (resistant varieties developed) Phytophthora
Pests	Heliothis /Thrips /Birds
Weeds	Sowing window offers opportunity to control late germinating weeds and/or herbicide resistant winter weeds and to incorporate additional IWM strategies

About GO Resources Pty Ltd

Australian clean technology business whose focus is the sustainable production and supply of renewable and biodegradable bio-based raw materials targeted to the industrial and oleochemical markets.

The game changer – super high oleic oil

Expectations for super high oleic oil:

- To replace fossil fuels for use in industrial and oleochemical markets.

Table 2. Wide adaptation of safflower as reflected by its diverse production localities.

	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Ord River				Plant					Harvest			
Gilbert River				Plant					Harvest			
Burdekin				Plant					Harvest			
Nth NSW						Plant						Harvest
Sth NSW					Plant	Plant						Harvest
Vic. - Wimmera	Harvest						Plant					
Vic – High R/F		Harvest			Plant	Plant		Plant	Plant			
Sth. East S.A.			Harvest					Plant				

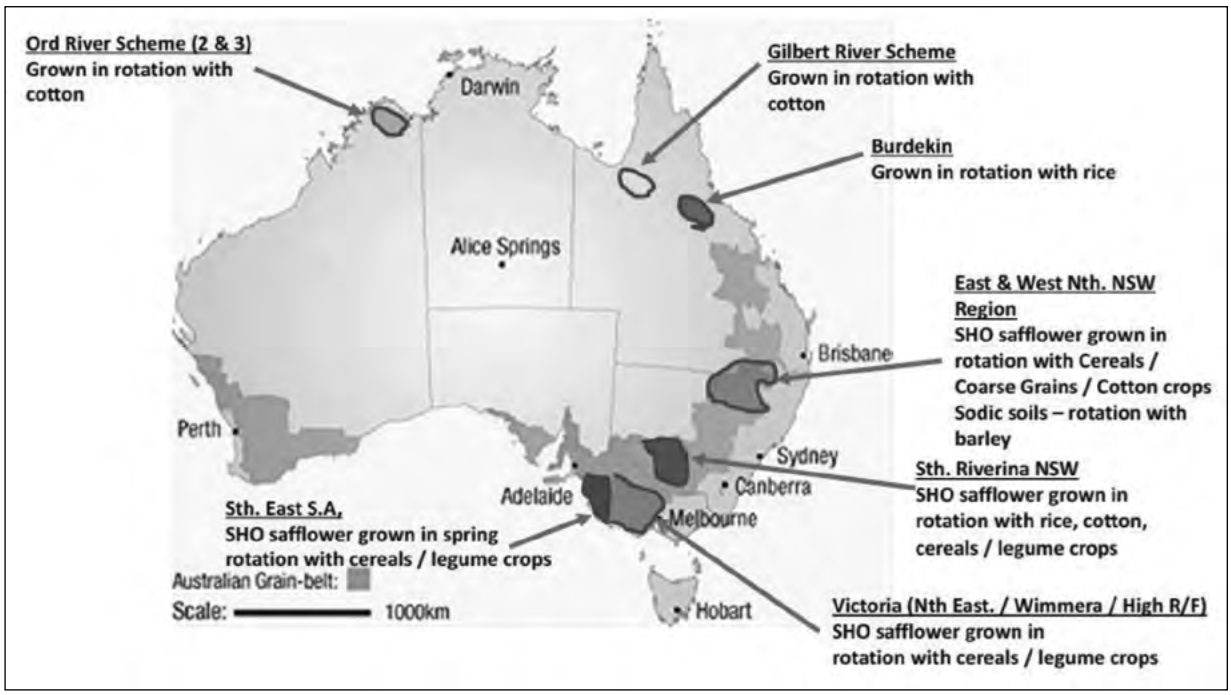

Figure 1. Diagram of safflower production locations demonstrating its adaption to varied environmental conditions.

- To replace palm oil.
- A new 'cash' crop for the agricultural industry.
- Crop Biofactories Initiative - A strategic alliance between CSIRO and GRDC to develop high-value industrial crops for Australian growers.
- The oil contains >92% oleic acid (a monounsaturated fatty acid) with very low levels of saturated and polyunsaturated fatty acids.
- No existing commercially available bio-based oil can reach this super high purity directly from the seed oil.
- The super high oleic oil is a new and unique raw material for the production of bio-lubricants, bioplastics, cosmetics and pharmaceuticals.

'Best in class' of vegetable oils

Not all bio-based oils are equal. Compared to palm oil, high oleic (HO) sunflower oil, HO soybean oil and HO canola oil, SHO safflower oil provides superior thermal properties and functionality which make it ideal for use in industrial applications.

Table 3. Comparison of super high oleic (SHO) oil with other vegetable oils.

Average content	Stearic acid (C18:0)	**Oleic acid (C18:1)**	Linoleic acid (C18:2)	Linolenic acid (C18:3)	Palmitic acid (C16:0)
GO Resources SHO Safflower	**2%**	**93%**	**2%**	**0%**	**3%**
HO Sunflower	3-7%	**Min. 75%**	5-15%	Max 0.2%	3.5-8%
HO Soybean	4%	**>75%**	<10%	<3%	
HO Canola	7%	**70%**	20%	3%	
Canola	2%	**62%**	20%	8%	4%
Palm	5%	**39%**	11%	0.2%	43%
Soybean	4%	**21%**	56%	7%	10%
Sunflower	5%	**15%**	71%	0.5%	6%
Safflower	3%	**15%**	73%	0%	6%

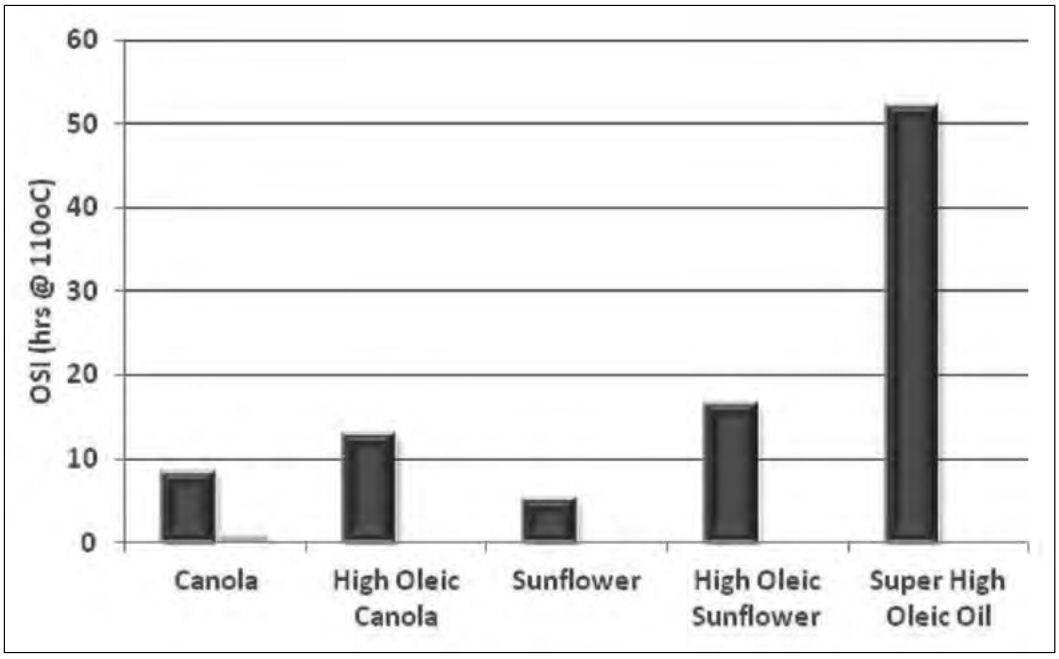

Figure 2. Performance as measured by thermal stability.

Demand for bio-based oils is increasing

Global lubricants market expected to reach US$166.9 billion by 2021.

'The adoption of bio-based lubricants to reduce harmful environmental effects is the current trend in the lubricants market and is boosting the overall growth of the market (Lubricants Market. MarketsandMarkets Report 2016)'.

Some of the factors that are driving increased demand include global warming, climate change, population growth, dwindling fossil resources and biodiversity (Figure 3).

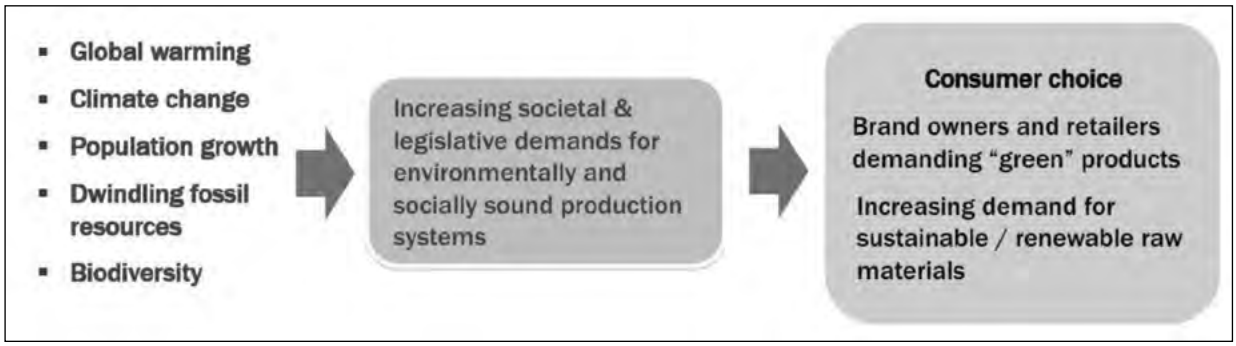

Figure 3. Factors driving increased demand of bio-based oils.

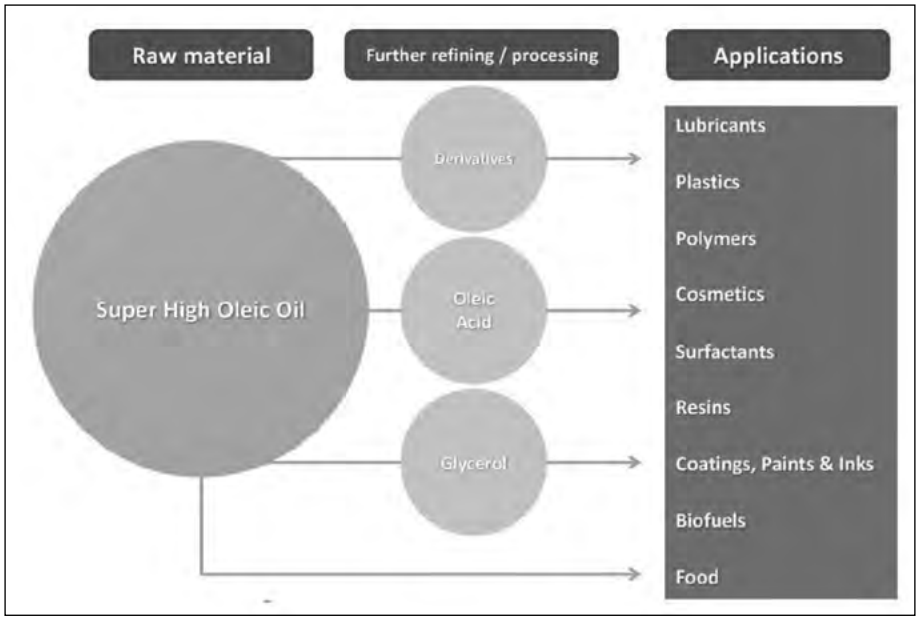

Figure 4. Example of applications for super high oleic oil.

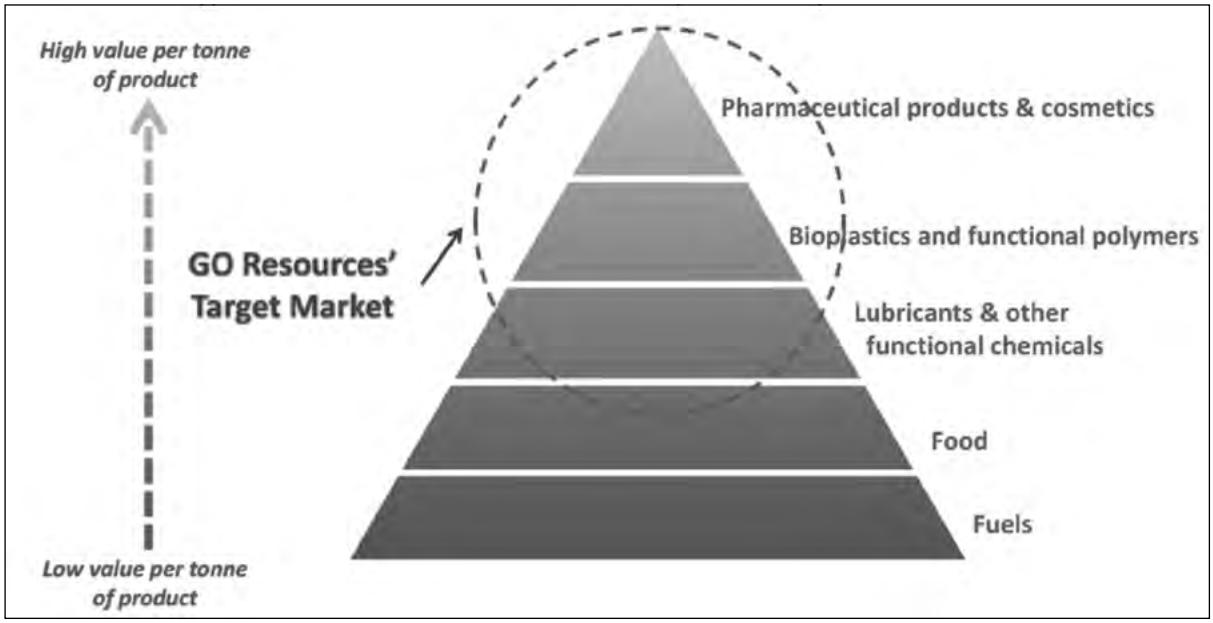

Figure 5. GO Resources market target plan.

There are many applications/many markets for super high oleic oil. Some examples are provided in Figure 4.

GO Resources' focus is on the industrial market

GO Resources will target the higher value/higher margin industrials markets where the superior functionality and quality of its super high oleic oil are valued and in demand by customers. GO Resources will bypass the low value end markets where price is a key driver of demand.

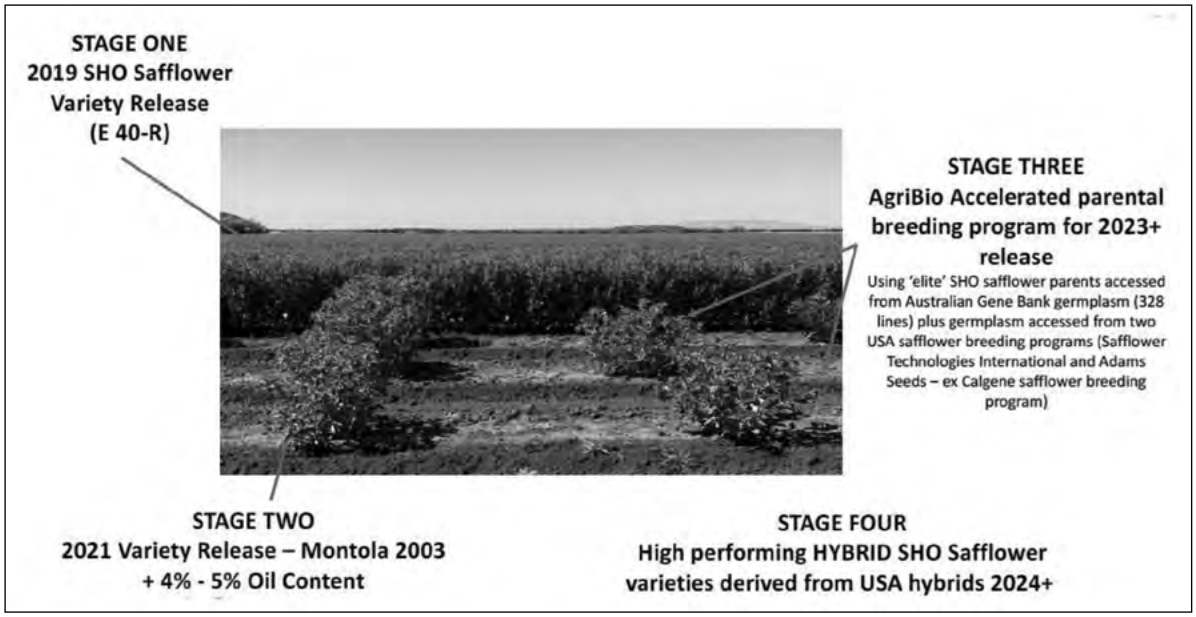

Figure 6. Diagrammatic representation of SHO safflower plant breeding strategy.

SHO safflower plant breeding strategy

Accessing diversity– 300+ safflower lines

Focused on four-value adding targets:

1. Increase grain yield reliability and oil content through the development of regionally adapted SHO safflower varieties:
   - Innovative use of diverse germplasm (accelerated breeding).
   - Reduced time to flowering on-set (i.e. short seasoned cultivars compared to canola).
   - Development of hybrid SHO safflower varieties.
   - Faming system optimisation.
2. Increase the harvest index (HI) and water use efficiency (WUE).
3. Increase the level of resistance to Alternaria (*Alternaria carthamii*), which may become more prevalent if safflower production increases due to additional sources of inoculum.
4. Add value to seed meal and trash.

Agronomy and farming systems strategy (2016 – 2019)

Objective: Develop SHO Safflower Crop Management Package (CMP)

Agronomy research:

- **Herbicide screen:** Establish and manage a large plot non-replicated herbicide screen of previously registered herbicides (pre-emergent, post-plant pre-emergent and post-emergent) for the purpose of assessing weed control efficacy and variety tolerance (2017 - 2018).
- **Seeding rate:** Assess impact of seeding rate on crop emergence and yield (Completed 2 016 - 2017).
- **Time to seeding:** Assess impact of time of sowing on crop emergence and yield (2016 – 2019).
- **Seed treatment:** Assess crop safety, disease control and impact on yield (Completed 2016).
- **Plant nutrition:** Assess impact of various fertilizer programs on crop mergence and yield. (2018/19).
- **Farming systems:** Identify fit in farming systems and quantify rotation benefits.

Time to seeding and seeding rate

Table 4. Recommended optimum (☺) and extended (▷or ◁) sowing window for safflower.

	May				June				July				August				September				October			
Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Northern NSW			◁	◁	☺	☺	☺	☺◁	☺◁	☺◁	☺	▷	▷											
Central NSW					◁	◁	☺	☺◁	☺◁	☺◁	☺	▷	▷											
Southern NSW								◁	◁	☺◁	☺	☺	☺	☺	▷	▷								
Victoria								◁	◁	☺	☺	☺	☺	☺	▷	▷	▷	▷	▷	▷				
South Australia								◁	◁	☺	☺	☺	☺	☺	▷	▷	▷	▷	▷	▷	▷	▷		

Table 5. Seeding rates of safflower for different regions and different climatic conditions.

	Favourable conditions	Drier conditions	Irrigated crops
Northern & central NSW	20-25 plants/m^2	15 plants/m^2	40-50 plants/m^2 (25-31kg/ha)
	(12-15/kg/ha)	(9kg/ha)	
Southern NSW	30-35 plants/m^2	25 plants/m^2	
	(18-22kg/ha)	(15kg/ha)	
Victoria & SA	30-40 plants/m^2	20-30 plants/m^2	
	(18-24kg/ha)	(12-18kg/ha)	

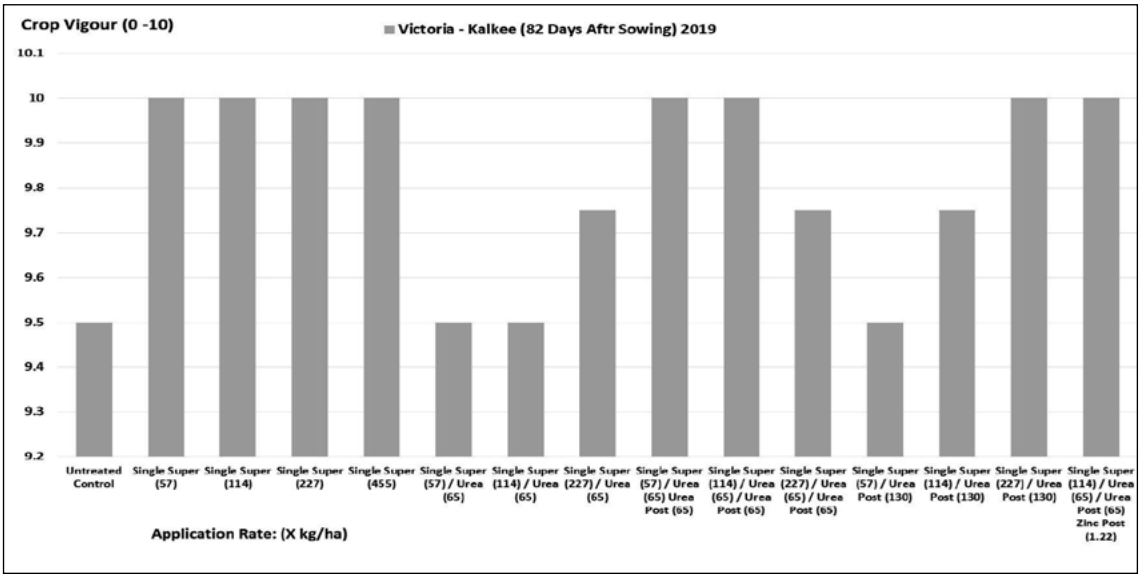

Figure 7. Safflower response to different plant nutrition treatments trialled at Kalkee, Victoria 2019.

Plant nutrition

Safflower response to different plant nutrition treatments (Figure 7).

Herbicides for use in safflower

Herbicide tolerance screens 2017 and 2018 - Horsham/Narrabri/Streatham. Details of trial are listed in Table 7.

Table 6. Nutrient removal by safflower (kg/t seed) compared with wheat.

Nutrient	Safflower	Wheat
Nitrogen	25	23
Phosphorus	4.3	3
Sulphur	4	2

Table 7. List of herbicides tested for use in safflower.

Registered	Minor Use Permit in Safflower - Status		
	Granted	Applied for in 2018	Applied for in 2019
Trifluralin	Ally	Sertin	Propyzamide
Avadex Extra		Dual Gold	Sakura
Diclofopmethyl			Boxer Gold
Propaquizafop			
Pendimethalin			

First commercial planting – 2019

Small scale commercial development which aims to:

- Evaluation of varieties.
- Continue to build knowledge of crop agronomy and role in farming systems.
- Generate commercial quantities of oil for customers.

Production areas:

- South – dryland / irrigated.
- North - irrigation (cotton)/dryland/sodic soils.

Grower requirements/logistics

- No Technology User Agreement including:
  - o Crop management plan.
  - o Good agricultural/management practices.
  - o Records.
  - o No farmer saved seed.
  - o Logistics.

Pricing

- Deliver competitive return per hectare

Crop management plan - key requirements

- Advise GO Resources if have or intend to plant conventional safflower.
- Notify neighbours of their intention to grow the genetically modified (GM) crop.
- Ensure good crop agronomy in a sustainable manner.
- Implement on-farm management practices to:
  - o Minimise the risk of outcrossing.
  - o Control GM high oleic safflower volunteers.
  - o Prevent the inadvertent mixing of plant material during planting, flowering, harvest, and storage.
  - o Manage machinery and equipment hygiene pre- and post-use in SHO safflower.
- Maintain a complete set of paddock management records = **good agricultural practice**

Grower case study

- Sow the crop early rather than later in spring as this is ideal if growing it as a cash crop.:
  - o 'Sowing it early gives it a chance to establish well and you can provide the right nutrition in order to make good yields.'
- 'It can also be grown as a strategic crop to soak up moisture or help tidy up a weed problem, or as an opportunity crop where things might go wrong with your normal winter program, such as an establishment failure with cereals.'
- There is tremendous opportunity for the crop, with CSIRO issuing a licence to GO Resources to commercialise genetically modified safflower technology to produce super-high oleic safflower oil for the high-value industrial oil market:
  - o 'For me, that could be the future of safflower – specialised oil production with varieties designed for a slightly drier climate.'
- 'I would only be prepared to grow safflower on a yearly basis if there was a stable market for it' - The industry is starting to look that way but we have seen plenty of players come and go over the years. 'We need a stable player in the market to ensure growers get a good price and are paid for what they produce.'

Contact details

Rosemary Richards
rosemary@bowmanrichards.com

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Sustaining our herbicide options into the future

Christopher Preston, David Brunton, Peter Boutsalis, Tijana Petrovic, Mahima Krishnan and Gurjeet Gill.

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

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

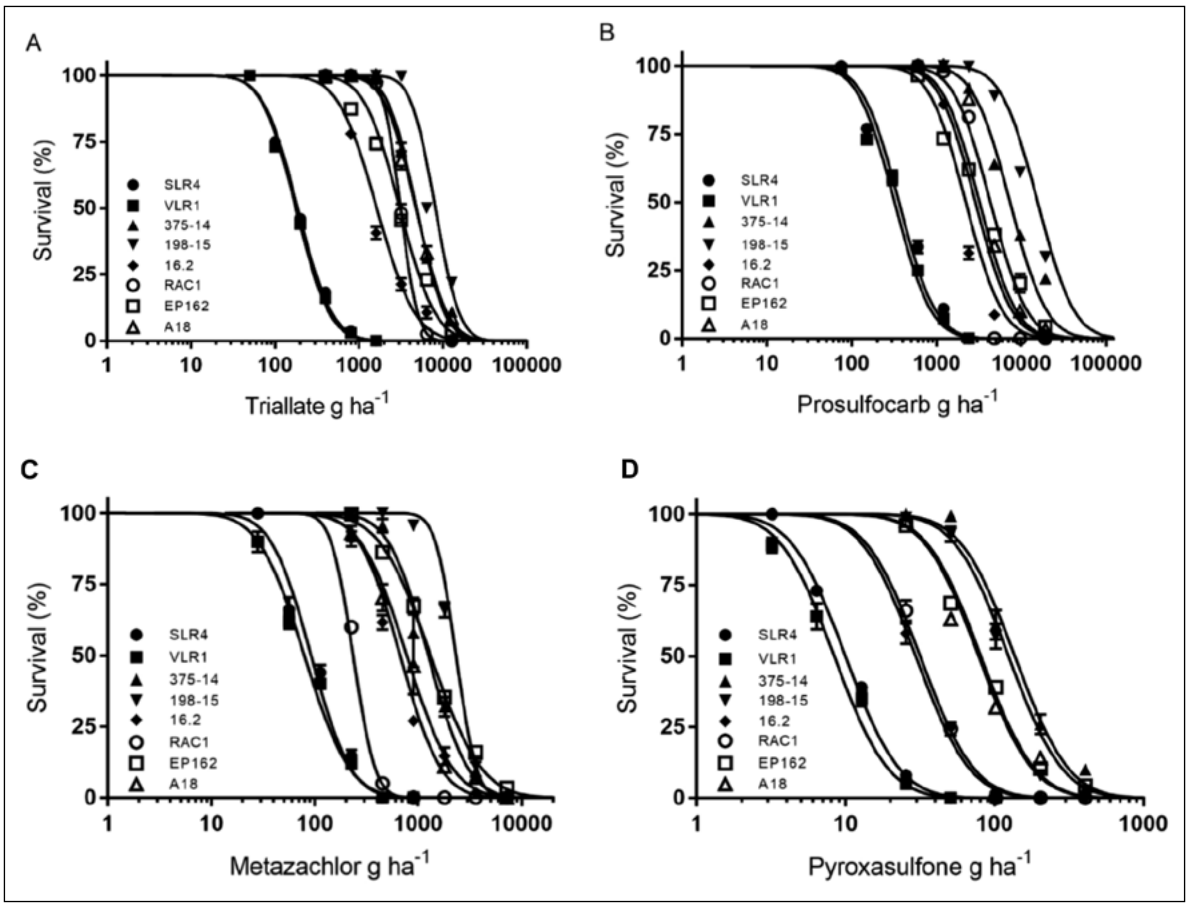

Figure 1. Response of two susceptible (SLR4 and VLR1) and six resistant annual ryegrass populations to various pre-emergent herbicides. (A) Triallate, (B) Prosulfocarb, (C) Metazachlor and (D) Pyroxasulfone.

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/m²)		Spike density (spikes/m²)	
		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.

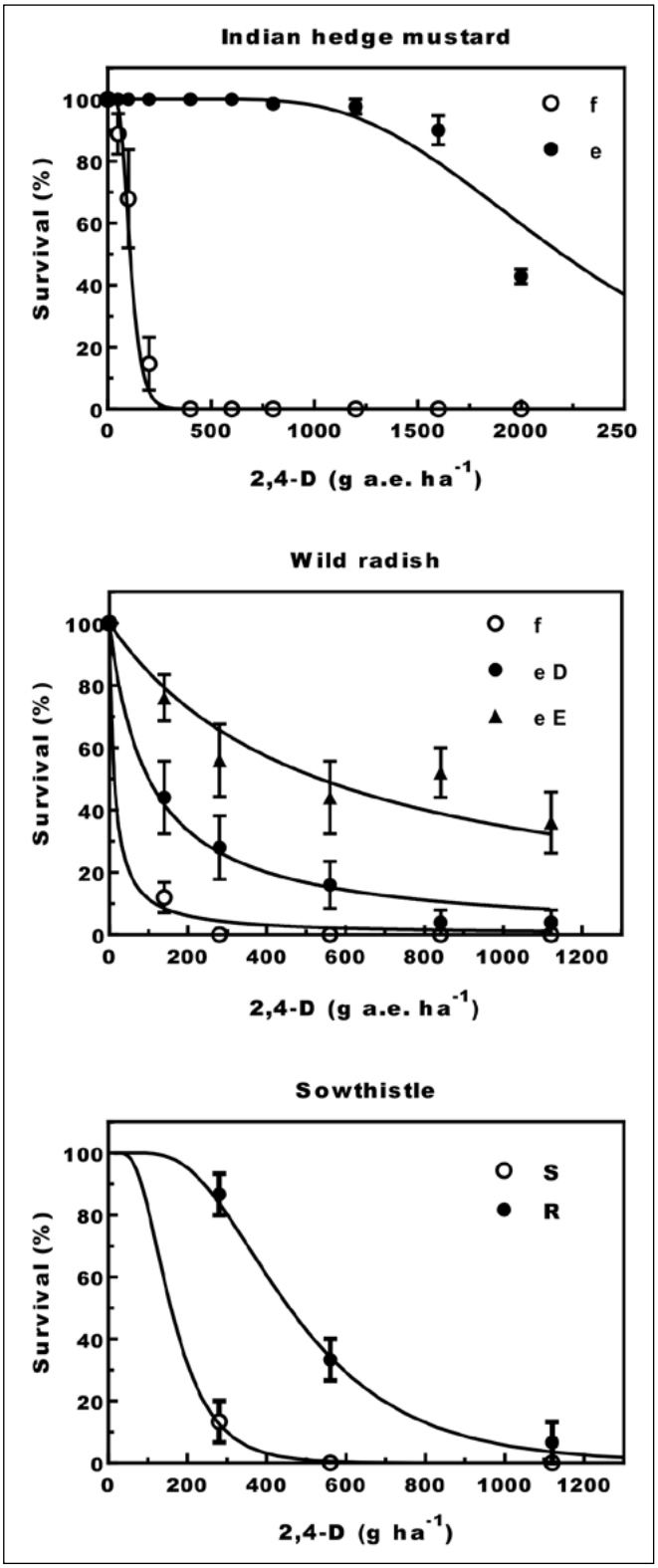

Figure 2. Response to 2,4-D of susceptible (S) and resistant (R) populations of Indian hedge mustard with high level resistance to 2,4-D (top), wild radish with high level and low-level resistance (middle), and sowthistle with low level resistance (bottom).

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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Contact details

Christopher Preston
School of Agriculture, Food & Wine,
University of Adelaide
0488 404 120
christopher.preston@adelaide.edu.au

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Utilising precision agriculture for better agronomic decisions

Quenten Knight.

Agronomy Focus.

Keywords

- precision agriculture, ground truthing, satellite imagery, soil amelioriation.

Take home messages

- Precision agriculture does not need to be complicated — keep it simple and use appropriate data layers to guide your agronomic decisions.
- Establish a good relationship with third party data processors — your strength is agronomy, not geographical information systems (GIS) and dealing with raw data — focus on practical agronomic solutions.
- Limit the amount of precision agriculture software you use — keep it simple.
- Precision agriculture is not always precise — do not get bogged down in too much detail.
- It is essential to ground truth data — precision agriculture cannot be implemented entirely with only desktop analysis — it requires boots on the ground to validate and avoid failure.

Background

Having been involved with precision agriculture for nearly 20 years, I have seen it continually evolve, however its adoption is still much lower than one would expect for many reasons.

In this presentation, I would like to demonstrate how I use various precision agriculture data sources to guide better agronomic decisions with my clients.

I am a consulting agronomist first and foremost and by no means a precision agriculture or GIS specialist, however I have developed very good third-party relationships for the provision of software, data processing and machinery implementation. These relationships allow my clients and I to access the tools and data to provide practical, profitable agronomic solutions from a multitude of data sources.

The data sources I use on a daily basis are:

- Satellite imagery (Satamap).
- Google Earth Pro.
- Yield data.
- EM38.
- Gamma radiometrics.
- Digital elevation models.
- Georeferenced soil test data.

Soil amelioration is the major focus in using precision agriculture for better agronomic solutions. For example:

- Variable rate gypsum.
- Variable rate lime.
- Deep ripping zones.

- Clay spreading and clay delving zones.
- Variable rate potassium.
- Surface water management (drainage).

Crop scouting and ground truthing are other important aspects of precision agriculture and the ability to bring these data into the paddock on mobile devices with GPS navigation. Satellite imagery, yield data and soil test data are incredibly valuable for this purpose.

Conclusion

Utilising precision agriculture is a natural progression for making better agronomic decisions. The amount of data available is increasing and largely the cost is decreasing. Our challenge as agronomists and advisers is not to become GIS experts, but rather play to our strengths and use processed data in easy to use software programs to deliver practical, profitable agronomic solutions to our clients, coupled with thorough ground truthing and grower knowledge.

Contact details

Quenten Knight
Agronomy Focus
9 Currong Street, Esperance WA 6450
0427 720 004
quenten@agronomyfocus.com.au
@QuentenKnight

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Phosphorus and phosphorus stratification

Graeme Sandral[1], Ehsan Tavakkoli[1,2], Roger Armstrong[3], Maryam Barati[1], Russell Pumpa[1], David Lester[4], Sean Mason[5] Rob Norton[6] and Mike Bell[7].

[1]New South Wales Department of Primary Industries, Wagga Wagga Agricultural Institute, Wagga Wagga, NSW; [2]Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga, NSW; [3]Agriculture Victoria Research, Department of Economic Development, Jobs, Transport and Resources, Horsham, VIC; [4]Department of Agriculture and Fisheries, Toowoomba, QLD, 4350; [5]Agronomy Solutions, Adelaide, SA; [6]International Plant Nutrition Institute; [7]School of Agriculture and Food Sciences, University of Queensland, Gatton QLD.

GRDC project codes: UQ00082, UQ00063, 9175108

Keywords

- phosphorus, stratification, deep phosphorus, critical soil phosphorus.

Take home messages

- Phosphorus (P) stratification can impact on the critical P requirements of grain crops. In northern NSW and Queensland placing P at 20cm below the soil surface resulted in significant grain yield responses (~13% increase in wheat) (Bell et al., 2016). These findings are worth further consideration in other regions of the Australian grain belt particularly where soil P values in the 10 - 30cm layer are very low (Colwell P < 5mg/kg soil) and surface soils (> 10cm) experience extended periods of low soil moisture that limits P uptake by roots.
- Testing the extent of P stratification on-farm (surface 0–10cm and subsoil 10–30cm) can assist in P budgeting as the lack of subsoil P can be offset by higher concentrations of surface P in most soils provided soil moisture conditions are adequate for P uptake.
- The extent to which P stratification impacts grain yield is influenced by; (i) the Colwell P values for 0–10cm and 10–30cm layers, (ii) the probability of poor crop P uptake due to low soil moisture at 0–10cm, and (iii) the crop type. The current understanding of these components for southern cropping systems is inadequate to provide any precise recommendations.

Background

In the grains-growing areas of south-east Australia, the bulk of plant nutrients in labile form usually occurs in the topsoil, with much lower amounts present in the subsoil. It is becoming increasingly evident that in environments where the nutrient-rich topsoil is prone to drying, nutrient uptake by crops is likely to be adversely affected despite the availability of water in the subsoil. This is likely due to impeded root growth in the dry topsoil or reduced diffusion of immobile nutrients to plant roots or both. Despite the numerous studies on vertical nutrient stratification, there is still limited information on the effectiveness of subsoil nutrition on yield productivity and also the efficiency of nutrient use. This paper reviews P cycling and budgeting in grain production systems with an emphasis on P stratification and the resulting consequences it has on crop P demand.

Phosphorus cycling

Soils of Australia in their native state are deficient in P with some exceptions through northern NSW and Queensland (e.g. Vertisols) which have only been depleted in more recent times through cropping. Consequently, advisers aim to ensure P fertiliser has been added in amounts that are approximately equivalent to the amount of P exported in grain plus other losses such as unrecovered P in stubble and soil. Phosphorus

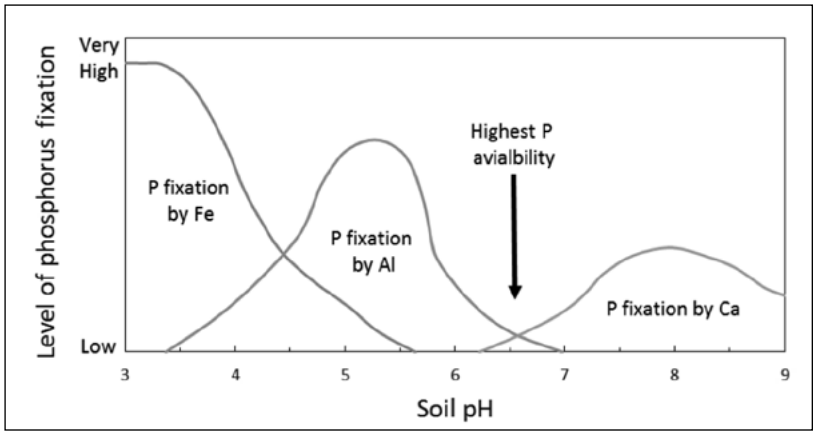

Figure 1. The effect of soil pH on phosphorus availability.

fertiliser that is added to the soil primarily goes into the 'soil reserve' where the P binds to soil, a process referred to as P sorption or fixation. Fixation occurs when P reacts with other minerals to form insoluble compounds and becomes unavailable to crops. An important factor controlling P fixation is soil pH as shown in Figure 1. There are three peaks of P fixation. The two highest peaks occur in the acid range of pH 4 and 5.5, where P precipitates with iron (Fe) and aluminium (Al). It is very difficult to supply sufficient P for crop needs when P solubility is being controlled by Fe and Al. The third peak occurs in alkaline soils around pH 8.0 when P is precipitated primarily by calcium (Ca). This fixation is relatively weak, and it is generally more economical to apply more P fertiliser than adding amendments to acidify the soil (Figure 1).

Plant available P in soil solution is predominantly present as dihydrogen phosphate ($H_2PO_4^-$) or as hydrogen phosphate (HPO_4^{-2}) in more neutral and alkaline soils. Various estimates indicate approximately 70–80% of P fertiliser added in the crop year becomes part of the soil reserve (Price 2006). The soil P reserve can be described further however for the purpose of this paper it's important to simply acknowledge that within the soil P reserve there is different bonding of P that influences the short- and long-term plant available P (Figure 2). For example the soil reserve is made up of (1) sorbed P (P held on the surface of fine clay particles), (2) secondary P minerals (freshly bounded Fe, Al and manganese (Mn) phosphates [acid soils] and Ca and magnesium (Mg) phosphates [alkaline soils]) and (3) primary P minerals (age and crystallised Fe, Al, Mn,

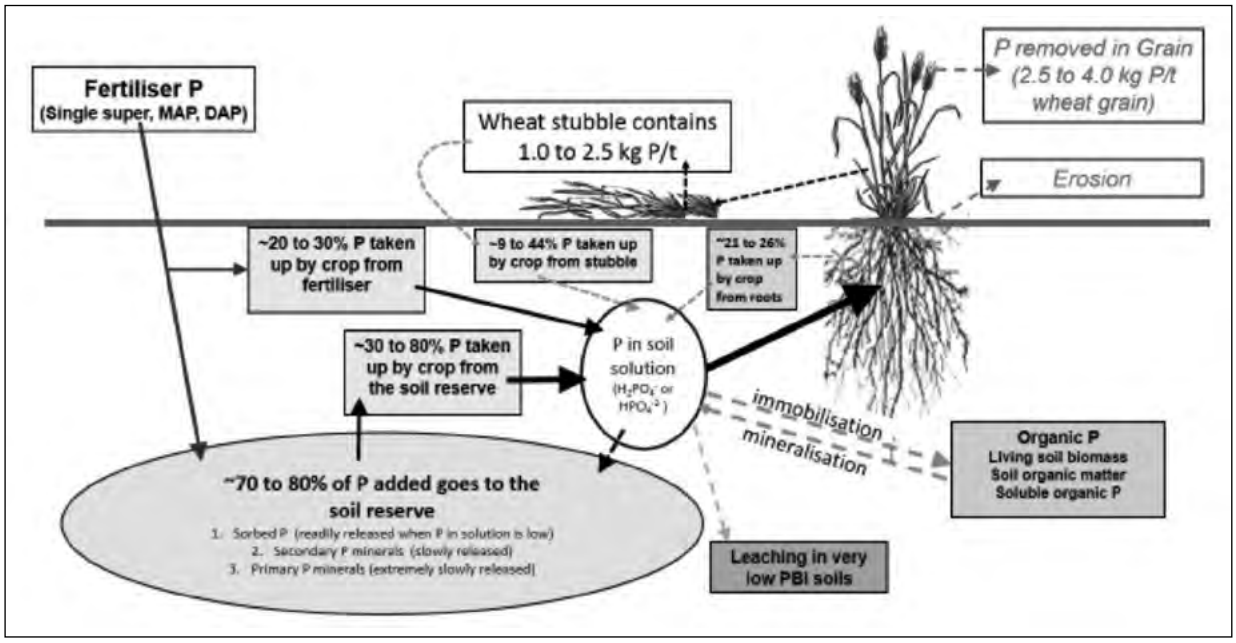

Figure 2. Soil phosphorus cycling in winter cropping systems.

Table 1. Colwell P (mg /kg soil) values for 90 and 95% of maximum grain yield for various crop and soil type combinations extracted from the BFDC database.

Species	Soil	90%	95%	Location	Species	Soil	90%	95%	Locations
Feed barley	All soils	20	25	National	Wheat	Calcarosol calcic	24	29	SA, Vic, WA
Field Pea	All soils	27	34	National	Wheat	Dermosol	27	35	NSW
Narrow leaf Lupin	All soils	22	26	National	Wheat	Kandosol red	24	30	NSW
Canola	All soils	20	25	National	Wheat	Tenosol	16	20	WA, SA, Tas
Wheat	All soils	24	32	National	Wheat	Sodosol brown	27	32	NSW, Vic, SA
Wheat	Chromosol red	30	38	NSW, QLD, Vic	Wheat	Vertosol black	25	33	NSW, QLD
Wheat	Chromosol brown	17	19	WA, SA	Wheat	Vertosol brown	24	32	NSW, SA
Wheat	Chromosol grey	18	21	WA	Wheat	Vertosol grey	18	21	Vic, NSW, QLD

n.b. Estimated Colwell P critical values for chickpea, faba bean, lentil and broadleaf lupins are not available from the BFDC database due to no or insufficient data. Similarly, not enough data exists for feed barley, field pea, canola and narrow leaf lupin to provide specific soil type estimates of Colwell P critical values. Where states are nominated under 'Location' this refers to the state where most of the experiments (not necessarily all) were conducted.

Ca and Mg phosphates). The soil P reserve (Figure 2) in P adequate soils (Table 1) provides the largest percentage of crop nutrient requirements in any one year which is estimated at approximately 30–80% (Price 2006, Mcbeath et al 2012). Phosphorus fertiliser can directly provide approximately 20–30% of crop requirements (Price 2006) with available P from stubble making up approximately 9–44% (Noack et al 2012) and roots approximately 21–26% (Foyjunnessa et al 2016).

Phosphorus Buffering Index (PBI)

The PBI test measures the P sorption of the soil. This is the process by which soluble P becomes adsorbed to clay minerals and/or precipitated in soil and it determines the partitioning of P between the solid and solution phases of the soil. A high PBI therefore results in a greater tendency for P sorption compared with a low PBI. Consequently, P sorption capacity of soil influences the availability of P to plants and can be useful for determining Colwell P critical values. Figure 3 shows the relationship between PBI and Colwell P critical for wheat. Usually large changes in PBI values are required to change crop critical P values. Examples of this are provided in Table 2 calculated from Moody (2007). In addition, estimates are also provided from Bell et al (2013) which are quantified from a large data set in the Better Fertiliser Decisions Cropping database (BFDC; http://www.bfdc.com.au/interrogator/frontpage.vm).

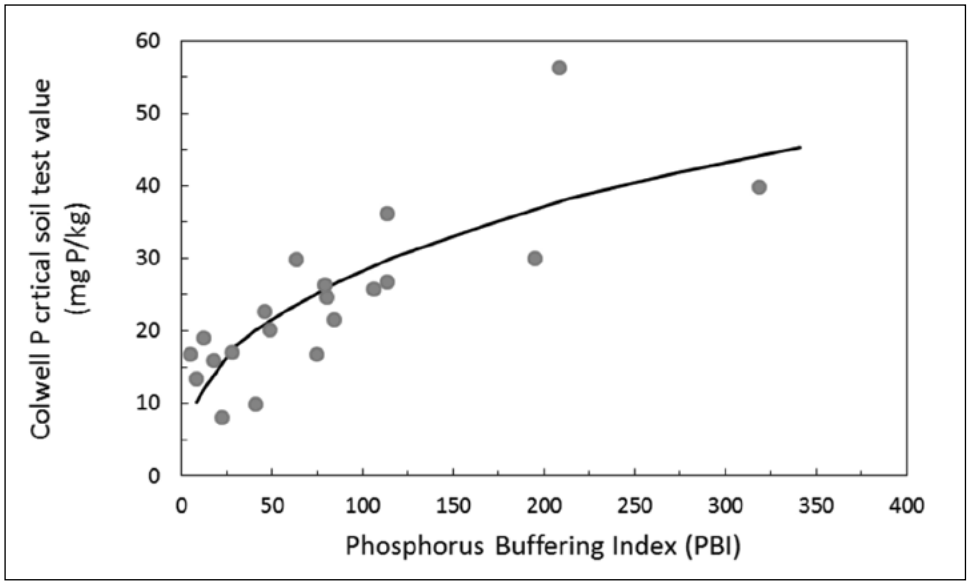

Figure 3. Effect of phosphorus buffering index on critical Colwell-P (0–0.10 m) required for 90% maximum grain yield of wheat. Critical Colwell P = 4.6 x $PBI^{0.393}$ (Moody 2007).

Table 2. Estimated 90% critical Colwell P soil values (mg P/kg soil) for wheat grown in soils with differing PBI (Moody 2007 and Bell et al 2013).

P Buffering	PBI	Estimated 90% critical P	P Buffering	PBI	Estimated 90% critical P
Extremely low	10	11.4	Low	80	25.7
Very very low	20	14.9	Moderate	180	35.4
Very low	40	19.6	High	350	46.0

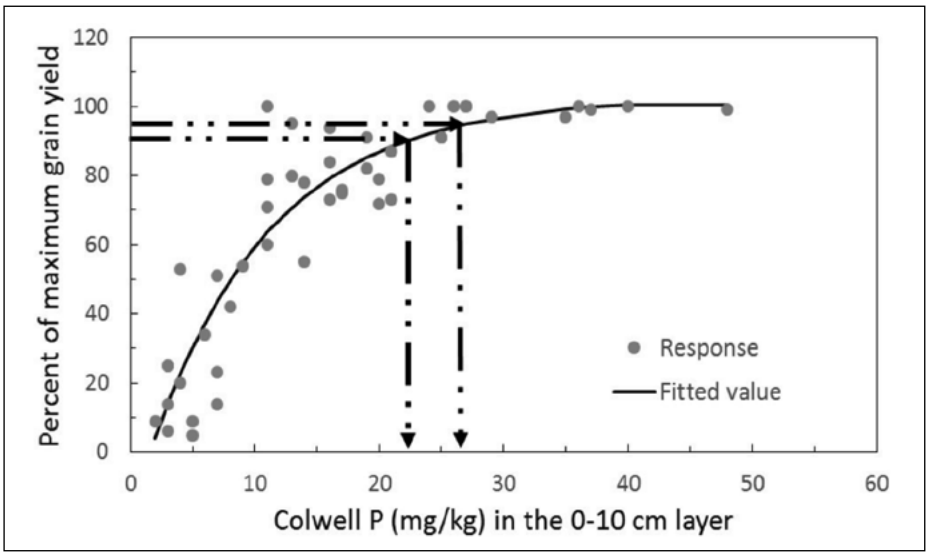

Figure 4. Grain yield response of canola across a range of soil types. Data taken from the BFDC.

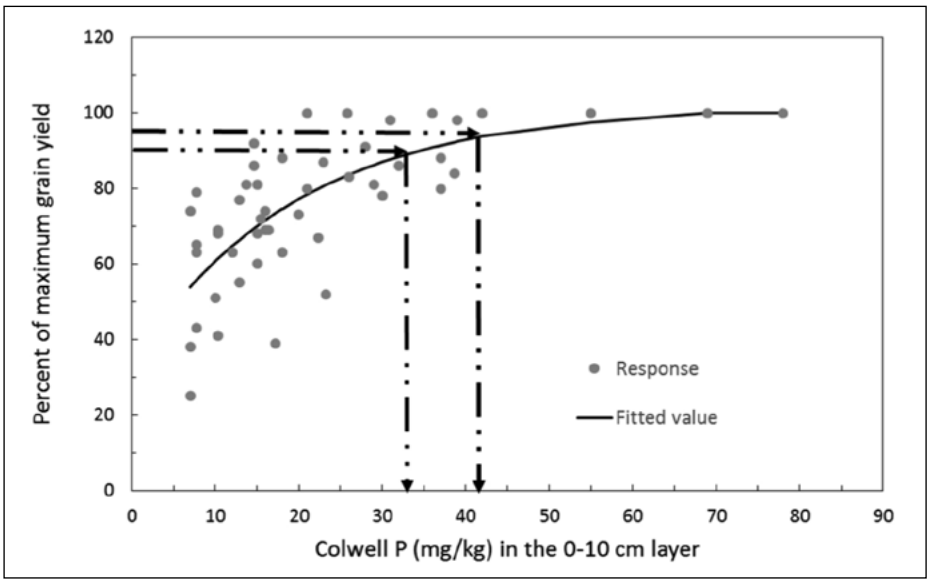

Figure 5. Grain yield response of wheat on Red Chomosol soils of NSW. Data taken from the BFDC.

Critical Colwell P soil test values

The critical soil test range is the soil P status, often measured as Colwell P, that will ensure 90-95% maximum crop production. This range may differ for different crop species and soil types that have a different PBI value or the level of soil moisture and degree of surface P stratification. The latter two factors are likely explanations for differences in critical values between years where species and PBI are fixed. Additional factors may include the type of equations used, as small changes in slope near the asymptote (e.g. maximum yield) can make large changes to soil critical values on the x axis.

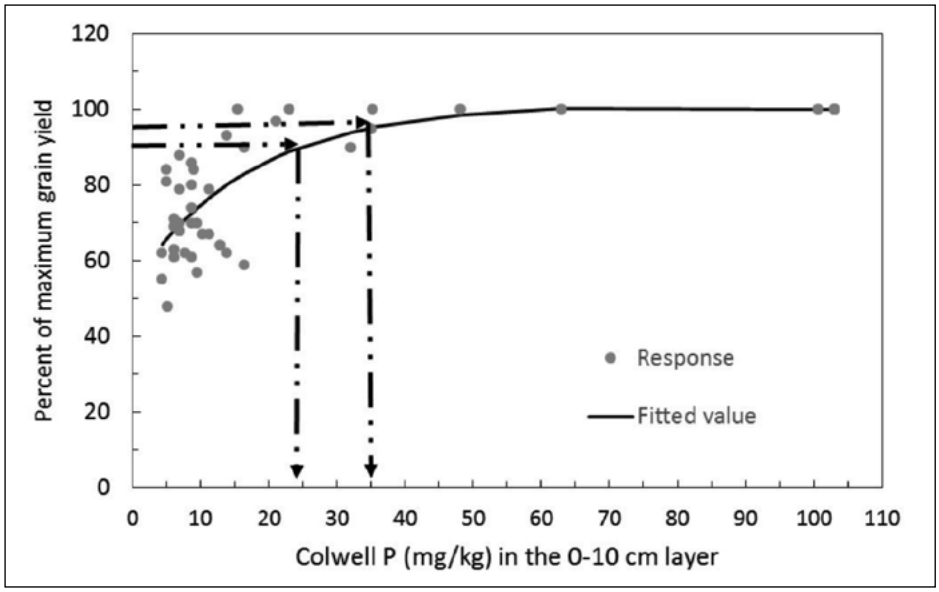

Figure 6. Grain yield response of wheat on Vertisol soils of NSW. Data taken from the BFDC.

An analysis of data from the BFDC database using Mitscherlich equations indicates 90 and 95% critical values for canola across soil types are estimated at 22 and 27mg P/kg soil using Colwell P at 0-10cm soil depth (Figure 4). The same comparisons for wheat on Red Chromosol indicates a Colwell P critical value of 35 and 42mg P/kg soil (Figure 5) and for wheat on Vertisol a Colwell P critical value of 25 and 35mg P/Kg soil (Figure 6). Using the Mitscherlich equation provides a slightly higher estimate of critical value than those estimated directly from the BFDC database (Table 1) that use quadratic equations to estimate critical P, however there is sound general agreement between the values calculated with different equations.

The sampling depth of P has a significant effect on its critical value. For example, data from the BFDC national wheat data set showed that across soil types, sampling at 0-5cm, 0–10cm and 0–15cm resulted in Colwell P critical value variation from 31 and 36, 24 and 32 and 15 and 20mg/kg for 90% and 95% of maximum grain yield, respectively.

Industry standard practice is to sample at 0–10cm however, knowledge of P concentration in the 10–30cm layer can be very informative in P budgeting. The differences in critical Colwell P for sampling depth may have resulted from (i) differing soil P status at deeper un-sampled depths, (ii) dilution and P stratification effects with greater soil sampling depth and (iii) different crop recovery of P from different depths of soil. The point raised here which will be examined in more detail later in this paper, is that P status at un-sampled depths can contribute to a reduction in wheat critical values as shown above.

Phosphorus budgeting

Phosphorus is exported in grain and recycled in stubble and roots provided the stubble component is retained. Phosphorus in wheat grain ranges from 2.7–3.9kg P/t while in canola seed the range is 3.9–7.8kg P/t (Table 3). Phosphorus in stubble for wheat and canola ranges from 1.0-3.0kg P/t and 2.0–4.0kg P/ha, respectively. Root P concentrations in wheat and canola ranges from 1.5–3.0 and 2.0–2.5kg P/t, respectively.

Approximations of P used for P budgeting in wheat include grain P export (2.7–3.6kg P/t) plus stubble P not accessible to the following crop (0.4–0.8kg P/t) plus soil losses (0.3–0.7kg P/t grain

Table 3. Concentration of phosphorus (kg/t) for wheat and canola grain samples selected from NVT sites. Values are expressed on a dry weight basis (Norton 2012; 2014).

State	NSW min	NSW max	NSW mean	SA min	SA max	SA mean	Vic min	Vic max	Vic mean
Wheat									
P in grain (mg/kg)	2.7	3.6	3.1	3.1	3.9	3.4	2.9	3.6	3.2
Canola									
P in grain (mg/kg)	3.9	6.6	5.2	5.1	7.8	6.2	5.2	6.5	5.7

production) which provides an estimated 3.6–5.5kg P required/t of grain production. Similarly, for canola seed P export (4.0–6.5kg P/t) plus stubble P not accessible (0.6–1.0kg P/t) plus soil losses (0.3–0.7kg P/t grain production) which provides an estimated 6.1–10.2kg P required/t of grain production. On a per hectare basis the export of P for wheat and canola is approximately the same assuming canola has half the water use efficiency for grain production as wheat. These budgets are estimates, and therefore, must be assessed and adjusted by tracking soil P values to determine if soil test values are increasing (over estimate of P budget), decreasing (under estimate of P budgeting) or remaining within the critical 90 and 95% range (P budget balance). After several years of soil testing and adjusting P inputs it is possible to ensure relatively stable soil P test values.

Phosphorus savings after drought

A recent meta-analysis (He and Dijkstra 2014) demonstrated that drought stress decreases the concentration of P in plant tissue, and several studies have shown that drought can decrease nutrient uptake from soil. Decreases in nutrient uptake during drought may occur for several reasons, including the reduction of nutrient diffusion and mass flow in the soil. Drought can also decrease nutrient uptake by affecting the kinetics of nutrient uptake by roots, however this effect is less well studied.

In cropping systems starter P is important for (i) early root development which assists the plant in exploring the greater soil P reserve and (ii) early head development when potential grain number is set (e.g. at or just prior to DC30).

Many P experiments have shown responses to starter P however, P savings can be made after drought especially where (i) December P export in grain is lower than P inputs at sowing and (ii) soil Colwell P values are equal to or greater than soil critical values. In these circumstances one third of historical average P inputs can be used down to a base level of 3–4kg P/ha. As an example, if wheat target yield for 2019 is estimated at 3t/ha and the P budget is estimated to be 3.6–5.5kg P/t of grain production then we have a P budget of 10.8–16.5kg P/ha or 49–75kg/ha mono-ammonium phosphate (MAP) fertiliser. If a medium value of 62kg/ha MAP (13.5kg P/ha) was assumed as our standard P budget this could be reduced by two thirds down to 18.6kg / ha of MAP or 4.1kg P/ha following the dry 2018. At this rate, the MAP granules are placed in-row at approximately 3.5–4.5cm spacings when using 25cm tyne spacing. Wheat sowing rates of 50–65kg/ha are likely to place seed at approximately every 2–2.5cm in-row while a full MAP rate of 62kg/ha provides an in-row granule spacing of approximately 1.0–1.2cm.

Phosphorus stratification

There are several reasons why P is often highly stratified near the soil surface, including; (i) 'native' Australian soils were deficient in P and farming systems, have for the most part, applied P in the top 0–10cm of soil, (ii) P is highly reactive in soils binding with Fe, Al and Mn at low pH and Ca at high pH as well as bonding with small clay particles, consequently P is not readily leached in most soils, (iii) farming systems have shifted from intensive cultivation prior to sowing to no-till or minimum-till systems and this has reduced soil mixing, and (iv) P in stubble retained systems is recycled to the soil surface.

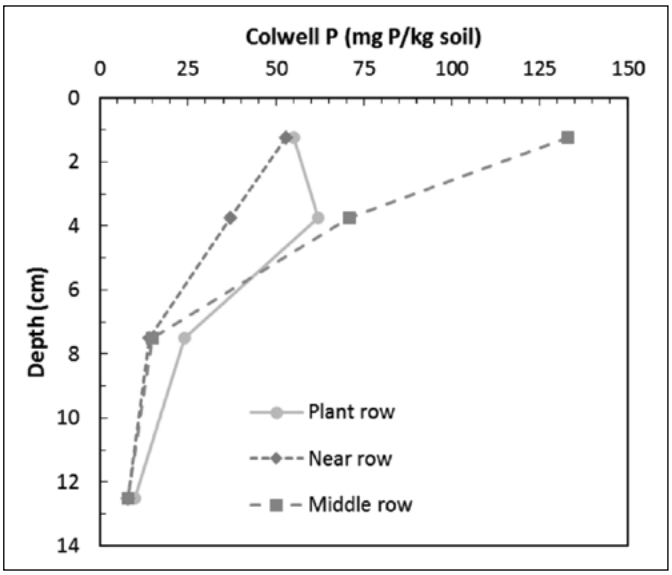

Figure 7. Vertical and horizontal stratification of P measured as Colwell P at the long-term Hart experiment. Samples taken in 2017 (Armstrong et al 2017).

An example of a stratified soil sampled in July 2017 is provided in Figure 7 (Armstrong et al 2017). In this example the 'plant row' has a Colwell P of approximately 55mg P/kg soil in the 0–2.5cm section and increases to approximately 62mg P/kg soil in the 2.5–5cm section, which reflects the fertiliser drilled at sowing. At 5–10cm the Colwell P value drop to approximately 24mg P/kg soil and declines to approximately 10mg P/kg in the 10–15cm layer. The sampling 'near row' has no fertiliser spike in the 2.5–5cm section (e.g. approximately 37mg P/kg 'near row' compared to approximately 62mg P/kg 'plant row' in the 2.5–5cm section). The 'middle row'

(inter-row) section shows very high Colwell P at the soil surface (approximately 133mg P/kg soil on the 0–2.5cm section). This is most probably because the tyne on the 'plant row' has thrown P rich surface soil into the inter-row space (e.g. middle row).

The calculated Colwell P at 0 - 10cm on the plant row is approximately 40.5mg P/kg (Figure 7). The question is; how much of this does the plant root access given sowing depth of around 5cm and frequent drying of surface soil. In this scenario, let's assume the plant does not access P in the top 0–2.5cm, and therefore, the estimated Colwell P at 0–10cm reduces to 27.4mg P/kg soil. In most cases, this is still adequate P for 90% of maximum yield (Table 2) however, it highlights a number of very important issues including what is the relative efficiency of P access at different depths and soil moisture. In the above example (Figure 7) if we assume a 0–10cm Colwell P was 30mg P/kg instead of 40.5mg P/kg and the same proportion of P stratification is applied with no access to P in the 0–2.5cm layer then the Colwell P value becomes approximately 20mg P/kg soil. In this contrived scenario, crop yield may be limited.

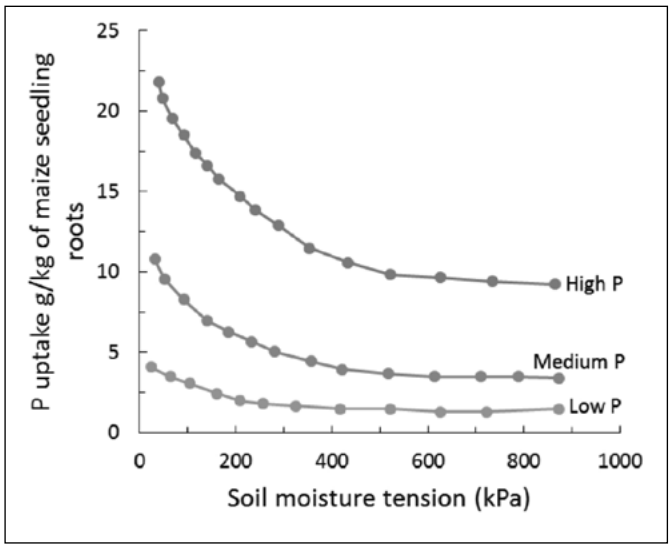

Figure 8. Phosphorus uptake in roots of maize to different soil moisture and soil phosphorus levels.

While the above scenarios are simplistic (e.g. zero P access in the 0–2.5cm section whereas low uptake efficiency is more likely in the 0-2.5 cm section), the point is clear that highly P stratified soils have the potential to limit yield particularly where P is high stratified in the 0–2.5cm layer and this layer is subject to frequent drying. Figure 8 demonstrates the principle that P uptake can be limited by soil moisture and soil P status. This evidence supports the theory that a frequently drying surface soil with adequate subsoil moisture may respond to deeper placement of P. However, this needs to be tested with wheat in southern NSW soil and climatic conditions before any conclusive statements can be made.

Phosphorus placement at sowing

Compared with broadcasting or banding fertiliser P with seed, the placement of P at 2–6cm below seed has shown significant yield increases in 14 scientific studies (**wheat**: Alston 1976; Nable and McConnell et al 1986; Webb 1993; Sander and Eghball 1999; Singh et al 2005; Wilhelm 2005; **canola**: Grewal et al 1997; Hocking et al 2003; Wilhelm 2005; **lupin**: Jarvis and Bolland 1990, 1991; Crabtree et al 1998; Brennan 1999; Crabtree 1999; Scott et al 2003) and no significant increase in five scientific studies (Hudak et al 1989; Reeves and Mullins 1995; Bolland and Jarvis 1996; McCutcheon and Rzewnicki 2001; Vyn and Janovicek 2001). All of these studies placed P at depths less than 15cm and some of these studies had starting soil P values below crop critical values.

In at Nebraska a P placement study determined the optimum P placement depth as 11.9cm (Figure 9). Research in WA by Bolland and Jarvis (1990) found wheat yield was increased by approximately 20% when the fertiliser was placed at 9cm below the soil surface compared to 3cm in the first year of sowing single superphosphate. In the second year, superphosphate placed at 13cm depth in the previous year increased grain yield by approximately 60% in lupins compared with freshly drilled fertiliser at 3cm deep.

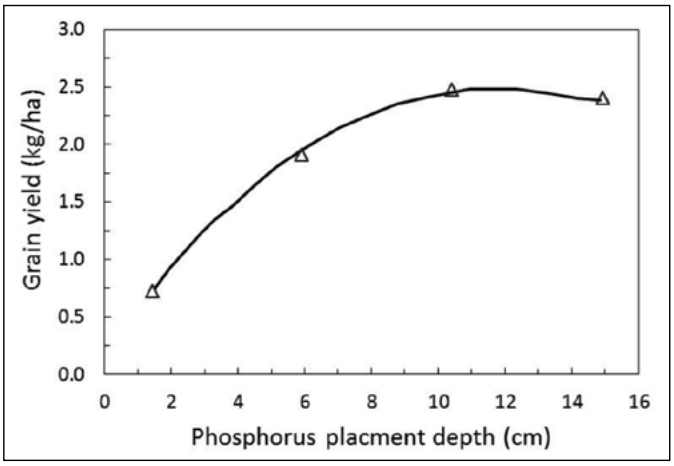

Figure 9. Effect of different depths of P placement at sowing on winter wheat yield in Nebraska (McConnell et al 1986).

Deep P

More recent research has focused on deeper placement (20cm) of P as MAP at 50cm row spacing in northern NSW and QLD. Figure 10 (Bell et al

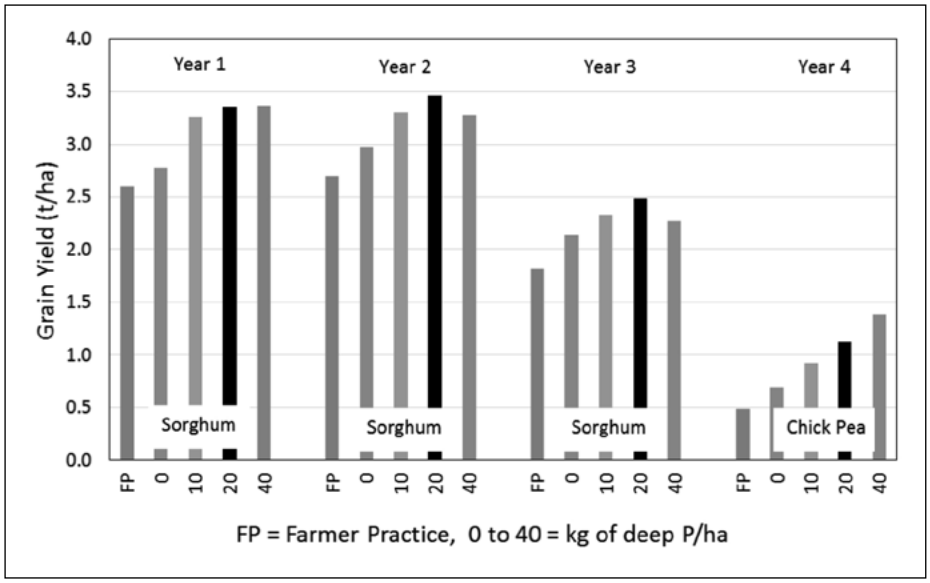

Figure 10. Deep P drill in Year 1 (2013) at a depth of 20cm and row spacing of 50cm and the subsequent grain yield response over four consecutive years at Dysart QLD for sorghum and chick pea. No additional deep P was applied in subsequent years and annual P at sowing was 6kg/ha.

2016) shows results from Dysart in Queensland where deep P was drilled in 2013. The zero deep P rate represents deep drilling at 20cm with no deep P applied (i.e. ripping effect) while the farmer practise represents no deep drilling and no deep P. The percent increase from the zero deep P rate to the best deep P response in each consecutive year was 17% (Year 1), 11% (Year 2), 7% (Year 3) and 59% (Year 4). In Year 2 (11% increase) and Year 3 (7% increase) nitrogen limited maximum yield production (Figure 10). Consequently, the P responses for Year 2 and Year 3 may be considered conservative. In each treatment 6kg/ha of P was applied at sowing and this plus the soil reserve P was not expected to limit potential yield (Figure 10). A summary of deep P results (data not shown) indicates deep P applied as MAP at 20kg P/ha provided an average of 13% yield increase in wheat yield, 11% increase in chickpea grain yield based on 10 and 4 crop years of research, respectively.

Future research

It is often assumed that because P requirements for crops have been extensively studied both in and outside Australia that all required knowledge for crop production is known. This is certainly not the case for modern cropping practices where subsoil P (0–30cm) is being exported in grain and redistributed on the soil surface via stubble. This process increases the degree of P stratification where soil P is very low in the 10–30cm layer (< 5mg P/kg soil) and high in the 0–5cm layer (e.g. 35mg P/kg soil). Other factors that contribute to P stratification include shallow placement of P at sowing, and for tyned implements, soil throw into the inter-row. In these circumstances surface drying events in the 0–5cm layer may limit grain production. Exceptions to this stratification process occur where P is leached in low PBI soils or where deep cultivation occurs which mixes the soil.

Conclusion

Phosphorus placement below seed at sowing is most likely to provide yield benefits compared to P placed with seed.

Testing the extent of P stratification on-farm (surface 0–10cm and subsoil 10–30cm) can assist in P budgeting as the lack of subsoil P can be offset by higher concentrations of surface P in most soils provided soil moisture conditions are adequate for P uptake.

Deep P placement (20cm) in northern NSW and QLD in winter dry and summer wet conditions are providing more insights into deep P responses however, these findings cannot be directly applied to cropping zones where rainfall is non-seasonal or Mediterranean in distribution because the frequency and duration of soil drying in the P rich 0–5cm layer is different and will impact on responses to deep P placement.

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Contact details

Graeme Sandral
NSW DPI, Wagga Wagga Agricultural Institute
Phone: 02 6938 1807
Email: graeme.sandral@dpi.nsw.gov.au
Twitter handle: @gsandral

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Companion cropping – should we be considering it?

John Kirkegaard[1] and Greg Condon[2].

[1]CSIRO Agriculture and Food, Canberra ACT; [2]Grassroots Agronomy, Junee NSW.

GRDC project code: CFF00011

Keywords

- diversity, intercrops, cover crops, companion crops, crop sequence.

Take home messages

- Diversity in farming systems can be increased using multi-species mixtures with different strategies including cover crops, grazed mixtures, companion crops terminated in-season, or intercrops harvested for grain.
- Potential benefits sought usually relate to the increased shoot or root biomass potential of the mixture, or specific impacts of the components such as nitrogen (N) fixation, weed or pest suppression and soil structural improvement.
- Case studies in southern NSW reveal the practical adoption of companion cropping has been successful when sown in mixes for grazing, but can be more challenging in grain only scenarios. Companion cropping systems are more complex and need to be well planned in advance to help achieve objectives and minimise losses.

Background

The idea of growing more than one crop/species on the same land in a mixture is not new – it has been common in subsistence agriculture and in organic agriculture for generations and is thought to currently provide 15%-20% of global food production (Fletcher et al., 2016). However, the application in broadacre mechanised agriculture has been limited. The biological mechanisms that underpin the benefits of mixtures have a sound scientific basis, but in large scale mechanised agriculture where labour can be a scarce or expensive resource, monocultures are generally more efficient, as less complex management is required (e.g. sowing, harvest, weed management, physical handling). In general, rotated monocultures are the norm. As precision machinery and new varietal options (e.g. herbicide tolerant) emerge, new opportunities may exist to more effectively capture the benefits of crop mixtures at a broader scale. Recently Fletcher et al. (2016) reviewed the current literature and considered not only the 'resource' dimension benefits to crop mixtures, but the 'farming systems' dimensions that are usually overlooked in scientific studies. A farming system benefit might derive from increased productivity of the mixture (related to better resource capture), but also reduced lodging, improved harvest-ability, reduced input needs, improved product quality, benefits to subsequent crops, nutrient recycling, and provision of cover. In addition, there may be a reduction in season-to-season yield variability, or a reduction in risk which may be as important to the farming system as an increase in mean yield. In mixed farming systems, grazed forages provide further opportunities to consider the potential benefits of mixtures. This paper briefly reviews the mechanisms underpinning the benefits of mixtures, outlines different strategies being used to manage mixtures, and then provides some case studies from southern New South Wales (NSW) where growers have been trialling some of those strategies, their rationale for doing so and some outcomes to date. Discussions of summer

cover crops grown between two cash crops are not included.

Farming systems, which include companion cropping, are inherently more complex. To mitigate this, a small group of long term no-till growers in southern NSW have worked together to trial what works with their machinery, rotations and soil types. They have sourced information on companion crops from growers overseas and locally to develop systems that help improve soil biology and cycling of nutrients and reduce risk and costs. The experience has not been without challenges — from dealing with weeds and herbicide plant-backs to managing seasonality with frost or even sourcing seed. They remain committed to including companions in their farming systems and are making adjustments every year based on the trials and experiences from within the group.

Mechanisms underpinning benefits from multiple species

Biomass 'over-yielding'

Mixtures of species often are more productive per unit land area than sole crops as a result of the way in which the resources for growth (light, water and nutrients) are more effectively shared and used. In general, these effects can be complementary — species use resources separated in space or time (e.g. different rooting depth or pattern, or different canopy structures to intercept light); facilitative — one species facilitates better resource use by the other; better resource use — same total resource use, but improved efficiency due to impacts of one component on the other (e.g. reduced disease or weeds, changed soil microbial profiles).

Nitrogen fixation from legumes

Legume components as intercrops provide N-fixation capacity to potentially improve the N economy of the mixture and increase N availability to both the non-legume component (by not requiring N uptake), and to the subsequent crop through increased N input.

Weed, disease and pest suppression

Some species have suppressive capacity to weeds by means of vigorous growth and resource capture, while both weeds and diseases can be suppressed by the release of specific compounds or by other plant characteristics that can deter pests and diseases.

Soil structural improvement

The root systems of some plant species can improve soil structure by either improving aggregate stability through extensive fine root systems and root exudates, or by producing large continuous and stable bio-pores that provide areas for the rapid infiltration of water and air, and channels for subsequent roots to access deeper soil layers (primer crops).

A recent and relatively simple example of the benefits of mixtures can be seen in Table 1, which summarises work from Couedel et al. (2019) on the benefits of legume and brassica mixtures compared to sole crops. Legumes are known for their N-fixation and green manure value, while brassicas are known for their deep taproots, vigorous growth, efficient capture of N and sulphur (S) from the soil and their ability to suppress weeds, pest and disease (i.e. 'biofumigation'). The individual crops can provide the maximum benefit in specific areas, but the 50:50 mixture provided much more than half of each benefit, so that overall, the multiple benefits are maximised in the mixture.

In some cases, there may also be potential for negative effects of mixtures or 'disservices'. For example, greater water use by the mixture may leave less for the following crops, or components of the mixture may host pests or pathogens of subsequent crops. In considering mixtures, it is important to be clear about what benefit is being sought, what unintended problems may arise, and that the activity does not create unacceptable levels of management complexity.

Table 1. Summary of the services provided by brassica and legume mixture compared with the sole crops. Services provided by the best sole-crop are set to 100%. In each case, the mixture delivers more than the average of the sole crops (from Couedel et al. 2019).

Service/benefit	Brassica sole crop	Legume sole crop	Brassica-legume mix
N capture	100	66	98
N green manure	18	100	63
S capture	100	30	99
S green manure	100	23	85
Biofumigation	100	/	81

Practical strategies to improve diversity with mixtures

Multiple species mixtures for grazing only

A range of different species are selected for the mixture specifically for increased forage production throughout the season which helps with improved animal intake and live-weight gain. Grazing mixes are usually terminated as a spring fallow to retain groundcover and soil protection over the summer and for ease of crop establishment the following season. The mixes are sown with a similar objective as brown manure pulse crops to improve soil N status, control resistant grass weeds and build soil water prior to high risk crops such as canola. In contrast to brown manure mixes, these crops are grazed and primer species, such as tillage radish and turnips, are included to penetrate dense clay subsoils and leave stable biopores.

Dual-purpose mixtures

A cash crop that is intended for grain harvest is included in the mixture (e.g. a grazing wheat or canola) and the remaining components of the mixture are terminated after grazing to allow grain recovery in the cash crop. Benefits sought are diverse feed sources for livestock to minimise metabolic issues, improved nutritive value and provision of additional dry matter through different growth habits or seasonality. Common examples include mixing vetch and tillage radish with cereals such as grazing wheat or oats. Winter canola for grazing is also mixed with vetch to improve feed diversity and soil N input and to also provide a source of arbuscular mycorrhizal fungi (AMF) with non-host species such as canola.

Companion cropping

In ungrazed systems, companion crops are sown with the main cash crop, but are terminated in-season. Benefits sought are weed suppression, N-fixation, soil structural benefits and AMF (mycorrhizae) hosting. Common mixes include wheat and tillage radish or wheat and pulses such as vetch, faba beans or field peas. Termination timing in southern NSW systems has been targeted during late winter-early spring prior to stem elongation of the cash crop.

A recent example of this used commercially is the frost sensitive faba bean (and some other species) that is sown as a companion with winter oilseed rape in France, where it is primarily aimed at repelling insect pests in young canola and reducing the need for early sprays. It also provides competition with weeds and some N-fixation, and the faba bean is killed naturally by frost in winter.

Intercropping (both crops harvested)

A mixture of two cash crops is sown with the intention of harvesting both crops. The benefits sought are the over-yielding arising from synergies and complementarities of the crop mixture which may relate to N dynamics (in legume mixtures), reduced disease epidemics, and improved nutrient uptake. Harvesting two crops at the same time can be difficult with header setup and separation. Cleaning grain can also be a challenge and adds further cost, but it is often worth the effort given lower costs of production compared to monoculture crops.

Field peas and canola have been recognised as suitable companion crops for many years and 'peaola' has been used by growers with various levels of success (Fletcher et al. 2016). Non-host species such as canola are mixed with pulses to improve AMF levels. Locally, these mixes have been challenging to get right with seasonality of the different crops difficult to manage. For example, field peas sown as companions with canola have been affected by bacterial blight when sown earlier than their preferred window. In Canada, growers have found mixing species, such as chickpeas and linseed, has helped reduce the risk associated with growing high value crops such as chickpeas, primarily through a reduction in disease epidemics.

Research at the University of Western Australia (UWA) by Bai Li et al. (2016) suggested that when faba beans and corn were intercropped, root interactions between the species boosted faba bean biomass and grain by 35% and 61%, respectively. Plants can communicate through the release of root exudates, which act as underground highways, promoting N-fixation between neighbouring plants.

Case studies

Case study 1

Grower and farm description: Damien and Brian McKelvie, Marrar. Red loam soils. Mixed farming operation with wheat, barley, canola, vetch, lucerne pastures and prime lambs.

What mixture is being used and how? Grazing mixes with vetch, radish, turnip and wheat sown in early autumn into cereal stubbles. The mix is grazed through winter and spring then spray fallowed in late spring to control grass weeds and retain soil moisture.

What benefit is being sought from the mixture? Provides high quality feed for their composite sheep flock through winter and spring. When dual purpose canola or wheat crops are locked up for grain recovery in late winter, the sheep move onto the vetch mix allowing lucerne pastures to be spelled. The mix replaces the need to sow a grain only pulse to get a legume into the crop rotation.

What has been the result – good and bad? The grazing mix has been used for several years with success to finish lambs to target weights with minimal supplementary grain plus include a low risk pulse (vetch) in the rotation. Sourcing soft seeded vetch has been a challenge and stocking rates need to increase to prevent radish flowering during spring.

Case study 2

Grower and farm description: Hugh and Libby Cruikshank, Coolamon. Red loam and sodic grey clay soils. Mixed farming operation with wheat, barley, canola, vetch, lupins, lucerne pastures, merino ewes, wethers and prime lambs.

What mixture is being used and how? Vetch, radish, turnip, wheat mix for grazing, a pulse added into the rotation to help improve dense sodic subsoils in combination with stubble retention, no-till and gypsum. Grasses are selectively controlled in late winter then the remaining vetch mix is spray fallowed in late spring.

What benefit is being sought from the mixture? Grazing mix provides a low risk pulse alternative, feeds merino wethers during winter and the deep tap-rooted brassicas (radish and turnip) help penetrate dense sodic subsoils providing pathways for subsequent roots to follow.

What has been the result – good and bad? Dry starts have limited early dry matter production from the vetch mix with limited feed production during late breaks and getting the ratios of pulse to cereal has been difficult. Observations of soil structure the year following the vetch radish mix have shown improved infiltration and aggregate stability.

Case study 3

Grower and farm description: Brendan and John Pattison. Red loam soils. Continuous cropping canola, wheat, barley, faba beans, lupins, companion winter and opportunity summer crops.

What mixture is being used and how? Canola and faba beans growing together with volunteer faba beans left in a canola crop or both sown as a mixed companion with both crops harvested. Wheat and barley are sown with tillage radish and vetch at low densities. The radish and vetch are terminated in late winter, with a goal of adding diversity with rooting depth and improved biological activity.

What benefit is being sought from the mixture? Provide a source of AMF (mycorrhizae) for non-host species such as canola, improve soil biota, reduce costs and build resilience in their cropping systems by minimising inputs such as N fertiliser and fungicides.

What has been the result – good and bad? Faba bean and canola mixes are still in the development stages, but the mix has shown good potential to date, albeit with low yields from the faba beans. Radish and vetch mixes have been successful when terminated in late winter in wheat grain crops. Soil water use by the companion crop has not reduced grain yield of the wheat or barley being harvested.

Case study 4

Grower and farm description: Matt and Belinda McKinley. Red loam, granite and grey clay soils. Winter companion crops, wheat, barley, faba beans, linseed, canola, chickpeas, lupins and opportunity summer crops. Trade cattle on mixed species grazing crops.

What mixture is being used and how? Grazing mixes of cereal rye, millet, corn, oats, tillage radish, vetch, field peas. Sowing mixes of faba beans and canola, field peas and canola, chickpeas and linseed.

What benefit is being sought from the mixture? Aiming to improve soil health through carbon cycling plus develop a resilient, low cost farming system.

What has been the result – good and bad? Achieved success with grazing mixes sown for cattle in late summer or early autumn using a disc seeder into tall cereal stubbles. Faba bean and canola mixes sown into double cereal stubbles have worked well on elevated paddocks, but yields have been reduced by frost in lower blocks. Field peas and canola mixes sown into cereal stubble have also been subject to frost issues, particularly with bacterial blight infecting the field peas. The field pea and canola crop was cut for silage in 2018 and sold to local livestock producers as a high quality feed source. Chickpea and linseed companion crop established well, but with limited herbicide choices, the broadleaf weed density was problematic at harvest.

Conclusion

Companion cropping potentially offers a range of benefits for improving soils, reducing disease and insect pest pressure along with helping to minimise risk. Whilst there is limited research data in Australian cropping systems to quantify the practice, growers are looking to adopt companion cropping to help diversify their rotations whilst reducing the cost of production. Companion cropping is not without its challenges and growers or advisers are urged to plan ahead to reduce any problems with issues such as herbicide plant-backs or machinery configurations.

Useful resources

The potential for companion cropping and intercropping on UK arable farms. Andrew Howard, UK Nuffield Scholars Report 2015 http://www.nuffieldscholar.org/news/andrew-howard-report-published

Intercropping – the growing of two different crops simultaneously. Bryan Granshaw, Australian Nuffield Scholars Report 2016. http://www.nuffieldinternational.org/live/Reports

Intercropping expands the mix of crops in Saskatchewan. http://magazine.topcropmanager.com/publication/?i=433339#{"issue_id":433339,"page":12}

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Contact details

John Kirkegaard
CSIRO Agriculture and Food
GPO Box 1700, Canberra ACT 2601
0458 354 630
john.kirkegaard@csiro.au
@AgroJAK

Greg Condon
Grassroots Agronomy
PO Box 73, Junee NSW 2663
0428 477 348
greg@grassrootsag.com.au
@grassrootsag

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Weed control in Australian grain production systems, now and into the future

Michael Walsh[1], John Broster[2] and Greg Condon[3,4].

[1]University of Sydney; [2]Charles Sturt University and [3]Grassroots Agronomy; [4]Australian Herbicide Resistance Initiative.

GRDC project codes: US00084, UWA00171

Keywords

- harvest weed seed control, chaff lining, site-specific weed management, energy requirements, targeted tillage.

Take home messages

- Harvest weed seed control (HWSC) is an important component of a successful weed management package.
- Suppression of weed emergence increases with increasing amounts of chaff.
- Site-specific weed control creates the opportunity to use alternative physical weed control technologies.

Background

The reliance on herbicidal weed control has resulted in the widespread evolution of herbicide resistant weed populations (Boutsalis et al. 2012; Broster et al. 2013; Owen et al. 2014). Changing regulations and expensive herbicidal development costs, combined with the perennial threat of herbicide resistance, means the effectiveness of future weed control programs will depend on the availability of alternative weed control technologies.

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 similar 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 approaches to HWSC concentrate the weed seed bearing 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 this practice can be as effective as other forms of HWSC in depleting weed seed banks.

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. However, most of these technologies have not been adopted, primarily due to cost, speed of operation and fit with new farming systems. The introduction of weed detection and actuation technologies creates the opportunity to target individual weeds i.e. site-specific weed management. This greatly increases the potential cost-effectiveness of many directional physical weed control techniques in conservation cropping systems.

The use of alternative weed control tactics is obviously critical to achieving near zero weed status, but ultimately successful growers keep seed bank numbers low every year through the strategic use of all available tools. This stems from a commitment by the grower and their agronomist to plan ahead and target weeds at every opportunity using an

integrated approach, not just with herbicides alone. There are numerous benefits of near zero weed densities including reduced weed control costs, prevention/delayed herbicide resistance evolution and increased flexibility in production practices. Significantly, lower weed densities create the opportunity for using cheaper and more accurate site-specific approaches to weed control.

Materials and methods

Chaff lining and chaff tramlining

The purpose of the experiments was to investigate the influence of different amounts of wheat, barley, canola and lupin chaff on seedling emergence of annual ryegrass. Wheat chaff trials were conducted at three locations — Toowoomba, Wagga Wagga and Narrabri with barley, canola and lupin chaff trials at Wagga Wagga. The similar approach used at each location involved eight rates of chaff with four replicates of each experimental unit. The trials were established by spreading a known number of annual ryegrass seed (100 or 200) on the soil surface potting mix filled trays or pots. Treatments were established by spreading chaff material, collected during the 2017 harvest, over the surface of the pots or trays. 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 were assessed using emergence over the 28 day period as a proportion of the 0t/ha chaff treatment.

Comparison of weed control technologies

There is a diverse array of effective physical weed control options with a proven ability to control weeds. The majority of these have not been commercialised and evidence of their efficacy relates to research findings, 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/m2 was chosen to represent a typical weed density in Australian grain fields, based on results from a recent survey of Australian grain growers (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 concentration of very high rates (>42t/ha) of chaff material. The increased 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 at the two other locations. Emergence in the Wagga Wagga trial was lower ($P<0.05$) than at both sites at 3t/ha, 6t/ha and 12t/ha chaff rates and lower than one of these sites at 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.

Barley chaff was generally more suppressive of annual ryegrass emergence at equivalent rates of wheat, canola and lupins. 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) (Figure 2).

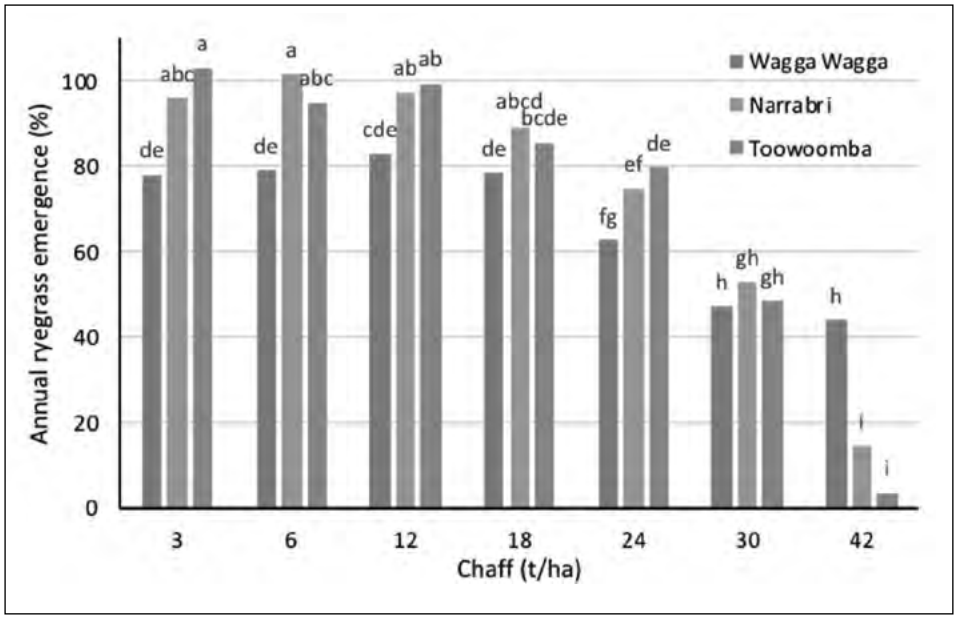

Figure 1. Influence of increasing amounts of wheat chaff on the emergence of annual ryegrass in pot trials conducted at three locations. Means with same letter are not significantly different (P=0.05.).

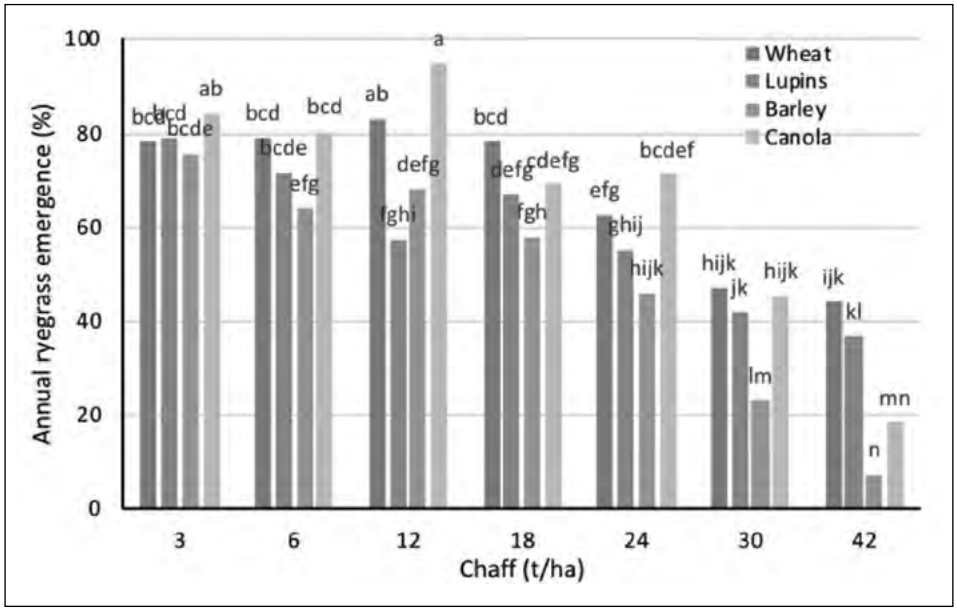

Figure 2. Influence of increasing amounts of wheat, barley, lupins and canola chaff on the emergence of annual ryegrass in pot trials conducted at Wagga Wagga, NSW. Means with same letter are not significantly different (P=0.05).

The greater emergence inhibition by the barley chaff at Wagga Wagga may be due to it being a greater physical barrier. For any weight of chaff, more barley chaff was needed than wheat chaff, with lupins and canola requiring even less. It is also unlikely that all crop species and/or varieties will have the same chaff percentage. In addition, a harvester using a stripper front will also produce less chaff (Figure 3) for a chaff line compared to a draper front.

Comparison of energy requirements for weed control

Historically, tillage was relied on for weed control as well as seedbed preparation and continues to be used extensively in global cropping systems despite the extensive reliance on herbicides. As a group, soil disturbance-based options are the most energy efficient form of physical weed control (Table 1) with no additional energy inputs beside the draught force requirements. Tillage acts to control weeds

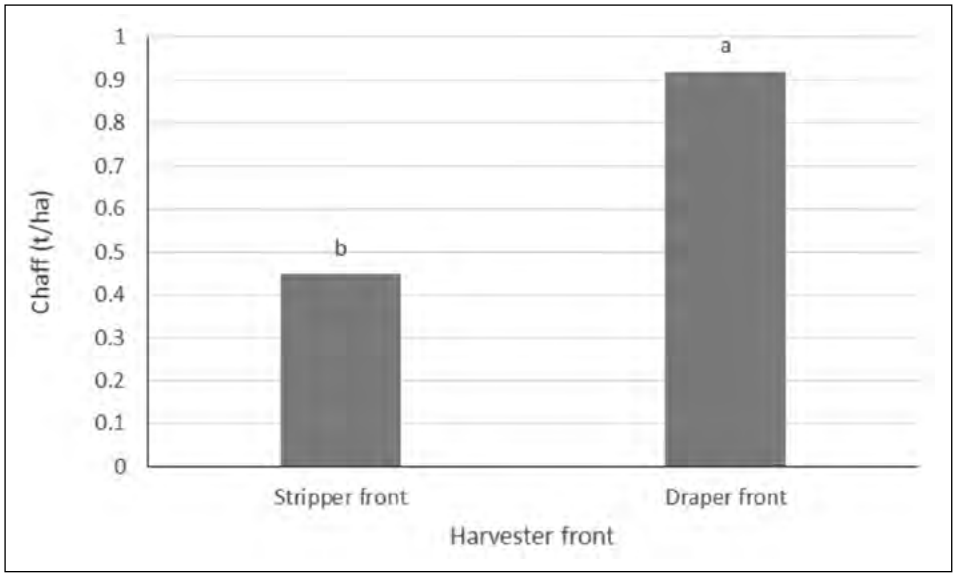

Figure 3. Amount of chaff fraction (t/ha) produced when harvesting wheat using two different harvester fronts. Means with same letter are not significantly different (P=0.05).

by uprooting plants, severing roots and shoots and/or burial of plants. Consequently, the efficacy and impact of this approach are reliant on rainfall and soil moisture. Effective control can only be achieved when disturbed weeds are exposed to a drying environment after the tillage operation. Although tillage can be a highly effective weed control option, the soil disturbance involved is not compatible with conservation cropping systems, therefore this approach needs to be used sparingly.

Table 1. 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

There are a group of thermal weed control technologies (flaming, hot water foaming, steaming, etc.) using chemical or electrical energy that may be used for broadcast weed control (Table 1). In comparison to tillage and herbicide-based options, these approaches are considerably more energy expensive. With 100 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, although in more intensive operations, flaming is used to some extent.

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 2). For example, microwaving, as one of the most energy expensive weed control treatments as a broadcast treatment (42,001 MJ/ha), requires substantially less energy when applied directly to the weed targets (17.8MJ/ha). Therefore, even though the same number of weeds are being controlled (five plants/m2), the specific targeting of these weeds results in a 99% reduction in energy requirements.

The accurate identification of weeds allows the use of alternative weed control technologies that are not practically suited for use as whole paddock treatments. For example, lasers are typically a narrow beam of light focused on a point target. In a site-specific weed management approach with highly accurate weed identification and actuation, lasers can be focused precisely on the growing points of targeted weeds, concentrating thermal damage. By reducing the treated area of the weed, off-target losses are further reduced allowing additional energy savings.

Table 2. 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
CO2 laser cutting	54.8
Targeted flaming	59.9
Electrocution: continuous contact	60.9
Nd:YAG laser pyrolysis	84.4
CO2 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

Diverse weed control – the need for both herbicide and cultural tactics

Ryegrass cross resistance and stacking HWSC with crop competition

Growers and agronomists now have a wide range of cultural tools to manage herbicide resistant weeds without compromising profit. Tactics such as HWSC, crop competition and diverse rotations are used to complement herbicide options including double knock strategies, pre-emergent herbicides and late season crop-topping. Known as the 'big six', these diverse weed management tactics are used in conjunction with best practice agronomy to drive weed seedbank numbers to zero.

Non-chemical tactics remain critical to controlling herbicide resistant weeds, particularly with new data emerging about cross resistance to pre-emergent herbicides in annual ryegrass. A population of annual ryegrass from South Australia (SA) has confirmed resistance to all pre-emergent herbicides – Avadex®, Arcade®, trifluralin, propyzamide and Sakura® (Brunton et al 2018). Sampled in 2014, testing by the University of Adelaide Weed Research Group showed that metabolic cross resistance was at play.

In addition, a random survey of 64 paddocks in the south-east of SA found populations of annual ryegrass with multiple cross resistance to a range of pre-emergent herbicides including Arcade®, Butisan® and Sakura®.

These findings by the University of Adelaide have huge implications for an industry now heavily dependent on pre-emergent herbicides in no-till systems, showing they can quickly break down in the face of metabolic cross-resistance. The diverse tactics outlined in the 'big six' are more important than ever to prevent seed set in resistant weed populations and to protect the longevity of pre-emergent herbicides for future use.

Research has shown that stacking of the 'big 6' tactics can have a far greater impact on preventing weed seed set than using them in isolation. Walsh & Broster (2018) highlighted that seed capture for HWSC was enhanced when combined with crop

competition. A survey of 71 wheat crops across Australia showed that the more competitive crops caused ryegrass to grow upright (seeking out light) and set seed higher in the crop canopy, where a greater proportion can be captured through HWSC.

The survey found that in an average wheat crop with a biomass of 9t/ha, 74% of the ryegrass seed was retained above 10cm in the canopy. However, there was a 12% difference in ryegrass seed above 10cm between the low and high biomass crops (<7t/ha and >12t/ha, respectively) due to differences in crop competition. Narrow row spacing, vigorous varieties and/or higher plant densities all contribute to crop competition and are already recognised for reducing weed seed set and improving crop yield, but this data shows the impact they can also have on improving the success of HWSC.

Chaff lining agronomy and advances in mill technology

HWSC is becoming recognised as one of the key tactics for managing herbicide resistant weeds with growers shifting to make the practice more mainstream. Narrow windrow burning (NWB) has long held the mantle as the most popular form of HWSC, but chaff lining and chaff tramlining (or chaff decks) are rapidly gaining favour. An online survey by WeedSmart of 269 growers at harvest 2017 indicated 32% of growers were planning to use NWB, with 27% chaff lining and 12% using chaff decks. Chaff carts were stable at 12%, mill technology at 3% and 14% indicated they would not use HWSC.

The increase in adoption of chaff lining and chaff decks seems largely due to the ability to retain stubble instead of burning rows or chaff dumps. The principle involves collecting chaff and weed seeds off the main sieve to drop in a single row or split onto three metre tramlines, with real time kinematic (RTK) allowing rows to accumulate in the same area each year. Weed seeds remain on the surface where they can be grazed or left to rot, while straw is chopped and spread. A reduction in dust from the tracks when summer spraying is a huge benefit of the chaff deck system for growers in controlled traffic farming (CTF) systems.

With any new practice, there have been challenges and these have occurred either at harvest or the following season dealing with rows of dense chaff and weeds. Harvest issues have primarily involved header blockages or dust accumulation around the engine bay. Modifications with baffle and chute set-up have helped minimise issues, but with so many different makes of header, growers have had to sort many of the problems in the paddock.

Dealing with chaff rows the following season has also created issues, particularly as growers aim to promote rotting of weed seeds, while also allowing crop rows to establish and compete in the chaff line. Sowing the chaff line with a disc unit is generally preferred, along with increasing herbicide rates of pre-emergent and post-emergent herbicides over the chaff rows. Growers and their agronomists need to be aware that weed numbers can be confronting during the early years of chaff lining or chaff decks in high pressure blocks. Remember that weed seeds will be captured in following seasons and placed back on the same rows so that weed numbers and selection pressure are confined rather than spread across the paddock.

Controlling high numbers of weeds in chaff rows using selective or shielded sprayers is an option in dense populations and is well suited to CTF systems. Growers can target dense populations of weeds on tramlines while only spraying a small percentage of the paddock, e.g. two 700mm tramlines (or 1.4 metres every 12 metres) only represents 12% of the paddock. Any survivors are again picked up at harvest and put back onto the chaff rows for further treatment or rotting the following year.

Mill technology remains the ultimate form of HWSC and complements all forms of weed control. With the mill pulverising all material leaving the sieves, it eliminates the need for burning or leaving weed seeds to rot. Mills can destroy 93% to 99% of the weed seeds while spreading residue back onto the paddock without any loss of nutrients or stubble. A higher capital investment is required with mills compared to other HWSC practices, with costs ranging from $85,000 to $180,000 depending on mechanical or hydraulic drive options.

The 2018 harvest has generally been a successful season for the different types of mills available. The hydraulic integrated Harrington Seed Destructor (iHSD) operates as two hydraulically driven cage mills, while the Seed Terminator uses a mechanically driven multi-stage hammer mill. A number of concerns with the mills and their performance have been addressed by the manufacturers, following an extensive review process in 2018. Issues included excessive mill wear in sandy soils, reductions in harvest capacity and high running costs.

A new vertical iHSD mill was also released for the 2018 harvest by McIntosh and Son and the de Bruin Group. This is a mechanical drive mill with several

key features including less cost ($85,000 plus GST and fitting), less moving parts, less fuel usage, less horsepower (compared to the hydraulic iHSD), an auger on the shaft to help minimise blockages, a stone trap to catch any mill destroying objects and the ability to measure harvest losses. Ten machines were running for this harvest with another 100 units sold for the 2019 harvest.

Conclusions

The emergence of annual ryegrass can be significantly suppressed with increasing amounts of chaff concentrated in chaff lines and chaff tramlines. It was only at very high rates of wheat (42t/ha) that annual ryegrass emergence was adequately controlled. The different crop species also provided different rates of reduction in emergence, although for wheat and barley the relative effectiveness varied between the three locations. Targeting treatments on individual plants such as in site specific weed management, results in significant energy savings and makes previously impractical options on a broadcast basis available for use on a site-specific basis. The opportunities here are immense for the future management of problem weeds.

Acknowledgements

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Contact details

Michael Walsh
University of Sydney
12656 Newell Highway, Narrabri 2390
02 6799 2201; 0448 847272
m.j.walsh@sydney.edu.au

John Broster
Charles Sturt University
Locked Bag 588, Wagga Wagga NSW 2678
02 6933 4001; 0427 296 641
jbroster@csu.edu.au
@JohnCBroster

Greg Condon
PO Box 73 Junee NSW 2663
0428 477 348
greg@grassrootsag.com.au
@grassrootsag

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Notes

Canola establishment across central NSW

Col McMaster[1], Ian Menz[2] and Alan Stevenson[1].

[1]NSW DPI Orange; [2]NSW DPI Wagga.

GRDC project code: BLG110

Keywords

- canola establishment, fertiliser placement, sowing speed, stubble management.

Take home messages

- Across 95 paddocks within the low, medium and high rainfall zones of central NSW, the average canola establishment was 48%, and ranged from 17% to 86%.
- Seed size was the main differentiating factor that improved canola establishment.
- Other key agronomic factors for improved canola establishment were stubble removal, reduced sowing speed, shallow seed placement and phosphorus (P) fertiliser separated from the seed.
- Hybrid (H) varieties were generally larger in size, and establishment was better than open-pollinated (OP) varieties.

Background

Canola establishment has become an emerging issue within central NSW over the past decade, due to increased seed costs, reduced seeding rates, unreliable autumn rainfall and sowing into marginal seedbed conditions.

Canola seed costs from 1990 to 2010 were relatively stable at 4% of total input costs, and have since increased to 14% of total input costs in 2018 (NSW DPI crop budgets). The increased seed cost is largely related to the dominance of H varieties over OP varieties since 2011 to 2018 (Figure 1). Target plant density during the era that OP varieties dominated the market place (pre-2010) was 50–80 plants m^2 (Wurst et al. 1997) and seeding rates between 3–5kg/ha. However, since the adoption of hybrids, the target plant density has been reduced to approx. 20–50 plants m^2 (Zhang et al. 2016, Matthews et al. 2018) depending on rainfall zone. Currently, best management practice is to firstly determine target plant density (plants m^2) for your rainfall region, and then determine seeding rates via knowledge of seed size, germination percentage (%) and estimate of establishment %.

Recent developments in understanding variety phenology, sowing time, and the adoption of slower developing spring varieties have brought forward the sowing window from 25 April to early April (Brill et al. 2018) for slower developing spring types. This broader, more flexible sowing window enables canola establishment to occur when seasonal conditions allow (i.e. rainfall events), rather than wait for the traditional Anzac Day trigger point to initiate sowing. This greatly improves the flexibility of the farming system, however, establishing canola in early April has the disadvantage of high seedbed moisture dry-back due to greater evaporation demands caused by higher temperatures. For example, at Parkes (medium rainfall zone), the average daily evaporation reduces from 5.9mm, 3.7mm to 2.2mm across the respective months of March, April and May (Figure 2). This means that a shallow planted canola seed is at higher risk of seedbed moisture dry-back if sown in early April compared to May, particularly in the warmer regions of NSW (i.e. Condobolin).

In summary, the margin for error in establishing canola is small, we are now sowing less seeds, they are costing more money, and we are placing those seeds in higher moisture dry-back conditions. Successful canola establishment is a significant factor, and a risk in canola production. The primary purpose of this survey was to evaluate current canola establishment rates and uniformity of plant spacings. The secondary purpose of the survey was to evaluate management practices that affect canola establishment, such as stubble management, seeding systems, fertiliser and seed quality.

Method

A field survey was conducted in 2017 across 95 commercial paddocks within the low, medium and high rainfall zones of central NSW (approx. 30 paddocks from each rainfall zone). Paddocks were selected from the following localities — Tottenham, Tullamore, Trundle, Condobolin, Bogan Gate, Parkes, Forbes, Marsden, Manildra, Cowra, Young, Boorowa and Jugiong.

Paddocks were selected to include various combinations of stubble management (burnt,

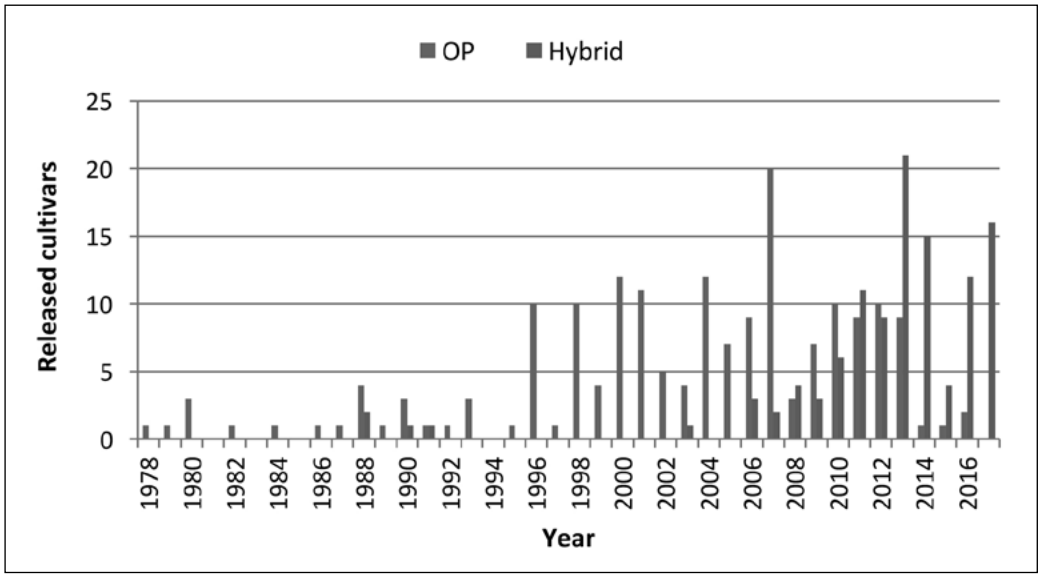

Figure 1. Year release of H or OP canola varieties in Australia from 1978 to 2017 *(Source: Steve Marcroft).*

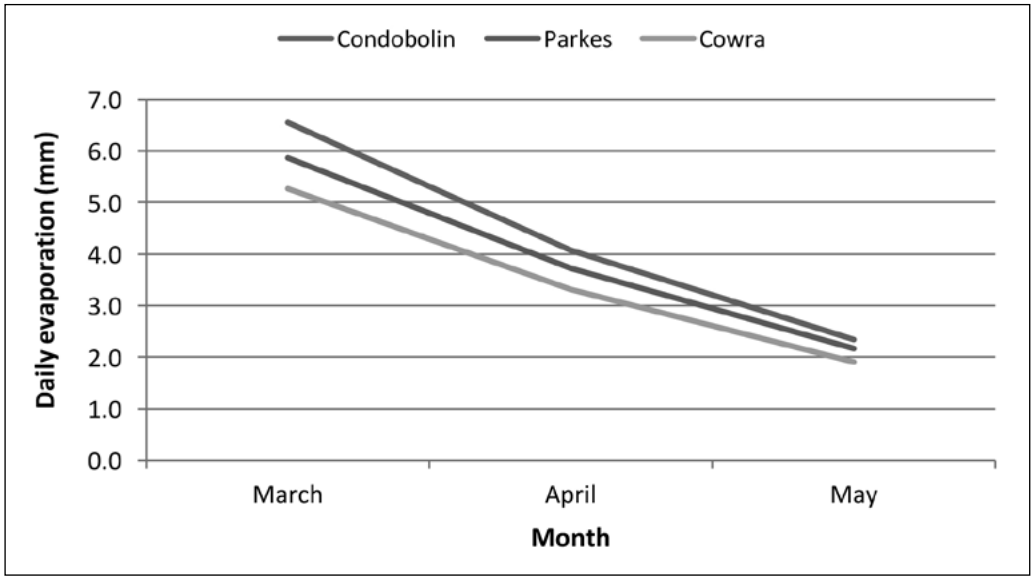

Figure 2. Average daily evaporation rates across central NSW during March, April and May *(Source: CliMate).*

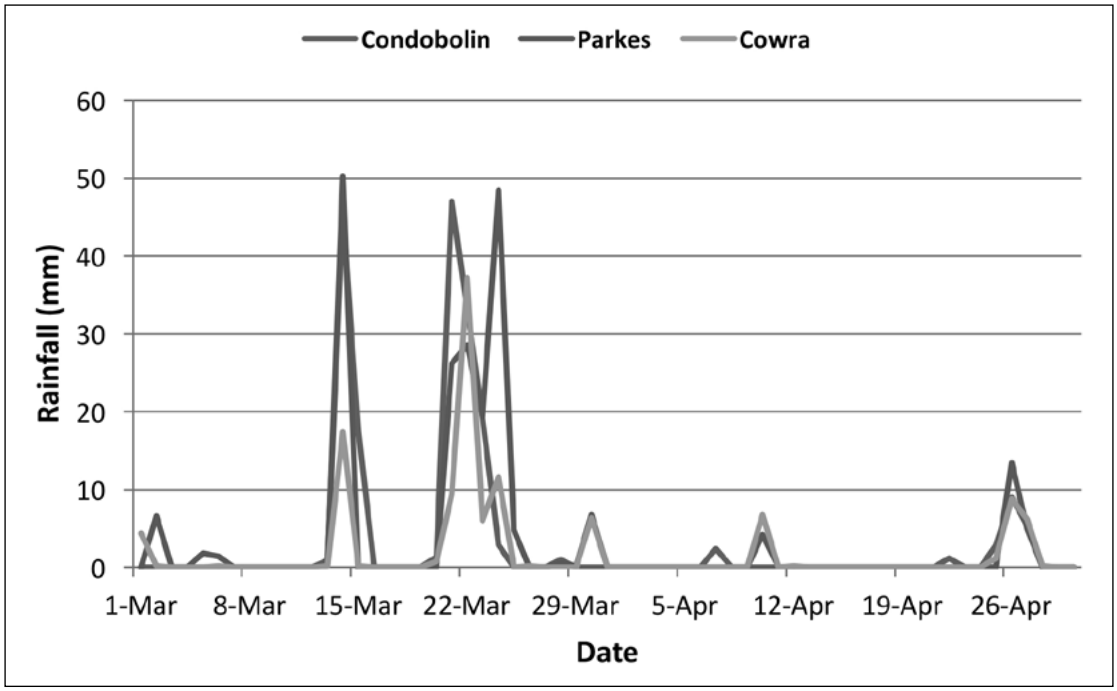

Figure 3. Daily autumn rainfall events across Condobolin, Parkes and Cowra in 2017.

retained and cultivated) and seeding system (knifepoint /presswheel, disc or scatter-plate). The survey design allowed for 10 paddocks with each combination of stubble management and seeding system from each rainfall zone (low, medium and high).

Plant establishment was measured across 15 x 1m^2 quadrants per paddock, and from this an establishment % was determined via knowledge of seed size and sowing rate. If the seed size was unknown, a sample was taken for seed size determination. Plant population and plant uniformity were measured via the development of the 'vacancy %' method. This method relies on using a 1m^2 section of mesh with 10cm squares. The mesh is used as the quadrant to count plants across 4 x 1m linear rows, as well as to count the total number of vacant squares within four linear metres. From this plant population and a vacancy % were determined.

Other data collected from each paddock includes sowing date, seeding depth, fertiliser rate/placement/source, variety, seeding rate, GPS coordinates, seed treatment, sowing speed, soil type, seedbed moisture conditions at sowing, and crusting events post sowing.

Results and discussion

A wet March and some timely rainfall events in April (Figure 3) allowed canola to be sown into favourable seedbed conditions across the low, medium and high rainfall zones of central NSW

Table 1. Breeding type and herbicide tolerance of paddocks surveyed across the low, medium and high rainfall zones of central NSW in 2017.

Breeding type	Rainfall region			Total
	Low	Med	High	
Hybrid	***4***	***18***	***22***	44
Clearfield®	1	9	7	17
Conventional	3	4		7
Roundup Ready®		2	2	4
Roundup Ready® + Triazine Tolerant			2	2
Triazine Tolerant		3	11	14
OP	***28***	***22***	***1***	51
Triazine Tolerant	28	22	1	51
	32	40	23	95

Table 2. Establishment, plant density and vacancy % on 95 paddocks surveyed in central NSW in 2017.

Frequency	Establishment (%)	Plants density (m^2)	Vacancy (%)
Min	17%	10	76%
1st Quartile	38%	19	56%
Mean	48%	26	47%
3rd Quartile	58%	32	39%
Max	86%	64	18%

in 2017. March rainfall was above the long-term average (LTA) at Condobolin, Parkes and Cowra, with an additional 41mm, 56mm and 49mm above the LTA, respectively. Seedbed moisture conditions were favourable at the start of April, and then started to decline from mid-April onwards. Additional rainfall around Anzac Day ensured favourable crop establishment for most of central NSW. In the paddock survey, the earliest, median and last sowing dates were 10 April, 22 April and 10 May, respectively.

Across the 95 survey paddocks, 44 were hybrid varieties and 51 were OP (Table 1). Breeding type (H or OP) was largely influenced by growing season rainfall and length of growing season, with H varieties dominating the high rainfall zone (22 H, 1 OP), OP dominating the low rainfall zone (4 H, 28 OP), and an even split between H and OP in the medium rainfall zone (H 18, OP 22). Refer to Table 1 for further details

Across the 51 survey paddocks that were OP, 16 paddocks were purchased seed and 35 paddocks were grower retained seed. Interestingly, only four of the 35 grower retained seed paddocks were not graded to seed size. Seed size grading ranged from 1.6mm to 2mm sieve size, however the sieve size was determined by the ratio of total seed graded to how much seed was required for the following sowing.

Interestingly, across all paddocks the average seeding rate was 2.5kg/ha for OP (1.6–4kg/ha), and 2.4kg/ha for H (0.9–3.2kg/ha). The average seed size from the H varieties was 4.9g/1000 seed (203,610 seeds/kg), and 3.9g/1000 seeds (257,106 seeds/kg) for the OP.

Table 2 illustrates a summary of results for establishment %, plant density and vacancy %. The average establishment was 48%, and the majority (between 1st and 3rd Quartile) of paddocks ranged between 38% and 58%. Establishment improved from low to medium to the higher rainfall zone, with the low, medium and high rainfall zones achieving a respective 43%, 47% and 55% establishment.

While each paddock had 36 pieces of information recorded, the main factor that differentiated establishment % was seed size. The mean seed size was 4.3g/1000 seeds and ranged from 3.3g to 6.6g/1000 seeds.

Figure 4 shows that establishment improved as seed size increased, however this trend was not linear and establishment decreased between the seed size of 4g and 4.5g/1000. In addition to seed size, there was an average increase in establishment by 6% (points) from selecting an H seed over an OP seed (51% establishment for H, and 45% establishment for OP).

After seed size, the top four agronomic practices that influenced canola establishment were seeding system (P=0.01), stubble management (P=0.02), sowing speed (P=0.02) and P fertiliser placement (P=0.05).

On average, reducing stubble loads via either burning or cultivation improved canola establishment by 10% (Figure 5). The main benefit appears to be from the physical removal of the stubble, rather than cultivated seedbed.

Table 2 shows that the average vacancy % was 47%, and ranged from 18% to 76%. Further research trials are being undertaken to develop calibration relationships between vacancy % and grain yield.

Interestingly, old seeding system technology such as 'scatter-plates' performed well in this survey. On average, the highest establishment of 58% was achieved with scatter-plates, and then reduced to 49% and 41% with the respective knifepoint and disc machine seeding systems. It is likely that the main benefits of the scatter-plate seeding system are due to shallow seed placement and favourable autumn conditions in 2017.

Establishment decreased as sowing speed increased, with a 16% establishment reduction if speed increased from 6–8km/hr to 13–17km/hr.

On average, there was a 7% reduction in establishment if P fertiliser was not separated from seed. There were two main groups of P fertiliser

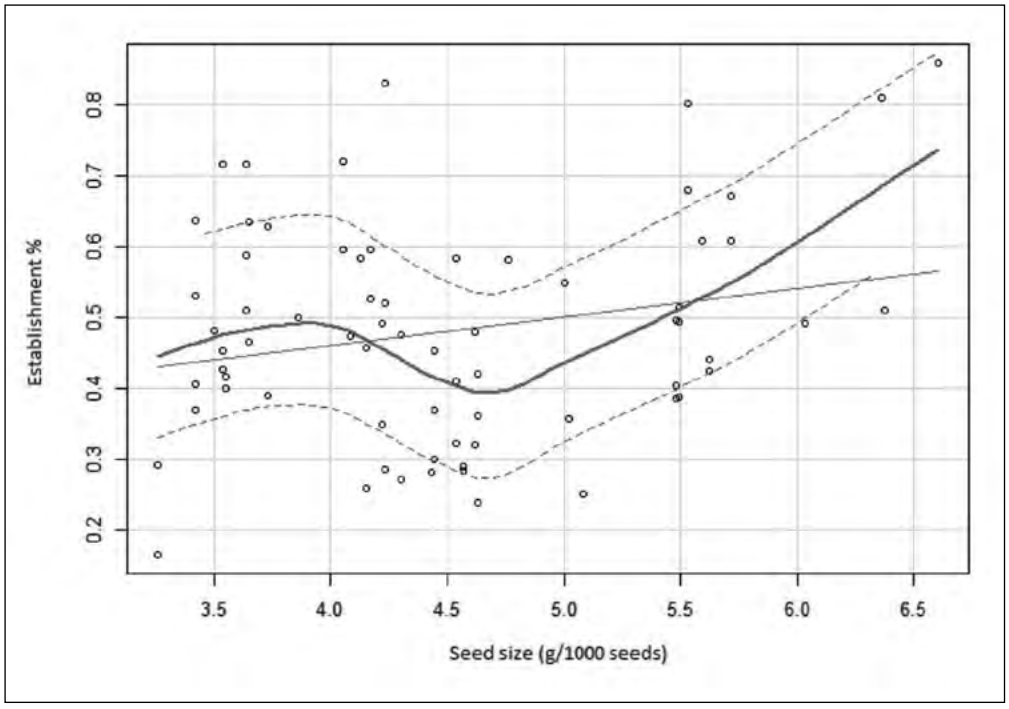

Figure 4. Fitted and observed relationship between seed size (g/1000 seeds) and canola establishment % with 95% confidence intervals.

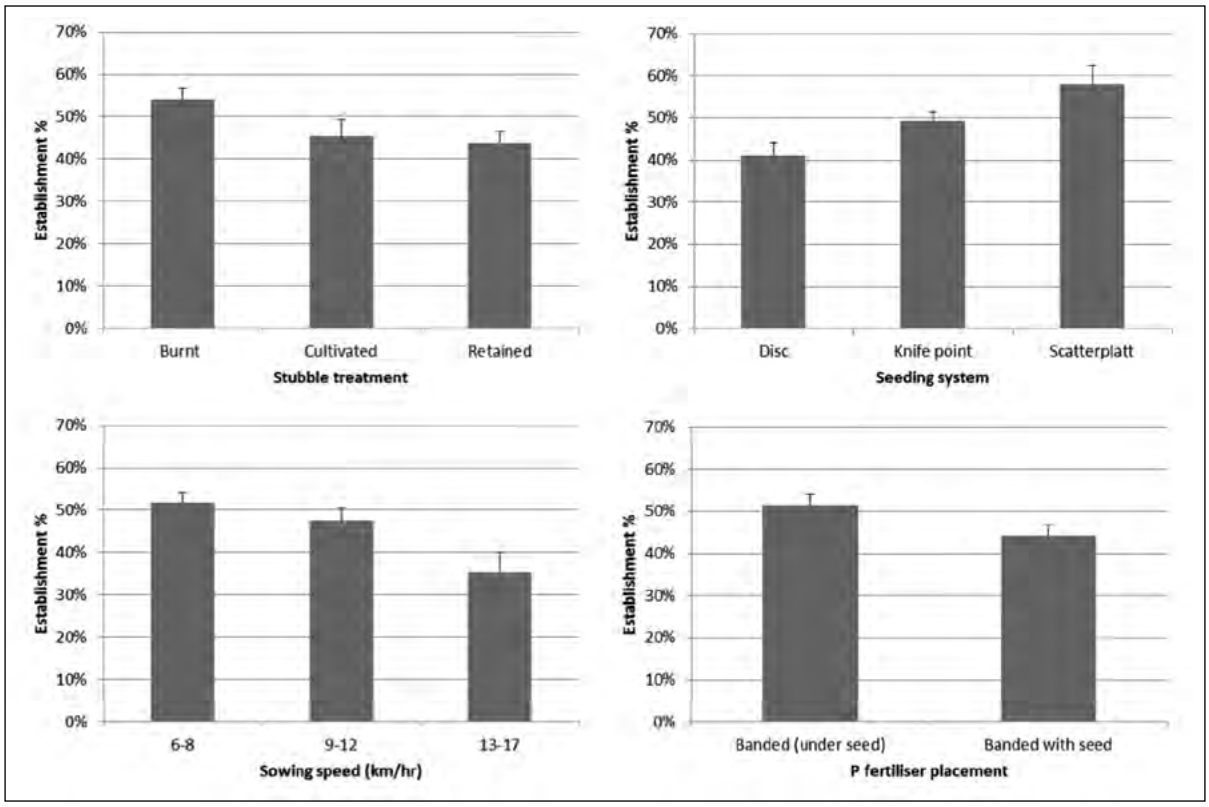

Figure 5. Effect of stubble management, seeding system, sowing speed and fertiliser placement on canola crop establishment. Standard error bars shown.

rates — 40% of paddocks had between 50–75kg/ha monoammonium phosphate (MAP) and another 40% had between 75–100kg/ha MAP.

Conclusion

Despite favourable sowing conditions in 2017, these results suggest there is an opportunity for improved canola establishment in central NSW. Effectively, growers are only establishing half of what they purchase, and if the autumn break was less favourable, it is likely to be much less. Traditionally, growers would apply an extra 1–1.5kg/ha of seed to compensate for poor sowing conditions, however this is no longer an option given the associated higher costs with hybrid seed.

Seed size was the main differentiating factor that improved canola establishment, while the other key agronomic practices were stubble removal, reduced sowing speed, shallow seed placement and P fertiliser separated from the seed. Hybrids were generally larger in size, and establishment was better than OP varieties. Further research is required to evaluate why the relationship between seed size and establishment was not linear.

The benefits of the scatter-plate seeding system in 2017 were likely to be associated with shallow seed placement combined with weather conditions that provided moist conditions for the canola seedling to germinate and establish. Canola establishment results are likely to be different if moisture seeking was required. These results highlight the importance of taking time to set up seeding equipment, particularly with the disc seeding machine as they are typically used in high stubble load paddocks, sowing speeds are higher and have limited fertiliser separation from the seed.

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Contact details

Colin McMaster
161 Kite Street, Orange NSW, 2800
0427 940 847
colin.mcmaster@dpi.nsw.gov.au
@master4colin

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Observations from the 2018 Saskatchewan Young Farmer of the Year Award winners

Jordan and Jennifer Lindgren.

Lindgren Farms.

Notes

Jordan and Jennifer Lindgren, along with their four children, own and operate Lindgren Farms at Norquay, Saskatchewan, Canada. Lindgren Farms is a grain and oilseed farm that works diligently at maximising production for these crops, while minimising cost of production. They do this by using field scale trials to determine what products, genetics and practices work on their farm. By combining these methods, with the latest advancements in technology, they continue to meet and exceed their production goals.

They not only place importance on educating themselves, but also sharing this information with fellow farmers. Jordan and Jennifer partner with local agricultural distributors to host the 'Field of Dreams' tour that is held annually on their farm. It is an opportunity to share trial results from previous years and showcase the current trials that are focussed on new genetics, applications and variable fertiliser rates. They also educate the next generation on the importance of farming and teaching them where their food comes from.

Contact details

Jordan Lindgren
jordan@lindgrenfarms.com

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Final session
Day 2

Served with a side of science — building community trust in food production

Heather J. Bray[1] and Professor Rachel A. Ankeny[2].

[1]School of Biological Sciences, University of Western Australia; [2]School of Humanities, University of Adelaide.

Keywords

- community trust, shared values, social licence.

Take home messages

- Producers have community support, but this support is fragile.
- Trust is not based on knowledge, so it cannot be gained by education alone.
- To build trust, agricultural industries need to be trustworthy.

Introduction

Growing community interest in food production and its impact on the environment has placed food producers and their practices under increasing public scrutiny. Media and political attention to the welfare of farm animals, the use of biotechnology, and the use of pesticides in food production, suggests that the community is increasingly concerned about these issues, and seeks to put pressure on food producers to change their practices. In addition, calls for increasing regulation in these domains have been interpreted as a loss of trust in agricultural industries, and that the community no longer believes that producers should be able to make their own decisions about how to use resources to produce food. In this paper, evidence from recent research is presented that suggests producers generally are supported by the broader Australian community, but there are some practices about which the community is concerned. We make the case that the key to building ongoing community trust in agricultural industries relies on understanding the nature of trust, including the idea that producers have been entrusted with the care of resources that are shared, and that actively managing those resources responsibly and responsively is a key aspect of building trust.

Science is at the core of many agricultural issues

Scientific research has significantly changed how food is produced over the past 50 years. Many of these changes were aimed at improving the productivity, efficiency and profitability of food production. More recently, innovation has also focused on increasing the sustainability of food production in the face of climate variability and increasing global population. However, many agricultural issues that are discussed in the popular media and about which the community are concerned have science at their core, e.g. the use of biotechnology to improve crops, how to measure the welfare of production animals in a range of housing environments, and the responsible use of pesticides and veterinary medicines. For some of these issues, there may be conflicting evidence presented by different groups who all claim to use science, and so it can be difficult for the general public to know who to believe. Despite science-based efforts to make operations more efficient and sustainable, sections of the Australian public feel that agriculture is no longer based on the same shared values that grounded more 'traditional' and small-scale family farming, and that economic drivers have led to a food system aimed at mass production and profit making that has changed too quickly for risks to be fully assessed (Kriflik and Yeatman 2005).

In some ways, agricultural science has become the 'victim of its own success' — as production practices have become increasingly complex and reliant on technology, they have become 'black-boxed', or hidden. Inputs and outputs enter and leave the production system, but processes within the system have become 'hidden' from everyday people's view, and only understood by those with specialist expertise. This is not unique to agriculture and the same could be said for most industries, for example, manufacturing and health care are also increasingly reliant on technology. However, food production is different from these activities because the broader community can, to some extent, produce some of their own food if they wish. Most people do not make their own cars or perform their own blood tests, but even people in quite urbanised areas can grow vegetables or keep some chickens for eggs, with little knowledge of 'agriculture' and these practices are at odds with the technical inputs required to grow food on a commercial scale. This is exacerbated further by the so-called demise of the 'country cousin', and idyllic representations of food production in the popular media (Phillipov 2016) which connect ideas about food production to nostalgic memories of how food production used to be. This mismatch between ideas of how food was and can be produced, and how it is currently produced on a commercial scale, is often blamed for decreasing community trust. At this point it is important to examine the evidence about community trust in agriculture, and then we can return to the role that perceptions and knowledge play in community trust.

Australians trust producers, but this trust is fragile

In addition to the anecdotal evidence provided by the outpourings of support for farmers during drought and other times of hardship, social research has demonstrated that Australians think that farmers are good contributors to Australian society, are well-educated about agriculture, use technology to improve their business, are good stewards of the land, and are generally good business operators (Worsley et al. 2015). Australian adults also believe that farmers look after their livestock well (Cockfield and Botterill 2012; Worlsey et al. 2015) and are producing clean, safe food (Cockfield and Botterill 2012). Further, farmers are the most trusted people in the food system, ahead of retailers, the media, and politicians (Meyer et al. 2012). In the 'Australian beliefs and attitudes towards science' surveys conducted by the Australian National University in 2017 and 2018, farmers were in the top three professions listed as 'contributing a lot' to society, along with doctors and scientists (Lamberts 2018).

However, there is also evidence that there are problems. In addition to claims about production practices being increasingly seen on food labels, social research has also shown that the community is concerned about some agricultural practices. Although there is little scholarly research that directly examines perceptions of the grains industry, one study based in Brisbane revealed that participants felt that cropping land was not in good condition, along with waterways, native vegetation, and grazing land (Witt et al. 2009). In this study, 45% of participants agreed that current rural land management is unsustainable, but encouragingly there was very strong agreement with the idea that farming and conservation are compatible. The use of biotechnology to improve crops has had mixed levels of support in Australia (see Bray and Ankeny 2017 for a review of some of this research) with the most recent polls revealing that 46.6% of participants thought that genetically-modified (GM) food was generally safe to eat, while 33.1% thought that it was generally unsafe (Lamberts 2018). In 2017, the same poll revealed that 62.3% of participants felt that foods grown with pesticides were generally unsafe (Lamberts 2017), and 'chemical-free' remains the most frequently cited benefit organic food by organic consumers (Lawson et al. 2018).

Trust is not based on knowledge, so cannot be gained through education alone

Differences of opinion about production practices between producers and the broader community are often attributed to a 'gap' in community knowledge. Australians generally have low levels of knowledge about agriculture — both school children (Hillman and Buckley 2011) and adults (Worsley et al. 2015) have been shown to have poor agricultural literacy. However, looking solely at knowledge is problematic for a number of reasons. Firstly, knowing a lot about a topic does not mean that you will feel positively about that topic, and knowing how a technology works does not guarantee that you will want it to be used in food production. Research in science communication has shown that blaming community ignorance for a lack of acceptance of a technology, known as the 'deficit model' (Sturgis and Allum 2004), and then trying to address this by increasing knowledge are ineffective at best, and may even have increased negative attitudes towards some technologies (Hart and Nisbet 2012). To use GM as an example, there are studies that have shown that different types of knowledge are associated with

attitudes and perceptions of risk (reviewed by Bray and Ankeny 2017), but other studies have shown that even those with very high levels of scientific knowledge, for example scientists, can have different opinions about GM crops. Interestingly, most studies that examine knowledge focus on science — there are few, if any, that examine knowledge about agricultural production systems. Secondly, what kind of knowledge is important when making decisions about what is 'right' and 'wrong' within food and fibre production systems? Should everyone in the community have the same kind of detailed technical knowledge as producers? Of course, this is impossible, as our society relies on people having different areas of specialist expertise aligned with their roles and there are other roles apart from food production that are important for society to function. This is why trust is important and leads on to a third reason why focusing on knowledge is problematic — trust is not based on knowledge. We trust people to fulfil their roles in part because we do not have the time or ability to acquire the detailed knowledge and expertise that they possess. Trust is the "optimistic acceptance of a vulnerable situation which is based on positive expectations of the intentions of the trusted individual or institution" (Meyer and Ward 2009). In other words, we know that we are putting something we care about into the care of others when we trust them, and we hope that they will not do anything to harm it. When it comes to food production, the community has entrusted food producers to produce safe and healthy food, and to do so by managing shared resources such as land and water in a responsible way, and in a way that also considers the welfare of other things that they care about, such as animals, and the environment.

Being trustworthy is the key to building trust

Part of the risk when we trust someone is that something may well go wrong, however we trust them to make the right decisions for the right reasons. As such, there need to be shared values between those who are trusting and those who are trusted, not just in terms of caring about the same things, but also sharing values about how things are done. For most people, that means that the people that we trust adhere to rules and standards and act with integrity. How people have acted in the past also becomes part of our judgement about whether to trust them. Another key component of trust relates to competence or expertise — 'to say we trust you means we believe you have the right intentions towards us and that you are competent to do what we trust you to do' (Hardin 2002). We have already presented evidence that, for the most part, Australians believe that food producers are worthy of trust.

However, and as stated previously, there is also evidence that the broader community perceives that some within the food production sector no longer share their values, do not have their best interests at heart, and place emphasis on profits over environmental sustainability, and the welfare of animals and the producers themselves. Recent media exposés and community action over some industry practices make this clear, but we do not know whether the actions of one industry sector affect attitudes to food production as a whole. It is important to note, however, that decreasing trust is also part of a much bigger trend in society — we have become far less trusting overall. The Edelman Trust Barometer for 2018 (Edelman 2018) shows that Australians, along with those in many other countries, are generally distrustful of non-governmental organisations (NGOs), businesses, government, and media. This has led to increasing interest from a range of industries in finding ways to (re)build trust with the community. Some recent work in agriculture from CSIRO researchers with experience in the mining sector has looked specifically at the egg industry (Moffat et al. 2018) and provides insights into community trust. In this study, the researchers found that trust was associated with perceptions that the industry was responsive to community sentiment, and that the industry was well regulated. Trust was also found to be the key factor for industry acceptance.

Conclusion

In summary, recent social research highlights that the community does have high levels of trust (broadly) in food producers, but there are specific industry sectors and practices that they are concerned about. The trust that producers enjoy is not motivated by high levels of technical knowledge about agricultural science, and as such, distrust cannot be managed by educating the community about agricultural science alone. Communicating about values that are shared between food producers and the community, and being responsive to community concerns, are important ways for industries to build community trust.

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Contact details

Heather J. Bray
School of Biological Sciences, M092,
University of Western Australia
35 Stirling Hwy, Crawley WA 6009
08 6488 2508
heather.bray@uwa.edu.au
@heatherbray6

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

Mick Rose[1], Lukas Van Zwieten[1,6], Pei Zhang[2], Gavan McGrath[3], Nikki Seymour[4], Craig Scanlan[5] and Terry Rose[6].

[1]NSW Department of Primary Industries; [2]Victorian Department of Economic Development, Jobs, Transport and Resources; [3]Ishka Solutions; [4]Department of Agriculture and Fisheries, Queensland; [5]Department of Primary Industries and Regional Development, Western Australia; [6]Southern Cross University.

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%.

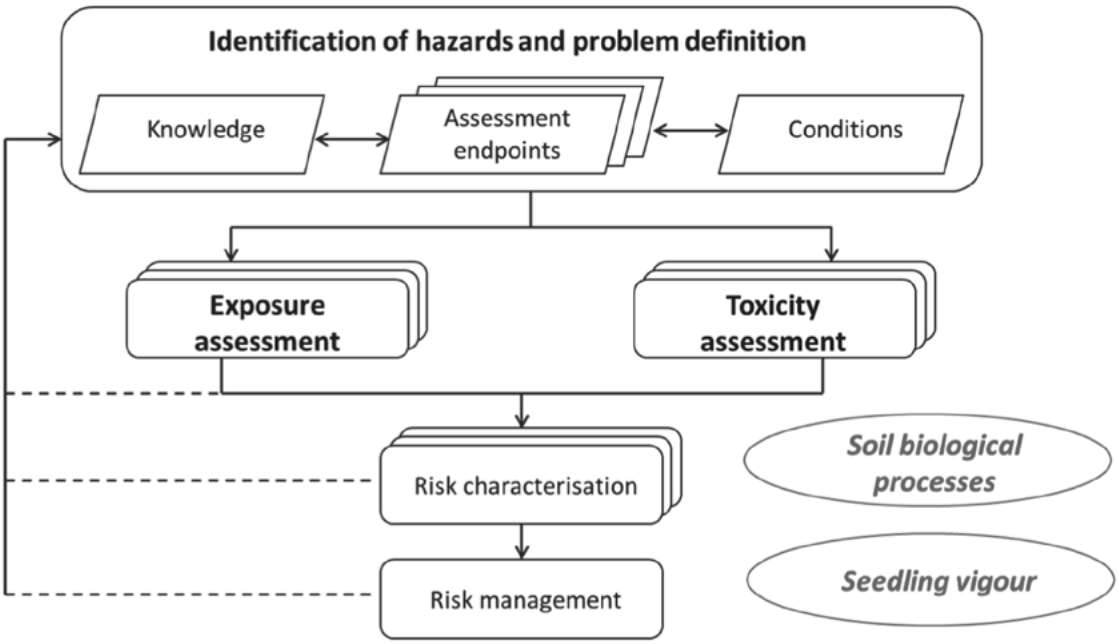

Figure 1. Risk assessment framework used to assess the potential scale of reduced soil and crop health due to herbicide residues in soil.

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

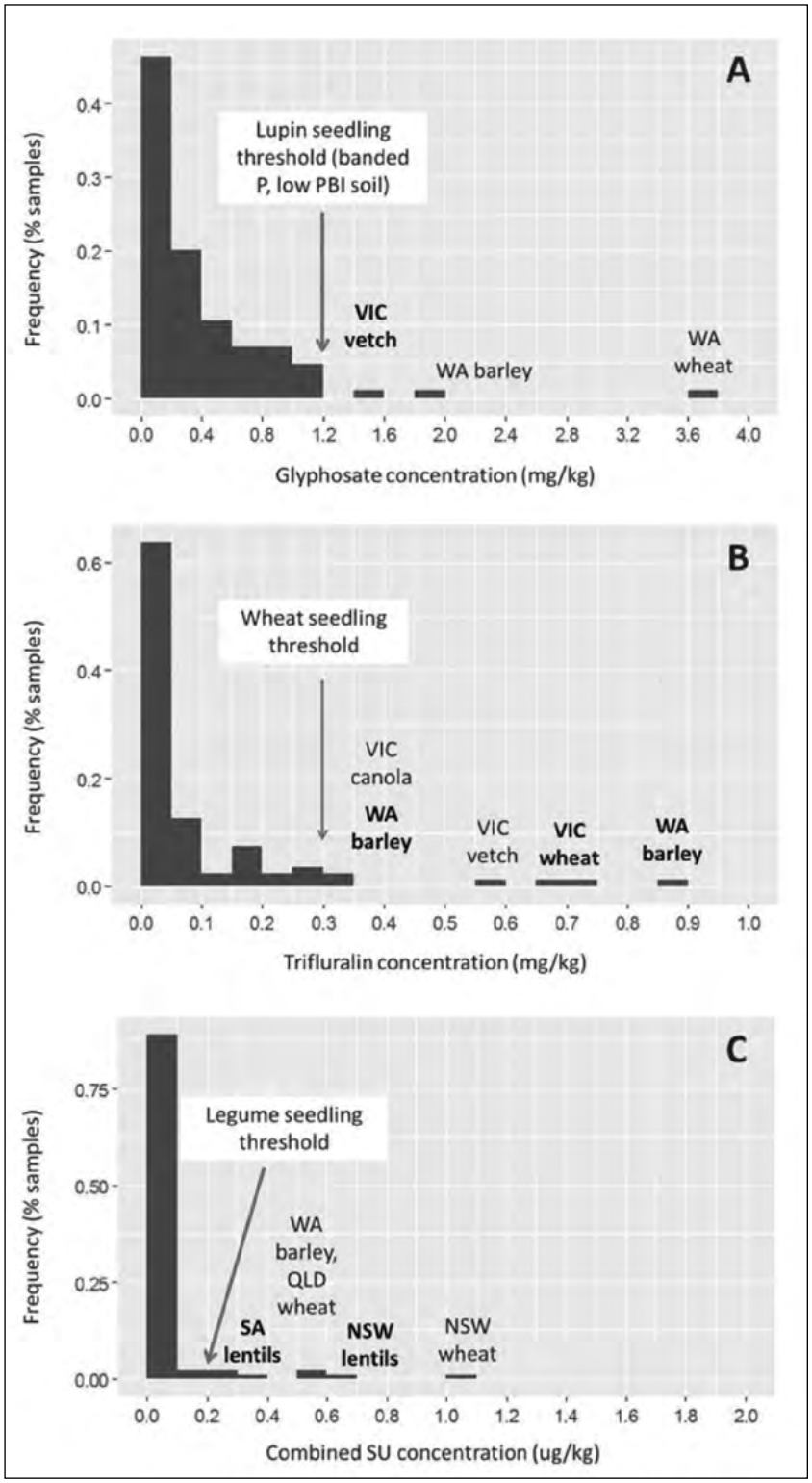

Figure 2. Hazard assessment for A) glyphosate, B) trifluralin and C) sulfonylurea residues in soil. Text in bold indicates potential negative impacts on growth of sensitive crop. Normal text indicates paddocks exceeded thresholds for sensitive crops but when planted with a tolerant crop unlikely to suffer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

Acknowledgement

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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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Contact details

Mick Rose
mick.rose@nsw.dpi.gov.au

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Notes

THE 2017-2019 GRDC NORTHERN REGIONAL PANEL

JANUARY 2019

GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHAIR - JOHN MINOGUE

John Minogue runs a mixed broadacre farming business and an agricultural consultancy, Agriculture and General Consulting, at Barmedman in south-west NSW. John is chair of the district council of the NSW Farmers' Association, sits on the grains committee of NSW Farmers' Assn and is a winner of the Central West Conservation Farmer of the Year award. His vast agricultural experience in central west NSW has given him a valuable insight into the long-term grains industry challenges.

M +61 428 763 023 E jlminogue@bigpond.com

DEPUTY CHAIR - ARTHUR GEARON

Arthur is a grain, cotton and beef producer near Chinchilla, Queensland. He has a business degree from the Queensland University of Technology in international business and management and has completed the Australian Institute of Company Directors course. He is a previous vice-president of AgForce Grains and has an extensive industry network throughout Queensland. Arthur believes technology and the ability to apply it across industry will be the key driver for economic growth in the grains industry.

M +61 427 016 658 E agearon@bigpond.com

ROGER BOLTE

Roger Bolte is a fourth-generation farmer from the West Wyalong area in NSW, operating a 6500 ha winter cropping program with his wife and family focussing on cereals, legumes and hay. During his 35-years in the industry, Roger has been involved in R&D in various capacities and has had the opportunity to travel abroad and observe a variety of farming systems. He believes that R&D and education are the cornerstones of the industry and feels privileged to be afforded the opportunity to share his experiences.

M +61 404 295 863 E rogerbolte@bigpond.com.au

ROY HAMILTON

Roy Hamilton operates a 4400 ha mixed family farming enterprise near Rand in NSW's Riverina. He was an early adopter of minimum till practices and direct drill and press wheel technology and is currently migrating to CTF. The majority of the property is cropped while the remainder runs ewes and trade lambs. He has held roles on the south east NSW Regional Advisory Committee, the GRDC's southern region Regional Cropping Solutions Network and was a founding committee member of the Riverine Plains farming systems group.

M +61 428 691 651 E roy@bogandillan.com

DR TONY HAMILTON

Tony is a grower from Forbes, NSW and managing director of an integrated cropping and livestock business. He is a director of the Rural Industries Research and Development Corporation. He has worked as an agricultural consultant in WA and southern NSW. With a Bachelor of Agricultural Science and a PhD in agronomy, Tony advocates agricultural RD&E and evidence based agriculture.

M +61 406 143 394 E tony@merriment.com.au

ANDREW MCFADYEN

Andrew is a grower and private agricultural consultant near Lake Cargelligo NSW with more than 17 years agronomy and practical farm management experience. He is an active member of the grains industry with former roles on the Central East Research Advisory Committee, NSW Farmers Coolah branch and has served on the GRDC northern panel since 2015. He is also a board member and the chair of Grain Orana Alliance.

M +61 436 191 186
E andrew@mcfadyenconsulting.com.au

PETER MCKENZIE

Peter operates a private agronomy consulting business based in Quirindi NSW. Prior to this he was facilitator/agronomist for AgVance Farming group, a communications conduit between industry and growers. He is a passionate supporter of research and has been active in extending weed management research information to industry, particularly in central west NSW, is a former director of Conservation Farmers Inc., a former member of the North East Regional Advisory Committee and a participant in Northern Growers Alliance local research group on the Liverpool Plains.

M +61 428 747 860 E pete@agcon.net.au

GRAHAM SPACKMAN

Graham has been Managing Director of a private agricultural consultancy at Emerald, Queensland, for the past 28 years, providing advice on the agronomy and management of summer and winter, dryland and irrigated crops in grain and mixed farming systems. He has extensive involvement in RD&E having participated in two decades of GRDC and DPI-funded farming systems research, particularly in weed management, soil fertility and adaption of agronomic practices in CQ farming systems. Graham was a member of the CQ Research Advisory Committee for over 10 years and Chairman for five years.

M +61 407 156 306 E gspackman@siac.com.au

BRUCE WATSON

Bruce and his family operate a 3400 ha family grain growing business near Parkes NSW, which produces a mixture of dryland winter cereals, pulses and oilseeds as well as summer dryland cereals, pulses and cotton grown on a 12m zero till CTF platform with full stubble retention. Bruce holds a Bachelor of Agricultural Economics from the University of Sydney and previously worked with PricewaterhouseCoopers in its Transfer Pricing practice. He is an active member of the grains industry and was awarded a Nuffield Scholarship in 2009.

M +61 408 464 776 E watson.woodbine@gmail.com

DR JO WHITE

Dr Jo White is an experienced researcher with over 15 years' experience in agricultural research programs based at the Department of Agriculture and Fisheries in Queensland (DAFQ) and the University of Southern Queensland (USQ), including 10 years' experience in the field of plant pathology of broad acre summer crops. Jo has a keen interest in developing and delivering on-ground practical research solutions to growers which improve productivity and profitability of their farms and is now working as a private consultant based in Queensland.

M +61 490 659 445 E joandsimonwhite@bigpond.com

DR NICOLE JENSEN

Nicole Jensen is GRDC General Manager for the newly created Genetics and Enabling Technologies business group. Nicole brings a wealth of experience in plant breeding and related activities arising from several roles she has held in Australia and internationally in the seed industry including positions as Supply Innovation Lead with the Climate Corporation - Monsanto's digital agricultural flagship, Global Trait Integration Breeding Lead for Monsanto.

T 02 6166 4500 E Nicole.Jensen@grdc.com.au

P Level 4 | 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604
T +61 2 6166 4500 **F** +61 2 6166 4599 **E** grdc@grdc.com.au

NORTHERN REGION GROWER SOLUTIONS GROUP AND REGIONAL CROPPING SOLUTIONS NETWORK

JANUARY 2019

The Northern Region of the Grains Research and Development Corporation (GRDC) encompasses some of the most diverse cropping environments in Australia, ranging from temperate to tropical climates – it has the greatest diversity of crop and farming systems of the three GRDC regions.

Implemented, to provide structured grower engagement, the GRDC Grower Solutions Group projects and the RCSN project have become an important component of GRDC's investment process in the northern region. The Northern Region Grower Solutions Group and the RCSN have the function of identifying and, in the case of Grower Solutions Groups managing short-term projects that address ideas and opportunities raised at a local level which can be researched demonstrated and outcomes extended for immediate adoption by farmers in their own paddocks.

GROWER SOLUTIONS GROUP AND REGIONAL CROPPING SOLUTIONS NETWORK CONTACT DETAILS:

NORTHERN GROWER ALLIANCE (NGA)

RICHARD DANIEL

Northern New South Wales and Southern Queensland (Toowoomba)

E **Richard.Daniel@nga.org.au**
W **www.nga.org.au**
M **0428 657 182**

Northern Grower Alliance (NGA) was established in 2005 to provide a regional capacity for industry-driven, applied agronomic grains research. NGA is currently working on a five year Grower Solutions project, fully funded by the GRDC, focussing on cropping areas from the Liverpool Plains to the Darling Downs and from Tamworth and Toowoomba in the east to Walgett, Mungindi and St George in the west. A network of six Local Research Groups, comprised of advisers and growers, raise and prioritise issues of local management concern to set the direction of research or extension activity. Areas of focus range from weed, disease and pest management through to nutrition and farming system issues.

GRAIN ORANA ALLIANCE (GOA)

MAURIE STREET

Central West New South Wales (Dubbo)

E **Maurie.street@grainorana.com.au**
W **www.grainorana.com.au**
M **0400 066 201**

Grain Orana Alliance (GOA) is a not for profit organisation formed in 2009 to help meet growers research and extension needs in the Central West of NSW to support their enduring profitability. Currently operating under the GRDC Grower Solutions Group - Central NSW project, one of the key priorities is to identify and prioritise R,D and E needs within the region through engagement with local growers and advisers. This grower engagement helps direct both the GRDC investments in research projects and GOA's own successful research programs. GOA's research covers a wide range of relevant topics such as crop nutrition, disease management and weed control. The structure of the project allows for a rapid turnaround in research objectives to return solutions to growers in a timely and cost effective manner whilst applying scientific rigour in the trial work it undertakes. Trials are designed to seek readily adoptable solutions for growers which in turn are extended back through GOA's extensive grower and adviser network.

CENTRAL QUEENSLAND GROWER SOLUTIONS GROUP

ROD COLLINS

Central Queensland (Emerald)

E **Rodney.Collilns@daf.qld.gov.au**
M **0428 929 146**

The Central Queensland Grower Solutions project, is a GRDC and DAF Queensland investment in fast-tracking the adoption of relevant R,D & E outcomes to increase grower productivity and profitability across central Queensland. Covering approximately 550,000 ha and representing 450 grain producing businesses, the central Queensland region includes areas from Taroom and Theodore in the south to Mt McLaren and Kilcummin in the north, all of which are serviced by the project staff, located in Biloela and Emerald. Team leader Rod Collins is an experienced facilitator and extension officer with an extensive background in the central Queensland grains industry. He was part of the initial farming systems project team in the region throughout the late 90's and early 2000's which led the successful adoption of ley legumes to limit nutrient decline and wide row configurations in sorghum to improve yield reliability across central Queensland. He has more recently led the development and delivery of the Grains Best Management Practices program.

COASTAL HINTERLAND QUEENSLAND AND NORTH COAST NEW SOUTH WALES GROWER SOLUTIONS GROUP

The Coastal Hinterland Queensland and North Coast New South Wales Grower Solutions project was established to address the development and extension needs of grains in coastal and hinterland farming systems. This project has nodes in the Burdekin managed by Dr Steven Yeates from CSIRO; Grafton managed by Dr Natalie Moore from NSW DPI; Kingaroy managed by Nick Christodolou (QDAF) and Bundaberg managed by Neil Halpin.

BUNDABERG QUEENSLAND:

NEIL HALPIN

E **Neil.Halpin@daf.qld.gov.au**
M **0407 171 335**

Neil Halpin is a principal farming systems agronomist with the Queensland Department of Agriculture and Fisheries. He has over 30 year's field trail experience in conservation cropping systems, particularly in the sugar-based farming systems of the coastal Burnett. His passion is for the integration of grain legume break crops, reduced tillage, controlled traffic and organic matter retention in coastal farming systems. Maximising the productivity and profitability of grain legumes (peanuts, soybeans and mung beans) is a common theme throughout the various production areas and systems covered by this project.

KINGAROY QUEENSLAND:

NICK CHRISTODOULOU

E **Nick.Christodoulou@daf.qld.gov.au**
M **0427 657 359**

Nick Christodoulou is a principal agronomist with the Department of Agriculture & Fisheries (QDAF) on Qld's Darling Downs and brings over 25 years of field experience in grains, pastures & soil research, with skills in extension application specifically in supporting and implementing practice change. Nick has led the highly successful sustainable western farming systems project in Queensland. Nick was also project leader for Grain & Graze 1 Maranoa-Balonne and DAF leader for Grain & Graze 1 Border Rivers project, project leader for Grain and Graze 2 and was also Project leader for the Western QLD Grower Solutions project. Currently he is the coordinator for the Grower Solutions Southern Burnett program.

BURDEKIN QUEENSLAND:

STEPHEN YEATES

E Stephen.Yeates@csiro.au
M 0417 015 633

The Burdekin & tropical regional node of the Coastal and Hinterland Growers Solution Project is led by CSIRO research agronomist Dr Stephen Yeates and technical officer Paul McLennan, who are based at the Australian Tropical Science and Innovation Precinct at James Cook University, Townsville. The Burdekin & tropical Grower Solutions node has a committed and expanding advisory group of farmers and agribusiness professionals. Due to the rapid increase in farmers producing mungbean in the region an open door policy has been adopted to advisory group membership to ensure a balance in priorities between experienced and new growers. The node is focused on integrating grain crops into sugar farming systems in the lower Burdekin irrigation area in NQ and more recently contributing to other regions in the semi-arid tropics that are expanding or diversifying into grain cropping. Information and training requests for information and training from the Ord River WA, Gilbert River NQ, Mackay and Ingham areas necessitated this expansion. Recent work has focussed on the introduction of mungbeans in the northern Queensland farming systems in collaboration with the GRDC supported entomologists Liz Williams and Hugh Brier, Col Douglas from the mungbean breeding team, the Australian Mungbean Association and Pulse Australia. Both Stephen and Paul have many decades of experience with crop research and development in tropical Australia.

GRAFTON NEW SOUTH WALES:

NATALIE MOORE

E natalie.moore@dpi.nsw.gov.au
P 02 6640 1637

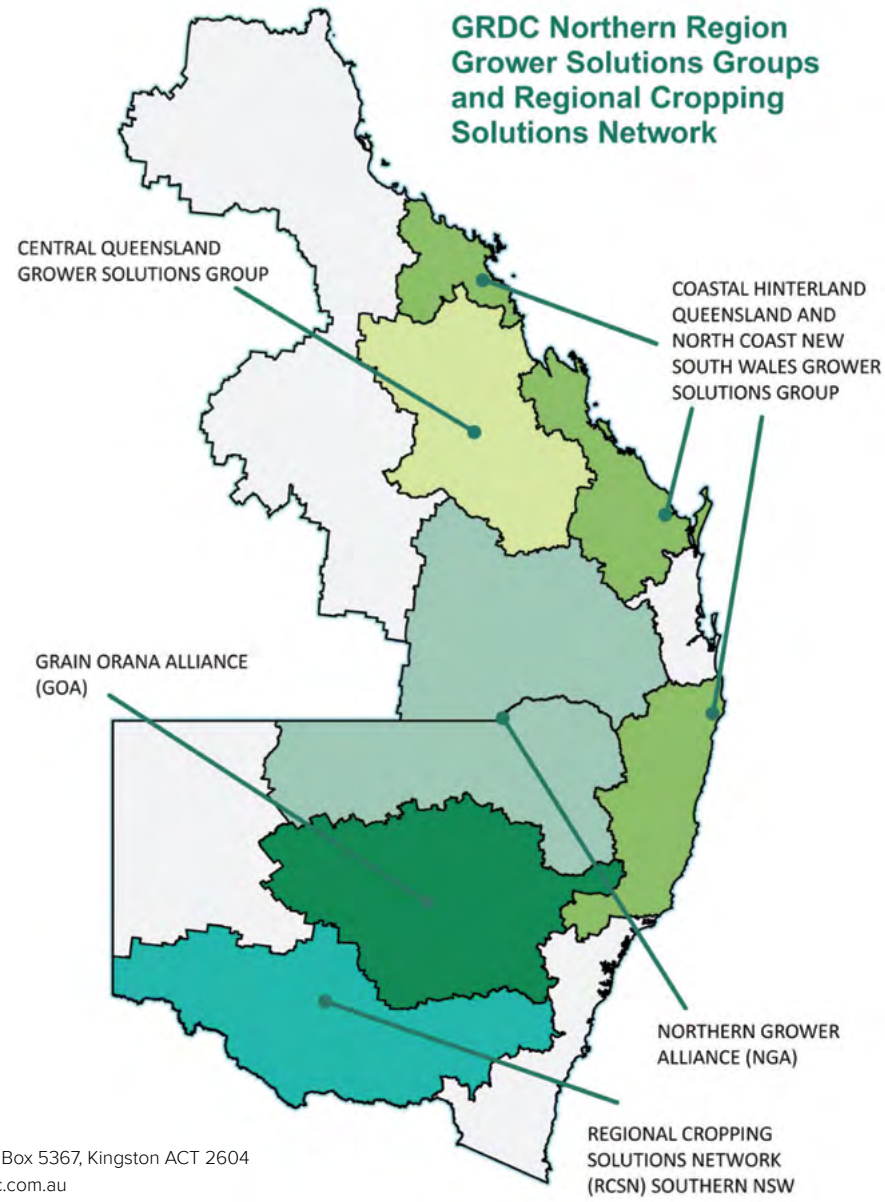
The NSW North Coast regional node of the Coastal and Hinterland Grower Solutions Project is led by NSW DPI research agronomist Dr Natalie Moore and technical officer Mr Nathan Ensbey, who are based at the Grafton Primary Industries Institute. The NSW North Coast Grower Solutions node prioritises and addresses issues constraining grain production via an enthusiastic advisory group comprised of leading grain growers, commercial agronomists from across the region and NSW DPI technical staff. In this high rainfall production zone (800-1400mm pa), winter and summer grain production is an important component of farming systems that also includes sugar cane, beef and dairy grazing pastures, and rice. The region extends east of the Great Dividing Range from Taree in the south to the Tweed in the north. Both Natalie and Nathan have many years experience with research and development for coastal farming systems and are also currently involved with the Australian Soybean Breeding Program (GRDC/CSIRO/NSW DPI) and the Summer Pulse Agronomy Initiative (GRDC/NSW DPI).

REGIONAL CROPPING SYSTEMS NETWORK (RCSN) SOUTHERN NSW

CHRIS MINEHAN

Regional Cropping Solutions Network Co-ordinator
Southern New South Wales (Wagga Wagga)
E Southern_nsw_rcsn@rmsag.com.au
M 0427 213 660

The Southern New South Wales Regional Cropping Solutions Network (RCSN) was established in 2017 to capture production ideas and opportunities identified by growers and advisers in the southern and western regions of New South Wales and ensure they translate into direct GRDC investments in local R, D & E priorities. The SNSW RCSN region covers a diverse area from the southern slopes and tablelands, through the Riverina and MIA, to the Mallee region of western NSW and the South Australian border. The region is diverse in terms of rainfall and climatic zones, encompassing rangelands, low, medium and high rainfall zones, plus irrigation. The SNSW RCSN is facilitated by Chris Minehan. Chris is an experienced farm business consultant and a director of Rural Management Strategies Pty Limited, based in Wagga Wagga, NSW. The process involves a series of Open Forum meetings which provide an opportunity for those involved in the grains industry to bring forward ideas, constraints and opportunities affecting grain grower profitability in their area. These ideas are reviewed by an RCSN committee comprises 12 members, including grain growers, advisers and researchers from across the region that meet twice per year to assist GRDC in understanding and prioritising issues relevant to southern NSW.



KEY CONTACTS

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

NORTHERN REGION

TOOWOOMBA
214 Herries Street
TOOWOOMBA, QLD 4350
northern@grdc.com.au

APPLIED RESEARCH AND DEVELOPMENT GROUP

SENIOR MANAGER CROP PROTECTION
Emma Colson
Emma.Colson@grdc.com.au
M: +61 4 5595 8283

BUSINESS SUPPORT TEAM LEADER
Gillian Meppem
Gillian.Meppem@grdc.com.au
M: +61 4 0927 9328

CONTRACT AND TEAM ADMINISTRATOR
Linda McDougall
Linda.McDougall@grdc.com.au
M: +61 4 7283 2502

MANAGER CHEMICAL REGULATION
Gordon Cumming
Gordon.Cumming@grdc.com.au
M: +61 4 2863 7642

MANAGER AGRONOMY, SOILS AND FARMING SYSTEMS
Kaara Klepper
Kaara.Klepper@grdc.com.au
M: +61 4 7774 2926

MANAGER AGRONOMY, SOILS AND FARMING SYSTEMS
John Rochecouste
John.Rochecouste@grdc.com.au
M: +61 4 7774 2924

CONTRACT ADMINISTRATOR
Tegan Slade
Tegan.Slade@grdc.com.au
M: +61 4 2728 9783

CROP PROTECTION OFFICER
Vicki Green
Vicki.Green@grdc.com.au
M: +61 4 2904 6007

GENETICS AND ENABLING TECHNOLOGIES GROUP

NATIONAL VARIETY TRIALS OFFICER
Laurie Fitzgerald
Laurie.Fitzgerald@grdc.com.au
M: +61 4 5595 7712

GROWER EXTENSION AND COMMUNICATIONS GROUP

SENIOR MANAGER EXTENSION AND COMMUNICATION
Luke Gaynor
Luke.Gaynor@grdc.com.au
M: +61 4 3666 5367

GROWER RELATIONS MANAGER
Richard Holzknecht
Richard.Holzknecht@grdc.com.au
M: +61 4 0877 3865

GROWER RELATIONS MANAGER
Susan McDonnell
Susan.McDonnell@grdc.com.au
M: +61 4 3662 2649

COMMUNICATIONS MANAGER
Toni Somes
Toni.Somes@grdc.com.au
M: +61 4 3662 2645

BUSINESS AND COMMERCIAL GROUP

MANAGER COMMERCIALISATION
Chris Murphy
Chris.Murphy@grdc.com.au
M: +61 4 2277 2070

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- 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
BASF Australia Ltd
Bayer Crop Science
Decipher AgTech
Nuseed Pty Ltd
Pioneer Seeds (GenTech Seeds)
Seed Force Pty Ltd
Seednet
Syngenta Crop Protection Pty Ltd
UPL Australia Limited
Wengfu Australia

GRDC
GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

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/Wagga-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 Wagga Wagga 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. Nitrogen and soil organic matter decline - what is needed to fix it? *Jeff Baldock*

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	**Protecting the longevity of new fungicide products:** *Nick Poole*	**Crown rot - what is the threat coming out of a dry year?** *Steven Simpfendorfer*	**Managing crop nutrient supply after a long dry period:** *Graeme Sandral*	**Effective soil sampling – high and low cost options to gain soil fertility information for management:** *Jason Condon*	**None**

Content relevance ____ /10 Presentation quality ____ /10

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

6. 11.45 am	**Canola agronomy forum:** *Rohan Brill Rajneet Uppal and Wayne Pitt*	**Post drought pasture management:** *Jeff McCormick*	**Biology and control options for wild radish, prickly lettuce and sow thistle:** *Hanwen Wu*	**Ameliorating subsoil constraints - new information on testing and diagnosing sodic soils:** *Ehsan Tavakkoli*	**None**

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

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

7. 12.25 pm	**Canola agronomy forum continued: (as previous)**	**Fixing more N - improving the performance of inoculants in suboptimal conditions:** *Ross Ballard*	**Effective soil sampling – high and low cost options to gain soil fertility information for management:** *Jason Condon*	**Protecting the longevity of new fungicide products:** *Nick Poole*	**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	**Phenology drivers in barley - how is Planet shaping up?** *Felicity Harris*	**Ameliorating subsoil constraints - new information on testing and diagnosing sodic soils:** *Ehsan Tavakkoli*	**Black leg - latest on upper canopy infection management:** *Susie Sprague*	**On the couch informal Q& A discussion:** *Jeff Baldock*	**None**

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

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

9. 2.40 pm	**Fixing more N - improving the performance of inoculants in suboptimal conditions:** *Ross Ballard*	**Post drought pasture management:** *Jeff McCormick*	**Managing crop nutrient supply after a long dry period:** *Graeme Sandral*	**On the couch informal Q& A discussion:** *Harm van Rees*	**None**

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

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

10. 3.20 pm	**Crown rot - what is the threat coming out of a dry year?** *Steven Simpfendorfer*	**Black leg - latest on upper canopy infection management:** *Susie Sprague*	**Biology and control options for wild radish, prickly lettuce and sow thistle:** *Hanwen Wu*	**Phenology drivers in barley - how is Planet shaping up?** *Felicity Harris*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

11. Student session: Can wheat be vernalised during grain development: ***Javier Atayde***

Content relevance ☐ /10 Presentation quality ☐ /10

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

12. Student session: Using Effects of surface incorporation of organic matter on subsurface soil acidity and wheat growth: ***Han Hoang Nguyen***

Content relevance ☐ /10 Presentation quality ☐ /10

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

13. Pesticides and regulatory impacts - the road ahead: ***Richard Holzknecht***

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	**Emerging management tips for early sown winter wheats:** *Felicity Harris*	**Assessing key pulse crops including lentils and chick peas:** *Mark Richards*	**Pest patrol – RWA under the spotlight:** *Jessica Lye*	**Super high oleic oil safflower - a future crop option for southern NSW:** *Rosemary Richards*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

15. 9.40 am	**Sustaining our herbicides into the future:** *Chris Preston*	**Utilising precision agriculture for better agronomic decisions:** *Quenten Knight*	**Phosphorus stratification - affects on utilisation and access:** *Graeme Sandral*	**Companion cropping - should we be considering it?** *John Kirkegaard and Greg Condon*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

16. 10.50 am	**Phosphorus stratification - affects on utilisation and access:** *Graeme Sandral*	**Integrated weed management round up forum:** *Mike Walsh Greg Condon and John Broster*	**Utilising precision agriculture for better agronomic decisions:** *Quenten Knight*	**Canola establishment - learnings around precision planting, sowing depth and density:** *Col McMaster*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

17. 11.30 am	**Assessing key pulse crops including lentils and chick peas:** *Mark Richards*	**Integrated weed management round up forum continued: (as previous)**	**Sustaining our herbicides into the future:** *Chris Preston*	**Pest patrol – RWA under the spotlight:** *Jessica Lye*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

18. 12.10 pm	**Applying R&D to help drive farm business profitability:** *Jordan Lindgren*	**Emerging management tips for early sown winter wheats:** *Felicity Harris*	**Canola establishment - learnings around precision planting, sowing depth and density:** *Col McMaster*	**Companion cropping - should we be considering it?** *John Kirkegaard and Greg Condonn*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

19. Served with a side of science - building community trust in food production: *Heather Bray*

Content relevance ☐ /10 Presentation quality ☐ /10

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

20. Herbicide residues in soil -what is the scale and significance? *Mick Rose*

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.