## **GRAINS RESEARCH UPDATE**







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Bendigo VIC 3552

- T 03 5441 6176
- E admin@orm.com.au
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## **GRDC** Foreword

#### **2022 GRDC Grains Research Updates Foreword**

On behalf of the Grains Research and Development Corporation (GRDC), I am pleased to welcome you to the 2022 Update series for the southern grain growing region.

Unfortunately, once again, the COVID-19 pandemic has impacted GRDC's ability to host this Update series across a face-to-face setting, but I can assure you, the latest research and information that's expected to be presented won't be diminished by the online platform.

GRDC's updates are focused on building the profitability of grain growers by delivering regionally relevant, strategic information that they can use to improve their practices and become more efficient and innovative on farm.

During the updates, you'll hear from our presenters about the cutting edge research, development and extension (RD&E) that GRDC has invested in to assist growers in making better, more informed management decisions and to adopt new farming practices and technologies.

With a global push to reduce greenhouse gas emissions, GRDC has identified significant opportunities and challenges for the grains industry and farming businesses. Determining how best to manage a shift in climate will be a highlight at this year's update, with a range of topics on the agenda.

Our first session will provide up to date research on assessing a farming system's greenhouse gas footprint and the key points growers need to consider regarding their footprint at a farm gate level. The presentations will also investigate the trending topic of carbon sequestration and highlight the pros and cons of soil carbon farming that growers can consider.

The series will also provide more hands on, practical information to help growers assess their management practices and identify where they could make changes to continue lifting their productivity and profitability.

Topics will include management of pests, weeds and disease, the latest in precision agriculture, soil and nutrition management and advancements in pulses and canola.

I trust that these updates will provide a wealth of knowledge to you as a member of the grains industry and arm you with useful information, networks, and contacts to improve your enterprise for the coming season and into the future.

The GRDC has an extensive network that aims to support growers, so please make the most of these online events and take advantage of the questions and answer sessions. While I know communicating over the computer can be difficult, we've worked to ensure our Updates allow participants a direct avenue to industry experts - so don't be afraid to participate.

The success of our Updates depends upon local support, and we are grateful to our suppliers, grower groups and presenters who have taken the time to help develop such a high-class series.

I sincerely hope you enjoy the 2022 Update series and thank you for supporting the GRDC.

Southern Region Panel Chair,

John Bennett





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## GRDC SOUTHERN Grains Research Update Series

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Grains Research and Development Corporation – Southern Office P Level 1, 187 Fullarton Road, Dulwich SA 5065 T +61 8 8198 8400 E southern@grdc.com.au

Grains Research and Development Corporation – Canberra Office P Level 4 | 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604 T +61 2 6166 4500 E grdc@grdc.com.au

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## GRDC SOUTHERN Grains Research Update Series

## FEBRUARY 2022 LIVESTREAM PROGRAM

NB. All times are Australian Eastern Daylight Savings Time (AEDT).

#### Program Day 1 – Agronomy & management for a shifting climate

#### Tuesday 8 February, 9am AEDT

Start time	Finish time	Торіс	Presented by
9:00	9:15	Welcome	<i>John Bennett,</i> GRDC Chair of Southern Panel
9:15	9:45	GRDC opening address	John Woods, GRDC Board Chair
9:45	10:15	Green-house gas emissions of Australian grain production	Maartje Sevenster, CSIRO
10:15	10:45	A realistic guide to soil carbon farming in Southern Australia	<b>Richard Eckard,</b> University of Melbourne
10:45	11:00	Morning Tea Break	
11:00	11:30	Adaptive plant establishment strategies for overcoming a shifting seasonal break	Bonnie Flohr, CSIRO
11:30	11:50	Farm level implications of the IPCC climate report	Peter Hayman, SARDI
11:50	12:10	Forewarned is forearmed	Dale Grey, Agriculture Victoria
12:10	12:40	Building carbon with regenerative farming - is it possible?	Mark Farrell, CSIRO
12:40	13:00	Lunch Break	
13:00	13:30	Long coleoptile wheats - new tool for drier sowings	Greg Rebetzke, CSIRO
13:30	14:00	New regenerating pasture for Low Rainfall Zone - feed your livestock and future crops	Ross Ballard, SARDI
14:00	14:30	Turning up the heat on wheat varietal selection - progress with heat tolerance breeding	<b>Daniel Tan,</b> University of Sydney
14:30	14:40	Close and evaluation	GRDC Representative







## The WeedSmart Big 6

## Weeding out herbicide resistance in winter & summer cropping systems.

#### The WeedSmart Big 6 provides practical ways for farmers to fight herbicide resistance.

#### How many of the Big 6 are you doing on your farm?

We've weeded out the science into 6 simple messages which will help arm you in the war against weeds. By farming with diverse tactics, you can keep your herbicides working.

#### Rotate Crops & Pastures Crop and pasture rotation is the recipe for diversity

- Use break crops and double break crops, fallow & pasture phases to drive the weed seed bank down,
- In summer cropping systems use diverse rotations of crops including cereals, pulses, cotton, oilseed crops, millets & fallows.



#### Mix & Rotate Herbicides Rotating buys you time, mixing buys you shots.

- Rotate between herbicide groups,
- Mix different modes of action within the same herbicide mix or in consecutive applications,
- Always use full rates,
- In cotton systems, aim to target both grasses & broadleaf weeds using 2 non-glyphosate tactics in crop & 2 non-glyphosate tactics during the summer fallow & always remove any survivors (2 + 2 & 0).

#### Increase Crop Competition Stay ahead of the pack

Adopt at least one competitive strategy (but two is better), including reduced row spacing, higher seeding rates, east-west sowing, early sowing, improving soil fertility & structure, precision seed placement, and competitive varieties.



#### Double Knock Preserve glyphosate and paraquat

- Incorporate multiple modes of action in the double knock, e.g. paraquat or glyphosate followed by paraquat \*
- Group 14 (G) + pre-emergent herbicide Use two different weed control tactics (herbicide or non-herbicide) to control





#### Stop Weed Seed Set Take no prisoners

- Aim for 100% control of weeds and diligently monitor for survivors in all post weed control inspections,
- Crop top or pre-harvest spray in crops to manage weedy paddocks,
- Consider hay or silage production, brown manure or long fallow in highpressure situations,
- Spray top/spray fallow pasture prior to cropping phases to ensure a clean start to any seeding operation,
- Consider shielded spraying, optical spot spraying technology (OSST), targeted tillage, inter-row cultivation, chipping or spot spraying,
- Windrow (swath) to collect early shedding weed seed.



#### Implement Harvest Weed Seed Control Capture weed seed survivors

Capture weed seed survivors at harvest using chaff lining, chaff tramlining/decking, chaff carts, narrow windrow burning, bale direct or weed seed impact mills.



#### WeedSmart Wisdom

Never cut the herbicide rate – always follow label directions Spray well – choose correct nozzles, adjuvants, water rates and use reputable

products, Clean seed – don't seed resistant weeds.

Clean borders – avoid evolving resistance on fence lines,

Test – know your resistance levels, 'Come clean. Go clean' – don't let weeds hitch a ride with visitors & ensure good hiscogravity



### Building soil carbon for your business

#### Richard Eckard<sup>1</sup>, Peter Grace<sup>2</sup> and Warwick Badgery<sup>3</sup>.

<sup>1</sup>Department of Agriculture and Food, The University of Melbourne; <sup>2</sup>School of Biology & Environmental Science, Queensland University of Technology; <sup>3</sup>Department of Primary Industries, Orange, NSW.

#### Keywords

■ carbon sequestration, soil carbon, soil organic matter.

#### Take home messages

- Growers should build soil organic matter for the right reasons.
- Growers should bank the inherent productivity benefit of improved soil health and not sell their soil carbon, as they will need this asset for the day when they might need to table it against the balance of their greenhouse gas emissions to meet supply chain demands.

#### Introduction

Since the Paris climate agreement (COP21), and more recently the Glasgow COP26 meeting, there is rising interest in the role that soils can play in helping Australia meet its greenhouse gas reduction targets. Under the Australian Emission Reduction Fund, there are two soil carbon offset methods available, although there are also a number of international voluntary soil carbon methods. To engage in these soil carbon offset markets, growers must be able to demonstrate they are undertaking activities which are in addition to their normal practice. For example, a grower who changes to zero till practices will be rewarded if they have registered the paddock (that is, defined a Carbon Estimation Area) and can show a measurable change in soil organic carbon in the top 30cm or deeper. A grower who has employed zero till for many years is unlikely to be rewarded as this is business as usual.

Unfortunately, placing a price on soil carbon has skewed the discussion away from what really matters to growers, which is soil health and productivity. Soil organic matter, of which only half (~58%) is soil organic carbon, is the engine room of soils, maintaining nutrient supply and soil structure. Soil organic carbon is usually only about 1 to 5% of the total soil mass, with the higher concentrations normally under long-term grasslands or crop rotations with substantial pasture phases.

#### What is soil organic carbon

There is some confusion about what constitutes soil organic carbon. Plant residues on the soil surface, roots and buried plant residues (>2mm) are not considered soil organic carbon. These first need to be broken down into smaller fractions to be considered soil organic carbon, which is why the soils are first sieved to two millimetres before an analysis, to remove all these larger fractions. Fractions considered to be part of the soil organic carbon (as per a soil analysis) would be particulate organic carbon (POC; 2.0 – 0.05mm) and humus (<0.05mm), with resistant organic carbon (ROC) being historic charcoal from fires or burning of stubbles. In other words, we must not confuse roots with soil organic carbon.

For sustained productivity, increasing the relative amount of POC is beneficial as this is readily decomposable and supplying nutrients. To have confidence to sell soil carbon, farmers want a substantial amount of carbon in a more recalcitrant (decomposing over decades) form, namely humus, so that you have confidence that the carbon sold will still be there in 25 to 100 years. These permanence time frames are required to engage in carbon markets.



#### The inherent benefits of soil organic matter

The inherent benefits of building soil organic matter are outlined in Table 1. In a modelling experiment in western Victoria, we quantified the inherent productivity benefits of just two of these attributes, being nitrogen mineralisation potential and water holding capacity (Meyer et al. 2015). In a permanent grassland situation, high soil organic matter (long term grassland) conferred between \$100 - \$150 of additional productivity value per hectare per year, when compared with a soil with low organic matter (long term cultivation then converted to grassland). Also noted in this research, the potential to increase soil organic matter was higher (0.3 - 0.5t soil C/ha/year sequestered) when moving out of long-term cultivation into a permanent pasture phase under high rainfall, that is, high potential to increase soil organic matter. Conversely, under the same conditions but with a high soil organic matter status due to long-term pasture, the potential to increase soil organic matter was largely determined by rainfall.

#### Building soil organic carbon

Building soil organic carbon is basically an inputoutput equation. The inputs are from decaying crop and pasture residues and roots. The outputs are CO2 from microbes which are actively decomposing and transforming the carbon, using it as energy, but in the process releasing nutrients back to the soil to support plant growth. In a good rainfall year, the inputs increase in response to plant growth with a subsequent increase in outputs and thus a more rapid accumulation of soil carbon i.e. carbon inputs exceed outputs. In a drought, carbon inputs drop dramatically in response to reduced plant growth, but the outputs remain constant because the microbes respond to episodic wetting events and soil carbon decreases i.e. carbon outputs exceed inputs. Fallow years are good example of major losses in soil carbon as there is no addition.

In Australia, rainfall determines the majority of soil carbon change in a stable management system (see Meyer et al. 2015). Unless there is a dramatic change in management or land use, such as moving out of conventional cultivation into permanent pasture in a high rainfall zone, the majority of the annual change in soil carbon is a function of rainfall. Change in soil carbon in mixed cropping systems can often be large and unpredictable, particularly from labile pools (Badgery et al. 2020).

In a country like Australia that has 23% more rainfall variability than most countries in the world (Love 2005), banking on selling soil carbon is therefore high risk given the frequency of drought. For example, Badgery et al. (2020) reported what to 12 years of increase in soil carbon was reversed in the following 3 years. Concluding that 12 years was not enough time to be confident that soil carbon sequestration was permanent. In contrast, our recent research showed that just two of the co-benefits of high soil organic matter, nitrogen mineralisation and water retention, could confer as much as \$150/ ha/year productivity value in a pasture system in western Victoria over the long term, when the carbon trading value under the same scenario is less than \$20/t/ha/year.

This raises the question, should growers focus on trading soil carbon, or just bank the inherent productivity benefit of having higher soil organic matter, as there is no paperwork, no contracts, no liabilities, but all the productivity benefits can be banked? In addition, when the farm needs to demonstrate carbon neutral production which is highly likely standard by 2030, this soil carbon will be essential to offset the balance of the

Table 1. The inherent biological, physical and chemical co-benefits that high soil organic matter may confer to       an agricultural production system.					
Biological roles	Physical roles	Chemical roles			
- Reservoir of nutrients	- Water retention	- Cation exchange			
- Biochemical energy	- Structural stability	- pH buffering			
- Increased resilience	- Thermal properties	- Complex cations			
- Biodiversity	- Erosion				

(Source: Jeff Baldock)



grower greenhouse gas emissions – double-dipping is allowed.

#### How much soil carbon can be accumulated

Over the past few years there has been an increase in the number of growers and carbon aggregators making claims of increases in soil carbon that do not align with the published peerreviewed science. Although conservative, the values presented in Table 2 are those estimated by the Australian Government official carbon model (FullCAM), showing likely increase in soil carbon in response to management. What is also seemingly ignored in some less scientific claims of soil carbon increase, is the assumption this can continue in perpetuity, which defies the law of diminishing returns. The more carbon you sequester, the more carbon inputs you are then required to maintain.

Where soil has a low organic matter content, but high clay content and good rainfall (namely, a high potential to increase soil organic matter), it is possible to achieve rates of soil carbon sequestration that exceed those presented in Table 2. The initial high carbon sequestration rates (that is, the first 5 to 10 years with rates from 0.7 to 1t C/ ha/year in the top 30cm when converting cropland to pasture (Meyer et al. 2015; Robertson and Nash 2013)) will result in a new steady state after 10 years that matches the rainfall and management imposed. In contrast, the same conditions but with a high soil organic matter starting point, would only vary in direct relation to annual rainfall and distribution.

Robertson and Nash (2013) report similar soil carbon sequestration values, with the average change in soil organic carbon in the top 30cm after 50 years across Victoria ranging from 21t/ha under perennial pasture to 6.5t/ha under a zero till grain rotation without fallow. Any reversion to conventional practices, even for a short period of time has a major impact on the magnitude of soil carbon sequestration (Figure 1).



**Figure 1.** The impact of occasional fallow and stubble burning on soil organic carbon accumulation in a cereal rotation over 50 years at Bendigo (Vic) (Robertson and Nash 2013).

The SATWAGL long-term trial at Wagga (Chan et al. 2011) also demonstrated the clear benefits of stubble retention, zero tillage and pasture phases for increasing soil carbon (Table 3). Over a 25-year period, stubble retention compared to burning was 2.2t C/ha higher, zero tillage compared to conventional cultivation was 3.6t C/ha higher, and a pasture rotation every second year was between 4.2 and 11.5t C/ha higher than continuous cropping.

### A new approach to soil organic matter in Australia

Perhaps there is a need to consider soil organic matter differently in the Australian context, by managing it more specifically for soil types by farming systems and also managing differently in high versus low rainfall periods. Sandy or granitic soils have very limited capacity to build soil organic matter as carbon is less protected from decomposition by microorganisms in these soil types. Clay soils generally have far higher potential

Estimating Sequestration of Carbon in Son Osing Delaut values, Methodology Determination 2015.									
	Categories of sequestration potential (t C/ha/year)								
Project management activity	Marginal benefit	Some benefit	More benefit						
Sustainable intensification	0.03	0.16	0.45						
Stubble retention	0.02	0.08	0.20						
Conversion to pasture	0.06	0.12	0.23						

### **Table 2.** Modelled soil carbon sequestration potential as stipulated by the Australian government ERF Offset method: Estimating Sequestration of Carbon in Soil Using Default Values, Methodology Determination 2015<sup>1</sup>.

<sup>1</sup>https://www.legislation.gov.au/Details/F2018C00126



## **Table 3.** Change in soil organic carbon (SOC, kg C/ha over 0–0.30m soil depth) and final stock (t C/ha) under different rotation, tillage, and stubble and pasture management in the SATWAGL long-term field experiment (1979–2004) (adapted from Chan et al. 2011).

Treatment	Tillage	Stubble	Rotation	Change (kg C/ha/year)	sig	Final stock (t C/ha)
T1	NT	SR	W/L	-52	n.s.	40.5
T2	CC	SR	W/L	-174	*	38.3
Т3	NT	SB	W/L	-98	n.s.	39
T4	CC	SB	W/L	-176	*	35.4
T5	CC	SB	W/W	-278	**	33.6
T6	CC	SB	W/W-N	-193	*	34.6
T7	CC	SR	W/C-G	-2	n.s.	41.7
Т8	NT	SR	W/C-M	257	*	48
Т9	CC	SR	W/C-M	104	n.s.	43.1

NT, no tillage; CC, 3-pass tillage; SR, stubble retained; SB, stubble burnt; W/L, wheat/lupin rotation; W/C, wheat/clover rotation; W/W, wheat/ wheat; N, N fertiliser; G, grazed; M, mown. \*P < 0.05; \*\* P < 0.01; n.s., not significant

to sequester carbon when rainfall is sufficient to maintain carbon inputs from stubble, roots or residual pasture biomass. The key to building soil carbon is to understand the capacity for the soil to store carbon in your specific environment (climate x soil type) and management system. This capacity varies considerably even within the same district. Therefore, we should not view the landscape with a single sequestration potential but target the areas that are low in carbon but high in sequestration potential, for example, the rehabilitation of degraded lands.

We should also be thinking of El Niño versus La Niña years quite differently, in that we have probably built more soil organic matter in eastern Australia during the recent La Niña, than in the previous three years put together. In higher rainfall years, we should focus on strategies that maximise the sequestration of carbon in our soils, and in low rainfall or drought periods, we focus on minimising the losses to provide a net positive result. Rather than focus on building soil carbon year by year, a longer-term approach would aim for a net increase in carbon over a 10-year period.

## Selling soil carbon for short-term gain may mean long-term pain

Finally, whilst carbon neutrality is being strongly supported by the agricultural supply chain companies, there is an inevitable point where growers will need to demonstrate progress towards lower emissions farming systems. Any increase in soil organic carbon you which to bank as a credit will be negated by on-field emissions, for example CO2 from fuel, N2O from N fertilisers or CH4 from grazing livestock. Selling soil or tree carbon means that asset value leaves your property, but you are left with the liability of maintaining the asset for the next 25 to 100 years (short term gain, long term pain). If the soil carbon is sold internationally, it also leaves the industry and the country, making any industry or national targets increasingly difficult to achieve as the carbon offset has left the industry and left Australia. Once the soil carbon is sold, the new buyer will be using it against their carbon footprint, which means that the farm will never again be able to use that soil carbon against their future liability, making their carbon neutral target increasingly impossible to achieve.

In the end, we should encourage growers to build soil organic matter for the right reasons. Bank the inherent productivity benefit of improved soil health and don't sell your soil carbon, as you will need this asset for the day when you might need to table it against the balance of your greenhouse gas emissions to meet supply chain demands.

#### References

Badgery WB, Mwendwa JM, Anwar MR, Simmons AT, Broadfoot KM, Rohan M, Singh BP (2020) Unexpected increases in soil carbon eventually fell in low rainfall farming systems. *Journal of Environmental Management*, **261**, 110192. http:// dx.doi.org/10.1016/j.jenvman.2020.110192

Chan KY, Conyers MK, Li GD, Helyar KR, Poile G, Oates A, Barchia IM (2011) Soil carbon dynamics under different cropping and pasture management in temperate Australia: results of three long-term experiments. *Soil Research* **49(4)**, 320-328. https://doi.org/10.1071/SR10185



Love G (2005) Impacts of climate variability on regional Australia. In 'Outlook 2005. Conference proceedings, climate session papers'. (Eds R. Nelson, G. Love) pp. 10–19. (Australian Bureau and Resource Economics: Canberra, ACT, Australia)

Meyer R, Cullen BR, Johnson IR, Eckard RJ (2015) Process modelling to assess the sequestration and productivity benefits of soil carbon for pasture. *Agriculture, Ecosystems and Environment* **213**, 272-280. http://dx.doi.org/10.1016/j.agee.2015.07.024

Robertson F, Nash D (2013) Limited potential for soil carbon accumulation using current cropping practices in Victoria, Australia. *Agriculture, Ecosystems and Environment* **165**, 130–140. http://dx.doi.org/10.1016/j.agee.2012.11.004

#### **Contact details**

Richard Eckard University of Melbourne rjeckard@unimelb.edu.au



## Adaptive sowing strategies to overcome a shifting seasonal break

Bonnie Flohr<sup>1</sup>, Therese McBeath<sup>1</sup>, Jackie Ouzman<sup>1</sup>, Bill Davoren<sup>1</sup>, Willie Shoobridge<sup>1</sup>, Greg Rebetzke<sup>1</sup>, Ross Ballard<sup>2</sup>, David Peck<sup>2</sup>, Rick Llewellyn<sup>1</sup>, John Kirkegaard<sup>1</sup> and Belinda Stummer<sup>1</sup>.

<sup>1</sup>CSIRO; <sup>2</sup>SARDI.

GRDC project code: 9175959

#### Keywords

■ farming system, grain yield, long coleoptile, seasonal break.

#### Take home messages

- Seasonal changes may be altering the pattern of sowing opportunities across southern Australia, but there is potential to adapt management to deal with these changes.
- Deep-sown wheat cultivars with long coleoptiles may reduce the dependence on the seasonal break to establish crops but soil texture and soil water are important factors for success.
- There are alternative methods to sow legume-pastures that avoid clashes with main crop sowing programs and establish pasture seedbanks.

#### Background

The seasonal break is a rainfall event that has traditionally initiated sowing and enabled plant establishment in southern cropping environments of Australia. Delays in the seasonal break reduce grain yield (~1-7% yield loss per week delay past optimal establishment time for wheat) and for graziers can result in continued summer-autumn feed gaps requiring supplementary feeding and reduced grazing during the winter period when cool temperatures slow pasture growth (Coventry et al. 1993; Pook et al. 2009; Hochman and Horan, 2018). Despite its importance to agricultural production, neither the pattern of the seasonal break, nor the impact of recent autumn rainfall decline in southeastern Australia on the pattern has been quantified at a national scale.

A shift towards early sowing systems and a drying trend in autumn in southern Australia are changing traditional farming systems, and growers need adaptive genetic and management strategies

for plant establishment that do not rely on the seasonal break. On cropping farms, a strategic response may include establishing deeply sown wheat cultivars with long coleoptiles on moisture accumulated during fallow periods (Flohr et al. 2018). A concern with this strategy is that the warmer soil temperatures at early sowing could shorten coleoptiles and negate the long-coleoptile benefit (Rebetzke et al. 2016) - an effect potentially offset by using stubble retention and deeper sowing into cooler soil. On mixed livestock-cropping farms, where sowing of pasture phases can clash with main season cropping programs, novel management may include the use of unscarified 'hard seed' of adapted pasture cultivar options, sown either in late summer (summer sowing) or with the previous crop (twin sowing) (Figure 1, Nutt et al. 2021). Novel pasture sowing systems avoid peak crop sowing times, reduce establishment costs and can increase early season feed supply but have had limited evaluation in the SA medium-low rainfall environment.



variable seasonal break													V Se	ariat easo brea	ole nal k					
Sowing type	Α	М	J	J	Α	s	0	Ν	D	J	F	М	Α	М	J	J	Α	s	0	Ν
Twin sowing													_			gra	azin	g		
Summer sowing															_	gra	azin	g		
Autumn sowing																gra	azin	g		
Main cropping program																				

**Figure 1.** Timeline of sowing date, hard seed breakdown and plant growth period of pasture sowing methods tested.

This study has three components:

- analysis of the seasonal break for southern Australia
- a case study evaluating factors for successful establishment of deep-sown wheat in the Mallee environment
- evaluation of the suitability of different legumepasture species to be established through summer and associated twin sowing methods that provide growers with greater flexibility in pasture establishment.

#### Methods

#### Seasonal break analysis

To construct a spatial map of the seasonal break, a variation of the Unkovich (2010) sowing rule was applied to daily rainfall and pan evaporation historical climate data obtained from the SILO database (Jeffrey et al. 2001) for the period of 1971—2018, with a spatial resolution of 0.05° × 0.05° (~5km × ~5km). A seasonal break was deemed to occur when the sum of rainfall over any 7-day period exceeded pan evaporation over the same period after 1 March.

### Case-study on deep sowing of long coleoptile wheat

As a case-study in 2020 at Lameroo, SA (Mallee), a soil temperature sensor experiment quantified seedbed conditions at depth during early (1 March to 30 April) and traditional sowing windows (1 May to 1 June) under stubble cover (0.8 or 2.6t/ha) and moisture treatments (decile 5 or 8) representative of typical farming systems in the region. A growth chamber experiment evaluated establishment factors: temperature representative of early (average 23°C) and traditional (average 17°C) sowing dates, moisture (marginal or optimal), sowing depth (5cm or 16cm) on wheat cultivars (Mace<sup>(b)</sup> and Mace<sup>(b)</sup>18) that were isolines with and without the genetic trait generating longer coleoptiles.

#### Novel pasture sowing methods

Three pasture sowing methods were evaluated in field experiments at Lameroo in 2020 and included legume pasture species that have not been traditionally grown in the region (Table 1). Soil type at Lameroo is sand (0—10cm pH CaCl<sub>2</sub> is 7). Sowing methods evaluated were:

- twin-sowing (20 May 2019), where 'hard' pasture seed/pod was sown with wheat seed in 2019 for 2020 pasture establishment (Table 1)
- summer-sowing, where hard seed/pod was sown in 18 February to germinate on the autumn break
- autumn-sowing (control treatment representing grower practice, 28 April 2020), where scarified germinable seed was sown on the break of the season in 2020.

Pasture treatments were compared to autumn sown brown manure vetch (terminated 15 September 2020), long fallow (16-month chemical fallow) and continuous cereal.

At each site, pasture and weed densities were recorded in June, and multiple measures of biomass production were recorded July — November. At the November biomass recording, a seed set estimate was made by sieving seed from biomass and surface soil in the quadrat area. The sowing rates for the legumes are reported in Table 1 and all legumes were inoculated with their specific rhizobia group using peat slurry. Granular inoculant (ALOSCA) was also sown with each legume at a rate of 10kg/ ha. The effects of the pasture treatments on the following wheat crop were measured at Lameroo in 2021, when plots were sown to wheat (cv. Scepter<sup>(b)</sup>) on 26 May 2021 with 20 kg N/ha, and pests and diseases were managed for maximum yield.



Table 1. Sowing rates of pod or seed rat	e (kg/ha) in twin and summe	er sowing treatments and	sown rate of germinable seed
(kg/ha) in the autumn sown treatment.			

Species	Cultivar	Twin and summer sowing kg/ha	Autumn sowing kg/ha
Medic	PM-250	30 (pod)	11
Trigonella Balansae	5045	12 (seed)	8
Bladder clover	Bartolo	12 (seed)	11
Rose clover	SARDI	10 (seed)	11
French serradella	<b>M</b> argurita <sup>(</sup> )	30 (pod)	8
Vetch	Studenica <sup>()</sup>		40
Wheat	Scepter		70

**Table 2.** Selected sites in the Australian cropping region showing 25-75th percentiles of the seasonal break (1971—2018), the range in days, and median 7-day sum of rainfall (mm) at the seasonal break based on the 7-day rolling sum of the rainfall:evaporation ratio.

Location	State	25th percentile	Median	75th percentile	Range (days)	Median 7-day rain sum (mm)
Lameroo	SA	19-Apr	11-May	29-May	40	21
Waikerie	SA	20-Apr	7-May	27-May	37	21
Roseworthy	SA	11-Apr	1-May	20-May	39	27
Minnipa	SA	3-May	24-May	9-Jun	37	22

#### Results and discussion

#### Seasonal break analysis

The analysis revealed spatial and seasonal variability with the earliest median seasonal break (27 March) in NSW and Victoria, and the latest (3

June) in WA. Table 2 shows the median seasonal date, range and rainfall volume that defined the seasonal break for local South Australian sites. The largest shift in seasonal break was a 17-day advance in the Mallee and Sandplain of WA, and an 11-day delay in Central NSW during the period 1990—2018 (Figure 2).



**Figure 2.** Median shift in seasonal break between the periods 1971—1989 and 1990—2018 in cropping regions throughout southern and western Australia based on the 7-day rolling sum of the rainfall:evaporation ratio (Flohr et al. 2021).





**Figure 3.** Average coleoptile length of long-coleoptile (LC, white) and short coleoptile (SC, grey) cultivars when grown in growth chambers under two temperatures A) 17.5°C B) 23°C.

### Deep sowing long coleoptile wheat pilot experiment

Soil temperatures during early sowing periods are unlikely to inhibit long coleoptile growth at the deep sowing depths as temperatures were not in the damaging range (31°C, Rebetzke et al. 2016), but soil moisture and texture had significant impacts (Figure 3).

The soil temperature in the field experiment was 6-8°C warmer with earlier sowing (March—April) than with more traditional sowing windows (May). At depth (16—18cm), soil temperature was less variable and was approximately 4°C cooler than the surface air temperatures in March. Soil at both depths (5cm or 16cm) was 2°C cooler with retained stubble in the early sowing window, but not different in the traditional sowing window. Soil at 18cm with stubble was 3°C cooler than shallow soil without stubble. There were no temperature differences between the 0.8 and 2.6t/ha stubble treatments, suggesting that removing some stubble for straw or grazing livestock use may not increase seed-bed soil temperatures at sowing, provided at least 1t/ha stubble cover is retained.

In 2020 the 1 March — 30 April window, there were nine days in with a maximum soil temperature over 30°C but average soil temperature did not reach 31°C, the temperature reported to reduce coleoptile length (Rebetzke et al. 2016). Our sensor experiment demonstrated that such extreme soil temperature conditions are unlikely to occur under field conditions in current climates in southern cropping regions where average soil temperatures ranged between 17 and 23°C in 2020, which was a near-average air temperature year.

At the 17.5°C temperature in the controlled growth room experiment when sown deeply and at the same moisture potential, coleoptiles were longer in sand than sandy loam, suggesting soil type can influence plant establishment from depth. At depth, the longest coleoptiles were measured in the wettest treatment in sandy loam, but the driest treatment for sand. It is important to note that there is a narrower range in water content between wet and dry for sand. In contrast to 17.5°C, at 23°C, coleoptiles were longer in wet sand than dry sand but were equivalent across all moisture treatments in sandy loam. The combined stress of low moisture and warmer temperatures had a greater effect on coleoptile length in the sand. However, under high moisture, total emergence was ~40% higher in the sand than sandy loam soil type at both temperatures. Treatments which successfully emerged from depth required an additional 3-6 days compared with shallow sown treatments.

#### Novel pasture sowing methods

There were inconsistencies between the species × sowing time combination that was optimal for pasture production in the 2020 growing season (Figure 4). Average plant establishment in autumn sown treatments was 72 plants/m<sup>2</sup>, summer sown treatments was 29 plants/m<sup>2</sup> and twin-sown treatments was 14 plants/m<sup>2</sup>. In Lameroo, an early break in the first week of March enabled earlier establishment of pasture species from summer and twin sowing and resulted in higher biomass production for summer-sown Trigonella and medic compared to autumn sown (Figure 4). However, lower plant numbers could not compete with autumn sown plant numbers and production of bladder



clover. Rose clover and serradella established adequate numbers from autumn sowing, but overall biomass production was low, suggesting the available varieties were not well adapted to the Lameroo environment. Weed density was greatest in summer sown (13 weeds/m<sup>2</sup>) and twin-sown (8 weeds/ $m^2$ ), compared to autumn-sown (3 weeds/ $m^2$ ). Pasture production was generally low for all species when twin sowing was implemented, presumably due to excessive seeding depth, an aspect of twin sowing that needs to be addressed before the method can be recommended for pasture establishment. At Lameroo, bladder clover and trigonella balansae production was competitive with medic at autumn sowing and are considered the best novel pasture options.



**Figure 4.** Biomass production of legume pasture species (15 September 2020) established via autumn, summer and twin sowing methods in Lameroo in 2020, Lsd (5%) 1.5t/ha, P-value <0.001. Number above each column is plant number per m2, Lsd (5%) 14, P-value <0.001.

The 2021 growing season rainfall was below average at Lameroo (170mm, long term average 270mm). The additional ~30mm of total soil water, and 70kg N/ha available under brown manure vetch and long fallow treatments resulted in an additional 1.5t/ha wheat grain yield compared to the continuous cereal treatment (Figure 5). The 2020 pasture seedbank establishment treatments were not terminated and therefore used more water than long fallow and brown manure vetch treatments, but still resulted in a 2021 wheat yield benefit of ~0.7t/ha. Pasture seed production was over 1t/ha for the best establishment treatment for each species. Autumn sowing generated the highest seed production for all except summer sown serradella, with medic and Trigonella the highest.





#### Conclusion

Characterisation of the seasonal break is an important step for novel cultivar adaptation and management strategies across crop growing regions of southern Australia. Earlier deep sowing with longcoleoptile wheat appears to be a promising adaptive strategy to declining autumn rainfall, as stubble and moisture at depth reduced soil temperatures which remained at levels unlikely to shorten coleoptiles. However, soil type and low moisture may have a greater influence on plant emergence from depth. More testing under field conditions in a range of target environments/soil types using farm equipment to develop successful establishment strategies is required.

Summer 'dry' pasture establishment methods have demonstrated potential in mixed farming systems; however, they are not well-suited for all pasture legume species and weed control challenges need to be addressed. There is potential to sow productive novel legume pastures and establish a substantial pasture seedbank while still achieving a substantial crop 'break effect'. Further development of establishment options to respond to shifting season breaks and increase sowing flexibility will be critical to the realisation of future crop-pasture system potential.

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#### References

Coventry DR, Reeves TG, Brooke HD, Cann DK (1993) Influence of genotype, sowing date, and seeding rate on wheat development and yield. *Australian Journal of Experimental Agriculture* **33(6)**, 751-757.

Jeffrey SJ, Carter JO, Moodie KB, Beswick AR (2001) Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling & Software* **16(4)**, 309-330.

Pook M, Lisson S, Risbey J, Ummenhofer CC, McIntosh P, Rebbeck M (2009) The autumn break for cropping in southeast Australia: trends, synoptic influences and impacts on wheat yield. International *Journal of Climatology* **29(13)**, 2012-2026.

Hochman Z, Horan H (2018) Causes of wheat yield gaps and opportunities to advance the water-limited yield frontier in Australia. *Field Crops Research* **228**, 20-30.

Nutt BJ, Loi A, Hackney B, Yates RJ, D'Antuono M, Harrison RJ, Howieson JG (2021)"Summer sowing": A successful innovation to increase the adoption of key species of annual forage legumes for agriculture in Mediterranean and temperate environments. *Grass and Forage Science* **76(1)**, 93-104.

Flohr BM, Hunt JR, Kirkegaard JA, Evans JR, Lilley JM (2018) Genotype × management strategies to stabilise the flowering time of wheat in the southeastern Australian wheatbelt. *Crop and Pasture Science* **69(6)**, 547-560.

Flohr BM, Ouzman J, McBeath TM, Rebetzke GJ, Kirkegaard JA, Llewellyn RS (2021) Redefining the link between rainfall and crop establishment in dryland cropping systems. *Agricultural Systems* **190**, 103105.

Rebetzke GJ, Zheng BY, Chapman SC (2016) Do wheat breeders have suitable genetic variation to overcome short coleoptiles and poor establishment in the warmer soils of future climates? *Functional Plant Biology* **43(10)**, 961-972.

Unkovich M (2010) A simple, self adjusting rule for identifying seasonal breaks for crop models "Proceedings of the 15th ASA Conference 'Food Security from Sustainable Agriculture'. Lincoln, New Zealand", 15–19 November 2010.

#### **Contact details**

Bonnie Flohr Locked Bag 2, Glen Osmond SA 5064 0475 982 678 bonnie.flohr@csiro.au @BonnieFlohr



## What's new in 2021 from climate science– a quick update for busy advisers

#### Peter Hayman.

SARDI Climate Applications.

GRDC project code: 16-03-007

#### Keywords

■ climate change, climate risk, seasonal forecasts.

#### Take home messages

- For most SA cropping regions, the 2021 season had a late start and winter. Forecasts in July for an increased chance of above average rainfall in spring were followed by a very dry August to mid-October and wet November
- New products released by BoM in 2021 as part of the Forewarned is Forearmed (FWFA) project include forecasts of extreme wet or dry and extreme hot or cold for the coming fortnight, month, and three months.
- In August 2021, the Intergovernmental Panel on Climate Change (IPCC) issued a report and summary for policy makers expressing increased confidence in warming and the urgency of reducing emissions. This is worth a read.
- Climate Services for Agriculture is a website developed by BoM and CSIRO. This site is worth bookmarking for future reference.

## New forecast products that go beyond exceeding the median

Seasonal climate forecasts from the Bureau of Meteorology (BoM) are expressed as the per cent chance of exceeding median rainfall or temperature. Grain growers have pointed out that there is a big difference between a season that is a few mm wetter or drier than the median and extremely dry or wet seasons. The middle deciles are easy to manage compared to the extremes. Forecasts of the chances of the driest or wettest, coldest or warmest two deciles have been developed as part of the Forewarned is Forearmed project (FWFA), funded by the Australian Government Department of Agriculture, Water and the Environment's Rural R&D for Profit program, with co-investment from 14 project partners including GRDC and SARDI. A grains industry reference group with GRDC panel members

from each of the three regions and GRDC staff have reviewed products and provided feedback.

Three new forecast products were made available on the BoM website (bom.gov.au) late in 2021:

- Overview
- Summary
- Climate Outlooks.

Examples will be given in the presentation. The first product is a series of maps showing the chance of having extreme high (deciles 9 and 10) or low (deciles 1 and 2) rainfall, maximum temperatures or minimum temperature for the weeks, months and seasons ahead. The second product is locationspecific bar graphs that indicate the shift in the probabilities compared to usual across the deciles. They are available for rainfall, maximum and minimum temperatures for the weeks, months and



seasons ahead. These location specific bar graphs come from the clickable map. The third product is the "climagram". These are location-specific timeseries graphs showing the forecast of rainfall totals, maximum and minimum temperatures for the coming weeks and months. Two further forecast products of extremes will be released in 2022.

The extra information on climate extremes meets a request from long term users of the forecasts. It is important to note that this extra detail is not adding accuracy to seasonal climate forecasts. There is ongoing work to characterise and improve the skill of the forecast, however they are likely to remain in the category of 'too good to ignore but not good enough to be sure'.

#### What happened in 2021 and what can we learn about using seasonal climate forecasts

Most SA cropping regions had a late start to the 2021 cropping season followed by a wet June and July. As can be seen in the regular updates on climate drivers from BoM (Table 1), the development and declaration of a negative Indian Ocean Dipole event coincided with the wet winter. The Indian Ocean Dipole (IOD) is measured as the difference in sea surface temperatures between the eastern and western tropical Indian Ocean. A negative phase (8 weeks below -0.4°C) is typically associated with

above average winter-spring rainfall in Australia. The very wet season of 2016 was a strongly negative IOD and the very dry 2019 was the strongest positive IOD on record. In early spring of 2021, although crops were less advanced than ideal, the winter rain in the profile and increased chance of a wet spring led to widespread confidence for nitrogen topdressing in early spring.

The wet June and July were followed by extremely dry August and September, a patchy October and wet November. For most of the SA grains belt, the 2021 growing season rainfall (April to October) was dry (decile 1—3) or average (decile 4—7). If spring is defined as September, October and November, the season was average (decile 4—7) or wet (8—10). The November rainfall, consistent with the developing La Niña, presented harvest challenges and, in some cases, opportunities to build soil water for the 2022 crop.

Figure 1 shows a time series of the of IOD and Nino 3.4. The IOD index fell to below the threshold of -0.4°C in April before rising in July and falling again in August. The Nino 3.4 index fell during spring (Aust BoM threshold is -0.8°C, US NOAA use a higher threshold of -0.4°C)

Growers and advisers correctly interpreted the expectation for increased chances of above average spring rainfall from most forecasts and commentators. So, what happened?

Table 1. Climate	e driver updates over 2021 from BoM.
16 March	La Niña nears its end
30 March	La Niña 2020–21 fades as El Niño–Southern Oscillation (ENSO) returns to neutral
13 April	El Niño-Southern Oscillation neutral
27 April	El Niño-Southern Oscillation likely to remain neutral for southern hemisphere winter
11 May	Southern Annular Mode positive, El Niño–Southern Oscillation neutral
8 June	Climate drivers currently neutral
22 June	Increased chances of a negative IOD event in 2021
6 July	Negative IOD event likely in 2021
20 July	Negative Indian Ocean Dipole established, supporting wetter winter-spring outlook
3 August	Negative Indian Ocean Dipole event continues
17 August	Negative Indian Ocean Dipole likely to continue for spring
31 August	Tropical Pacific Ocean likely to cool, but remain ENSO-neutral
14 September	La Niña WATCH—chance of La Niña increases
28 September	La Niña WATCH; negative Indian Ocean Dipole near its end
12 October	La Niña ALERT; tropical Pacific continues to cool
26 October	La Niña ALERT continues—likelihood of La Niña around 70%
9 November	Negative IOD weakens, La Niña ALERT continues
23 November	La Niña established in the tropical Pacific
7 December	La Niña firmly established in the tropical Pacific
21 December	La Niña continues as Indian Ocean Dipole returns to neutral





Figure 1. Time series of IOD and Nino 3.4. BoM website http://www.bom.gov.au/climate/enso/indices.shtml

As shown in Figure 1, in 2021, the relatively weak negative IOD fluctuated around the -0.4°C threshold. This contrasts with a year like 2016 where the IOD was clearly negative with monthly values below -1.4°C. IOD and ENSO are major drivers of seasonal rainfall in southern Australia, but there are shorter term drivers such as the Southern Annular Mode and the Madden Julien Oscillation. The excellent Climate Dogs animation from Agriculture Victoria introduced many in agriculture to ENSO, Indy, SAM and Mojo as four dogs along with the subtropical ridge (Ridgy) that can pull in different directions to 'round up' weather for southern Australia Climate Kelpie. Factors that may have contributed to the dry spring include the Madden Julian Oscillation (MJO) early in spring staying in a phase associated with drier conditions in southern Australia and a positive Southern Annular Mode. Advisers and growers who followed the forecasts in the 2020 season will recognise the pattern of an outlook for increased chance of a wet spring from a negative IOD that failed to eventuate until a La Niña later in spring. In 2020, the rain came in October rather than November which was timely for most of the SA grain crop. For example, for some early crops in low rainfall areas, October rain in 2020 was more disruptive to harvest than November rain in 2021.

The failure of the IOD to deliver a wet spring in 2021 poses the question 'should growers and advisers follow the trends and forecasts for climate drivers such as SAM and MJO along with ENSO and IOD?' Individual growers and advisers are the best to judge how much time and attention they want to give to following climate drivers. The most straightforward approach is to use the seasonal climate forecast and let the experts worry about the alphabet soup of climate drivers. It is important to acknowledge that understanding ENSO and IOD has been an important step in building trust and confidence in the basis of seasonal forecasts and useful when interpreting the forecasts. Following climate drivers such as SAM and MJO will come at a greater cost of time because they tend to fluctuate within a given month rather than locking into a positive, neutral or negative phase during the growing season. It is very hard to collate the information and almost impossible to give the appropriate influence that each driver will affect rainfall, be that a mental calculation for busy growers or even by using a spreadsheet. There is a good reason that climate science increasingly relies on dynamic climate models run on super computers, the oceans and atmosphere.

In 2013, the BoM switched from statistical to dynamic seasonal climate forecasts. Statistical forecast systems, used since the 1990s, are based on correlations between patterns of sea surface temperatures and local rainfall in the following 3-6 months. Dynamic forecast systems use the power of super computers to model future changes in the ocean and atmosphere for each day over the 6-9 months ahead. Because the model captures some of the stochastic nature of weather, no two runs of the model will be the same. The range of possible futures is widened by incorporating uncertainty in the starting conditions and uncertainty in the model. The result of the many model runs is 100 possible futures, some drier than the long-term median and some wetter. A forecast of 70% chance of exceeding the median rainfall is a statement that while 70% of the model runs were wetter. 30% were drier.

Gigerenzer (2005) asked participants in US and European cities what they understood from the statement of 30% chance of rain tomorrow. Did it mean, with current weather conditions, rain was expected i) 30% of the time (that is, about 7 hours), ii) 30% of the area or iii) 30% of days? A recent Australian example of a misinterpretation is here: https://www.abc.net.au/everyday/howto-read-the-weather-forecast-what-do-symbolsmean/100580374.



Many studies have shown that probabilistic forecasts are difficult to understand. The statement 'it will be a wet spring' is simpler than '70% chance of above median rainfall'. The problem with an interpretation based on headlines of 'BoM predicts wet spring' is that this simple categorical forecast will be wrong 30% of the time. A useful rule suggested by Gigerenzer (2005) is that when someone mentions a percentage, take time to ask yourself 'a percentage of what?' The problem with probabilistic forecasts isn't the maths. Grain growers understand and use percentages, such as 80% germination rate, 5% of a wheat sample contaminated with weeds or the soil moisture is 70% full. A probabilistic forecast is simply expressing the percentage of futures that will be wetter than the median. Thinking of a seasonal forecast as 30% of the model runs ended up with a drier season at my location and 70% were wetter is one way to better understand the forecast. When this shifts to 80% chance of exceeding the median, there is still 20% of computer runs that are drier. This clarity in thinking becomes even more important when dealing with extremes. A statement that there is 40% chance of decile 9 and 10 is a doubling of the long-term climate odds of being in the top two deciles.

Working with Upper North grower and consultant Barry Mudge and other colleagues, SARDI Climate Applications is working on methods to use these revised probabilities in decision making. For a quick explanation, see Rapid Climate Decision Analysis Tool (forecasts4profit.com.au). For a longer discussion, contact Barry Mudge or Peter Hayman.

#### An important IPCC report released in 2021

A number of important climate change science and policy responses occurred in 2021. The most media attention was on the November climate conference in Glasgow. This conference was preceded in August by an important report released from Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC). This 30-page summary document is worth a read. https://www. ipcc.ch/report/ar6/wg1/downloads/report/IPCC\_ AR6\_WGI\_SPM\_final.pdf

The IPCC aims to provide a rigorous and transparent update on science relevant to climate change. Rigour and transparency are achieved through an extensive review of drafts by scientists and policy specialists from governments. This is the 6th IPCC report and many commentators have observed the stronger language expressing more confidence in warming and the urgency to reduce emissions. The presentation will provide a brief introduction to some of the key graphs.

For a local South Australian focus, the AgExtra annual conference in July 2021 included a plenary session on climate change with Professor Mark Howden from ANU, Fiona Simpson from National Farmers Federation and Professor Richard Eckard from the University of Melbourne. AgEx Plenary -Session 1 (brightcove.net). Other local presentations worth following up include Dr Amanda Schapel (Rural Solutions, now SARDI) on soil carbon status of SA soils.

In March 2021, climate scientist Dr Kimberly Nicholas published a book 'Under the sky we make' (kimnicholas.com). She provides a clear summary in five short sentences: 'It's warming. It's us. We're sure. It's bad. But we can fix it'. In the last two decades, well-meaning growers and advisers have drawn my attention to strong contrarian arguments on the first four points. These include a challenge to whether the warming is really happening, the relative role of humans compared to volcanos and solar cycles, the fact that some scientists have different views and that the benefits of higher carbon dioxide will outweigh the problems. It is noteworthy that some of the same voices that dismissed the problem of human-induced climate change are now questioning the effectiveness of attempts to reduce emissions. Those of us involved in agriculture need to carefully and critically consider the impacts and adaptation options and the role for agriculture in reducing emissions including sequestering carbon. A local perspective on the challenges and opportunities presented by climate change is the PIRSA website Climate change resilience and adaptation - PIRSA.

### A new website worth bookmarking – climate services for agriculture

As part of the National Drought Initiative, CSIRO and BoM have been funded to produce the Climate Services for Agriculture tool. This tool provides historical data (1961-2020), seasonal forecasts (1—3 months) as well as future climate projections (2030, 2050, 2070) for a given location. The tool is in prototype form and feedback is welcome. See Climate Services for Agriculture (indraweb.io) User name: csa Password: demo



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#### References

Gigerenzer G, Hertwig R, Van Den Broek E, Fasolo B, Katsikopoulos KV (2005) "A 30% chance of rain tomorrow": how does the public understand probabilistic weather forecasts? *Risk Analysis* **25(3)**, 623-629.

#### **Contact details**

Peter Hayman Climate Applications SARDI 0401 996 448 Peter.Hayman@sa.gov.au



## Forewarned is forearmed: new forecasts for agriculturalists

#### Dale Grey<sup>1</sup> and Kate Finger<sup>2</sup>.

<sup>1</sup>Agriculture Victoria; <sup>2</sup>Birchip Cropping Group.

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#### **Keywords**

■ ACCESS-S, climate, forecasts.

#### Take home messages

- A range of new outlooks for the weeks to months ahead, with richer detail, are becoming available from the Bureau of Meteorology.
- Some products are currently live, but others will become available over 2022.
- A forecast that is more insightful than chance of above median is now a reality.

#### Background

New forecasts from the Bureau of Meteorology's ACCESS-S model have been developed to give insight to hotter, cooler, wetter or drier conditions out weeks, fortnights and months. This work provides more detailed information of upcoming conditions and is focussed on the period beyond the 7-day weather forecast. New forecasts of extreme conditions are now available on the Bureau website. These predictions of extremes are specifically looking at the chances of receiving decile one and two events or decile nine and ten events. It is hoped that these forecasts will allow growers to plan farm operations in the murky zone past the weather forecast, for planting, harvesting, topdressing and haymaking logistics. Predictions are available for rainfall, and maximum and minimum temperature.

The new products are seamlessly embedded into the existing Bureau climate outlooks graphical forecasts (http://www.bom.gov.au/climate/outlooks/#/ overview/summary/) and have a 'click on your location' feature. For the first time ever, growers will be able to get a decile range forecast for rainfall to provide more detail than the current chance of above median forecast. Additional products will be made available to the public later this year. The

forecasts are based on a total of 99 separate model runs. This is needed to account for uncertainty in the way that the weather will evolve and allows the outcome to be plotted in a probabilistic fashion (for example, what percentage of the runs predict a certain outcome). As with all probabilistic forecasts, they never tell you exactly what will happen but show the range of odds of various amounts of rainfall or temperature occurring. When all the model runs are stacked up in a particular direction, you can be confident that the overarching climate and weather setup is causing that to happen; but just like 100:1 chances can win horse races, so too can unlikely events occur in weather and climate. Many times, though, forecasts show a great spread (or neutral) forecast which some people falsely interpret as average being the most likely. This is not correct, as such forecasts more correctly show that anything is possible. Forecasts such as these are not worth agonising over. Recently, the ACCESS-S1 model was updated to the S2 version, which has a number of improvements and 'Australianisation' of some parameters. This includes in-house Bureau inputs of the ocean and the soil moisture for the start of the forecast, which are improvements on the original UK Meteorological Office data that was used in ACCESS-S1.



#### The NEW tools

There are five new products that will be listed on the Bureau website over 2021-22.

#### Product #1

The first product is maps showing the chance of having extreme rainfall, maximum temperatures or minimum temperatures for the weeks, months and seasons ahead. These maps are a natural extension of the Bureau's currently available 'probability of above median' maps and show the chance of having **very** wet, dry, hot or cold conditions. For example, Figure 1 shows the forecast issued in January 2022 for the February to April period and the chance of having an extremely dry next three months. For these maps, 'extreme' has been defined as being amongst the driest, wettest, hottest or coldest 20% of periods (weeks/months/seasons) from the climatological (historical) period (that is, deciles 1 and 2 (bottom 20%) or deciles 9 and 10 (top 20%)). This product went live in November 2021.

#### Product #2

The second product is the 'decile bars'. These are location-specific bars that indicate the shift in the probabilities compared to usual across the deciles. They are available for rainfall, and maximum and minimum temperatures for the weeks, months and seasons ahead. Figure 2 shows an example of the bars for a forecast of three-month rainfall. These were one of the most popular products that arose from consultation with producers and advisors. This product went live in November 2021. For the first time in Australia, more detailed information is available on the forecast, rather than just 'chance of above median'.



**Figure 1.** Extreme rainfall map. Example of the chance of having an extremely dry Feb-Apr 2022 (amongst the bottom 20% in the climatology period). The forecast shown here is suggesting a low risk of having decile 1 or 2 rainfall totals over much of Australia (probabilities are less than the usual risk of 20% over large areas). In yellow, there is an increased chance of drier (decile 1 or 2 rainfall) in the SW quarter of Victoria.





**Figure 2.** Decile bars. Rainfall forecasts for Feb-Apr in the Wimmera (generated on 13 January 2022). The forecasts show the probabilities across five

different decile ranges. The long-term average probability ('usual chance') for each category is 20% and the forecasts show the shift in the odds compared to usual. For example, the odds are showing a swing to drier being almost twice as likely, with about double the usual risk of having decile 1 or 2 rainfall (that is, being amongst the bottom 20% of driest Feb-Apr). Importantly, it can be seen that every other outcome is still on the table, just that the chance of decile 9 and 10 rainfall has halved and would be less likely. It is common for forecasts to show 20% chances of each decile range which is what is termed a neutral forecast. The stars give a representation of the historic skill of the forecast, the more stars the better the skill. Explanation of the methodology and its interpretation can be found, by pressing the (i) button

#### Product #3

The third product is the 'climagram'. These are location-specific timeseries graphs showing the forecast of rainfall totals, and maximum and minimum temperatures respectively for the coming weeks and



**Figure 3.** Climagram. Timeseries of observed (red solid line) and forecast (red box plots) maximum temperature (y-axis) for consecutive weekly periods (x-axis) for Walpeup. The box plots indicate the range in the expected outcomes from the forecasts. The grey shading indicates the usually expected temperatures for that time of year (based on 1981-2010). The thresholds shown for the box plots and the grey shading are the 10th, 25th, 50th (median), 75th and 90th percentiles. For example, Week 1 (15 Jan–21 Jan 2021) is forecast to have a weekly mean maximum temperature of around 29.8°C (the median of the forecasts), which is around 2°C cooler than usual (for example, the median line of the box is below the median line of the grey shading and is around the 25th percentile of usually expected temperatures). Week 2 is also possibly going to be cooler but with greater spread from the model. In contrast, in Week 3 temperatures are expected to return to close to usual, with a weekly mean maximum temperature of ~32°C (that is, the median of the forecasts is close to the historical median). The display of the product shown here is from the R&D prototype. Work is progressing to enhance the display for the public website, and as such, the product will look slightly different when it goes live.



months (Figure 3). Past observations are also shown on the graph. Insight from producers and advisors really drove the creation of this product due to the strong desire to visualise the forecast as a timeseries for a given location (rather than having to look at multiple maps). The forecasts of rainfall totals and temperatures (rather than departures from normal) facilitates flexibility for temperature/rainfall thresholdspecific decisions. The week one forecasts of all products importantly includes the actual weather forecast, which is much more accurate at predicting short term rainfall and temperature than using the first week of the climate model forecast. This product is in its final stages of testing before going live.

#### Product #4

Probability of exceedance (POE) graphs for rainfall are the fourth product and probably the most complex of the new tools to understand. However,

once understood through the consultation process with producers and advisors, the overwhelming feedback was that this tool is valuable and will allow users to delve deeper into the forecast information. It forms part of a hierarchy of complexity of forecast tools. Insight from the producers in the reference groups indicated that for some users this information is too detailed, but for others, it could provide very useful input into their decision-making. Figure 4 shows an example of a POE forecast. The POE curves give the probability (y-axis) that different thresholds of rainfall (x-axis) will be exceeded at the location in question. The curves slope from the top left down to the bottom right, because as the rainfall totals increase, the probability of exceeding those totals decreases. The black curves are for the forecast POE and the grey curves are for the historical POE (that is, climatology). Comparing the black and grey curves indicates how different the forecast is from usual conditions. The forecast



**Figure 4.** Probability of exceedance. Example forecast for rainfall from 15 September 2021, showing the forecast (black) and usual conditions (grey) for November 2021. The black line indicates that ACCESS-S was predicting greater chances of higher rainfall than normal at all volumes. The display of the product shown here is from the R&D prototype. Work is progressing to enhance the display for the public website, and as such, the product will look slightly different when it goes live.



product gives users the flexibility to identify the rainfall threshold that they are interested in on the x-axis, and then read off the associated probability of exceeding that threshold on the y-axis (or vice versa). This product is in its final stages of testing before going live.

#### Product #5

The final product is the 3-day rainfall accumulation (or 'burst') forecast which is a map-based product and available for multi-week forecasts (see Figure 5). The forecast product shows the likelihood (probability) of receiving a pre-selected threshold of rainfall over three consecutive days in the upcoming weeks or fortnights. This arose in discussion with growers in northern Australia where they are looking for accumulated totals from 'bursts' of the monsoon. It is unclear yet how this product might be used in southern States but it is plausible that it might be useful around the autumn break or hay and harvest operations. The experimental product currently has four thresholds that can be selected but it will be possible to add more thresholds. This product is in its final stages of testing before going live.



**Figure 5.** 3-day rainfall accumulation (burst) product. A forecast map showing the probability of receiving an intense 'burst' of rainfall over a short period of time. For example, in this map, parts of mountainous Victoria have a greater than 25% chance of receiving more than 50mm of rainfall in three consecutive days during a fortnight from 22 January to 4 February 2022 from a forecast made on 15 January. Higher probabilities exist in northern Australia. The display of the product shown here is from the R&D prototype. Work is progressing to enhance the display for the public website, and as such, the product will look slightly different when it goes live.



#### Conclusion

Growers and advisors are encouraged to familiarise themselves with the new products that come out in 2022 and to stay alert for the webinar launches and explanations of how to interpret the products.

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#### Useful resources

Bureau of Meteorology climate outlooks

(http://www.bom.gov.au/climate/outlooks/#/rainfall/ extremes/p20/weekly/0)

Forewarned is forearmed. New extremes outlooks for agriculture. (How to interpret products one and two) (https://www.youtube.com/ watch?v=lhHmZS9h2LI)

#### **Contact details**

Dale Grey 03 5430 4395 PO Box 3100, Bendigo DC VIC 3554 dale.grey@agriculture.vic.gov.au @eladyerg



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STORED GRAIN PROJECT

## Soil organic matter in dryland systems – management and opportunities

#### Mark Farrell<sup>1</sup>, Vadakattu VSR Gupta<sup>1</sup>, James Hunt<sup>2</sup>, Senani Karunaratne<sup>3</sup> and Lynne M Macdonald<sup>1</sup>.

<sup>1</sup>CSIRO Agriculture & Food, Kaurna Country, Glen Osmond, SA; <sup>2</sup>School of Agriculture & Food, The University of Melbourne; <sup>3</sup>CSIRO Agriculture & Food, Black Mountain, ACT.

#### Keywords

■ carbon sequestration, regenerative agriculture, soil constraints, soil organic matter.

#### Take home messages

- It is well known that stocks of soil organic carbon have declined over the past decades in many Australian agricultural systems, including dryland grains production.
- This loss of carbon (C) has also resulted in a substantial reduction in soil nutrient stocks, particularly nitrogen (N), that supply a large proportion of a crop's nutrition.
- Rebuilding soil C and N stocks is slow and depends upon increased biomass production to drive C inputs, supported by fertiliser requirements being met. It is possible this may be assisted by some regenerative approaches.
- Identifying and addressing the primary constraints to water use efficiency, inclusion of legumes in crop sequences, and estimating and managing the N budget of the system over multiple seasons should turn a system towards rebuilding C and N stocks.
- Practices that fall under the umbrella definition of regenerative agriculture may limit C losses, or assist in building stocks, provided other constraints are overcome.
- This paper is largely a revision of Farrell et al. (2021) and Macdonald et al. (2020).

#### Introduction

Soil organic matter (SOM) contains the largest stocks of both C and N, including those under agricultural management. Globally, 1200—1550 gigatonnes (Gt) of C are stored in soils, with estimates of 22.6–39.7Gt in the top 30cm of Australian soils (Viscarra Rossel et al. 2014). Assuming a C:N ratio of 11.8, this equates to 1.92– 3.36Gt N stored in the SOM of the top 30cm of all of Australia's soils, an average of just over 4t N/ha. Most N is not immediately available, and is bound within SOM as organic N. As plants can only take up mineral N and a small proportion of dissolved organic N (DON), SOM must be decomposed to release these compounds. A snapshot study found, on average, only 0.59–4.80% of total N was present in plant available forms in Australian agricultural systems (Farrell et al. 2016).

Soil organic matter is responsible for provision of nutrients (particularly N), maintaining a diverse and healthy microbial community, infiltration and water retention, amongst others. It can be separated into three measurable fractions, with distinct properties for nutrient supply and stability (Baldock et al. 2013), which were described in detail in our update to GRDC last year (Farrell et al. 2021). In addition to SOC, two smaller important pools of C exist: microbial biomass C (MBC), which typically contains approximately 1% of the total organic C in a soil and represents the C stored in live microorganisms, and dissolved organic C (DOC) which is the soluble fraction. This latter pool contains most of the C



directly accessible by microorganisms, but also compounds that, while soluble, do not directly reflect availability of C. Though representing only a small percentage of C in the soil, they turn over quickly and yet are very important. In many ways, this could be thought of in terms of a bath: If you were to run the tap with the plug out and measure the amount of water in the bath, you would find very little there at any point in time. However, you would be wrong to conclude that water is not important for the function of a bath. This same concept of 'flux' versus the 'pool' needs to be considered for N also.

#### Regenerative agriculture practices

As many would be aware, there has been a groundswell in the 'regenerative agriculture movement' over the past few years. This primarily comes from overseas, and at its simplest, aspires to effectively leaving the land in a better condition than that in which it started. Robertson et al. (2022) propose an elaborated definition of regenerative agriculture (RA): 'Regenerative agriculture is a form of farming in which explicit attention is paid to the state and trajectory of the natural capital base (soil, water, biodiversity) underlying farm production and acknowledgement that there are non-farm stakeholders interested in its responsible management. It is not a prescriptive recipe of farm practices, but rather has a focus on positive outcomes for the natural resource base, particularly soil health, and farm productivity and profitability.'

Whilst not prescriptive (unlike organic or biodynamic systems), typically promoted RA practices include:

- minimum soil disturbance
- stubble retention
- diverse rotations (including cover crops and the inclusion of livestock in the system)
- a reduction in synthetic inputs (including pesticides and fertilisers).

In Australian broadacre agriculture, minimum soil disturbance, through the adoption of no-till (NT) and stubble retention, have been almost universally adopted over the past 20-30 years, whilst diverse rotations are increasingly seen as a best practice way to manage disease and the risk of seasonal variations. Thus, the first three RA practices, far from being something new, are widely adopted conventional farming practices in Australia, with the general presumption that amongst other agronomic benefits, SOC stocks also increase. Contrasting findings in the literature, even between global meta-analyses (Kopittke et al. 2017; Powlson et al. 2014) suggest this outcome to be variable, and likely climate- and soil- specific. Sanderman et al. (2010) reported improved cropping practices in Australia has the potential to increase SOC stocks by 0-2-0.3t/ha/yr, though many of the improvements within that definition (for example, NT, stubble retention, and diverse rotations) are now well established as best practice.

On the other hand, in many cases, reducing the amount of synthetic inputs is a far more complex topic, separable into two distinct categories:

- agrichemicals for weed, pest and disease control
- synthetic fertilisers.

In-depth discussion of the impact of agrichemicals is beyond the scope of this paper, but it is well known that NT systems rely primarily upon chemical methods for weed control. Conversely, negative impacts of mechanical weed control via regular tillage on soil structure and erosion are well documented.

When considering an aspiration to reduce synthetic fertiliser inputs, particularly N, it is important to recognise the intrinsic links between SOC and N — the majority of N in soils is chemically bound to SOC in the form of SOM. If synthetic N inputs are reduced and the balance is not replaced via N fixation, N will be 'mined' by the crop from SOM, resulting in a loss of SOC. This is discussed further below.

### Linkages between the soil carbon and nitrogen cycles

#### Organic matter – form and function

To better understand how C accumulates, is lost and behaves in soil, a fractionation procedure has been developed to separate measurable fractions of discrete chemistry and functionality. This separates C in the <2 mm portion of soil (excluding gravel and coarse plant debris) into three fractions:

- Particulate organic C (POC): The least decomposed fraction that is accumulated rapidly but also is most vulnerable to loss and is dominated by partially decomposed plant material.
- Humus-like organic C (HOC): Stabilised organic carbon, mostly in the form of dead soil microorganisms, that has undergone degradation and is often protected from loss due to binding to the soil mineral phase and protection within microaggregates.



 Resistant organic C (ROC): This is a charcoallike substance, typically with a very high C:N ratio >100:1 as SOM and a residence time of millennia.

#### Inputs and retention of C in dryland soils

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

As discussed in more detail in Macdonald et al. (2020) and Farrell et al. (2021), it is possible to estimate the inputs of plant C to the soil on the basis of observed crop yield. This can be done on the basis of several literature-derived figures for the key aspects of harvest index, C allocation within a crop, and retention factors for C additions to soil (Figure 1).

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



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



### Without nitrogen, there is little opportunity to increase carbon

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

Even in more heavily fertilised irrigated cotton systems of New South Wales and Queensland, the majority of N taken up by a crop is accessed via soil processes; primarily SOM mineralisation (Macdonald et al. 2016), and thus, the acknowledgement that efficiency of fertiliser N use sits at approximately 50% in a given season obscures the use of N supplied in previous seasons.

The 'elephant in the room' when it comes to N export or loss from farming systems is actually the amount that is removed in the produce itself. As reported at previous GRDC Updates events, a comprehensive study by Norton (2016) found that the majority of properties studied in southern and eastern Australia were net exporters of N from the crop alone. Harries et al. (2021) found negative N balances in 60% of paddocks surveyed in WA. If other losses (particularly N2 from denitrification, which is the least quantified) are also present in the system, this could contribute to substantial N mining in the medium to longer term, with concomitant impacts on SOC stocks (Baldock et al. 2018).

## Management to build carbon and n itrogen stocks

For both C and N, the same principle applies; the stock in the soil is a function of inputs and outputs. While the inputs of N are perhaps somewhat simpler to conceptualise and manage, it is primarily plant growth that results in C inputs to soil, and there are several means of manipulating this to improve the likelihood of increasing C stocks. Also, as C stocks increase over the longer term, it is likely

that the ability of the soil to supply N through the mineralisation of SOM will also increase, provided that the N balance remains positive.

### Addressing soil constraints to increase soil organic matter inputs

Despite gains in productivity from broad adoption of NT and early sowing, there remains a yield gap between paddock production and the water limited yield potential. In many Australian cropping systems, crop water use is limited by a range of surface and subsurface constraints which limit root growth and exploration. Common abiotic constraints include compaction, soil acidity and associated toxicities (aluminium, magnesium), alkalinity, sodicity and associated toxicity (boron, chloride, salt), and water repellence. Biotic constraints are also recognised as important in Australian agriculture and include disease, weed, and pest pressures (Lawes et al. 2021). While conservation practices and crop selection are useful tools in mitigating the impact of these constraints, they will not correct the physicochemical condition of the soil.

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

#### Nitrogen balance, excess and the 'nitrogen bank'

Typical N fertiliser decisions focus either on rules of thumb for a district, or predictions of yield, and thus, likely N demand on the basis of model predictions, for example, Yield Prophet®. By and large, such predictions target maximum profit over yield. Importantly, they typically focus on returns within a single season. As Norton (2016) has shown, the net N balance of such practice is usually negative, meaning that N is being 'mined' from the SOM at a greater rate than it is returned, resulting in a concomitant loss of C. Thus, yields are effectively being 'subsidised' by SOM loss resulting in mediumlong term reduction in the ability of soil to supply N



through in-season mineralisation. This reduces the soil's fertility in the longer term, and as mineralisation tends to release N at a rate closely matching the crop's pattern of N demand, it is unlikely that extra fertiliser can simply offset lost N mineralisation potential in the longer term. Further, the main factor driving the yield gap in Australian grains systems is N limitation (Hochman and Horan 2018), and in wet and favourable seasons, this conservative approach to N management may impact profit in the short-term.

Instead, growers and advisers could consider the N requirement of the system as a whole by:

- considering nutrient balance in the mediumlong term, namely N balance over a 5–10-year period, not just the season ahead, and
- considering the need to 'feed the soil' via immobilisation of nutrients, as much as the crop itself.

This second point explicitly accounts for the fertiliser N required to build SOM which is sometimes seen as a negative cost of building C stocks but allows for the replenishment of the store of N that is released slowly through mineralisation.

An emerging approach to slow and potentially reverse declines in SOC and N stocks is known as the 'nitrogen bank' strategy (Meier et al. 2021). Recognising that losses of N from dryland grains systems are often low, and thus, economic and environmental risks are minimal (Smith et al. 2019), we suggest that applying greater rates of N will increase profitability through addressing the main constraint to yield and reducing SOC run-down. A major limitation in calculating a crop's N requirement is the ability to forecast rainfall and water-limited yield potential early in the season. A simple solution to this uncertainty is proposed whereby fertiliser application is calculated as the balance of crop N demand required to achieve economic yield in the majority of seasons after subtraction of the available N stock at sowing, ignoring in-season mineralisation. If it is a dry season, excess N will mostly remain in situ and be captured in the next season's presowing N testing, and fertiliser application rates adjusted accordingly. This approach effectively removes much reliance on SOM to deliver N through in-season mineralisation, and SOM that is mineralised is likely replaced through greater plant C inputs and the higher N availability resulting from the increased fertilisation rates. It should be noted that whilst showing early promise with minimal fertiliser N losses in the drier systems that dominate the southern region (Smith et al. 2019), substantial

losses through denitrification of larger up-front N additions have been documented in ex-pasture systems in the high rainfall zone (for example, up to ~90% applied N, Harris et al. 2016). Further research is required to better understand the climatic and soil boundaries at which higher up-front N applications can be applied with minimal loss.

Regardless of the system or strategy (Yield Prophet, N banks, rules of thumb) used to decide how much N to apply, a long-term field experiment in the Victorian Mallee has shown that systems which run a neutral to small positive N balance (that is, are not mining SOM) are also the most profitable (Figure 2).



**Figure 2.** The relationship between partial N balance (fertiliser N additions minus offtake in grain) and mean gross margin from a 4-year BCG experiment (2018-2021) at Curyo in NW Victoria. NB=nitrogen bank at different targets (100, 125 and 150kg N/ha); YP=Yield Prophet® at different levels of probability (25, 50, 75 and 100% where 50% targets median seasonal yield potential); R=replacement (N offtake in grain balanced with fertiliser); NA=National Average (45kg N/ha). For further details see https:// www.bcg.org.au/managing-n-fertiliser-to-profitablyclose-yield-gaps-2/

#### Legumes and nitrogen fixation

One of the key benefits of grain and pasture legumes in crop rotation is the N contribution through legume-rhizobia symbiosis that provides a component of the legume N requirements and is an important contributor of N supply to subsequent crops. The effect of recent intensification of Australian cropping systems and the consideration of grain legumes as rotational crops has the


potential to reduce N inputs and increase N use efficiency in following crops and improve overall soil quality. It is generally accepted that for many legume species, on average 20kg of shoot-N per tonne of dry matter is fixed by grain legumes, although the actual amount of N fixed can vary 15 — 25kg N fixed per tonne depending on the legume type, field conditions including management practices applied and seasonal conditions (Peoples et al. 2009). However, it should be remembered that N fixation provides the majority of the N demand of the grain legume crop itself, and a large part of the fixed N is exported in the grain.

Despite the increased preference for cropping in recent years, pastures remain a dominant part of southern farming systems which can play a key role in sustaining and improving SOM and fertility. Nitrogen fixation from pastures provides an important component of the N supply to subsequent cereal crops, which are further complemented by the C inputs from above and below ground plant components. The amount of N fixed by various annual and perennial legumes in Australia can vary from <10 to >250kg N/ha/year. Additionally, the below-ground pool of N in roots and nodules provides an important source of N inputs, for example, 40-55% of total plant N is estimated to be present below ground in pasture systems (Peoples et al. 2017).

There is an opportunity to improve our understanding of the constraints to N fixation. For example, inappropriate herbicide use has been shown to reduce N fixation in grain legumes (Drew et al. 2007). Implementation of management strategies that can improve legume productivity and N fixation can not only arrest the decline in the N supply capacity of soils but also contribute to the improvement of overall SOM quantity and quality (Sanderman et al. 2017). Given that the formation of new SOM is not only contingent on there being sufficient C and nutrients, but also the need for them to be co-located near clay minerals and in conditions suitable for microbial growth, conversion of legume root biomass to more stabilised SOM is likely to be more efficient than other plant inputs supplemented with nutrients supplied by fertiliser.

#### Cover crops

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

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

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

#### Looking to the future

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

Recognising the monetary value of the N tied up in SOM (and indeed, exploited through N-mining) suggests that a longer-term approach to N fertilisation strategies and legume rotations which result in a net import of N are required. The nitrogen bank strategy provides one possible solution whereby longer-term profitability and higher N applications are not mutually exclusive. Coupled with strategies that increase plant C inputs, either



through the alleviation of soil constraints or where appropriate, increased plant growth and time of soil cover through cover cropping, it is likely that, over time, SOM and thus, N and C stocks, will increase. It is possible to achieve a neutral or positive N balance with RA and thus build SOM, but this likely requires 50% of rotation in pasture legumes or winter cover crops, or affordable access to organic inputs to balance N removed in grain. In some regions with good access to waste streams, this may be feasible, whilst in other regions it would be cost prohibitive.

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

#### References

Angus JF, Grace PR (2017) Nitrogen balance in Australia and nitrogen use efficiency on Australian farms. *Soil Research* 5**5(6)**, 435–450. doi:10.1071/ SR16325

Baldock JA, Farrell M, Macdonald LM, Welti N, Monjardino M (2018) 'Nutrient mineralisation in Australian grain producing soils: mechanisms, magnitudes, gaps and future research.' (CSIRO: Canberra).

Baldock JA, Sanderman J, Macdonald LM, Puccini A, Hawke B, Szarvas S, McGowan J (2013) Quantifying the allocation of soil organic carbon to biologically significant fractions. *Soil Research* **51(8)**, 561-576.

Chowdhury S, Farrell M, Bolan N (2014) Priming of soil organic carbon by malic acid addition is differentially affected by nutrient availability. *Soil Biology and Biochemistry* **77**, 158–169. doi:10.1016/j. soilbio.2014.06.027

Drew EA, Gupta VVSR, Roget DK (2007) Herbicide use, productivity, and nitrogen fixation in field pea (Pisum sativum). *Australian Journal of Agricultural Research* **58(12)**, 1204-1214. Farrell M, Allen DE, Macdonald BCT (2016) Pools and fluxes: a snapshot of nitrogen dynamics in Australian soils. Proceedings International Nitrogen Initiative Conference, Melbourne, December 2016, pp. 1–4.

Farrell M, Gupta V, Macdonald LM (2021) Addressing the rundown of nitrogen and soil organic carbon. Proceedings GRDC Grains Research Update, Bendigo, February 2021, pp. 51-60.

Farrell M, Stanley M (2021) Mixed cover crops for sustainable farming' (https://research.csiro.au/ mixedcovercrops/)

Fleming N, Fraser M, Dohle L, Hughes B (2020) Subsurface acidity – how far has the research advanced? Proceedings GRDC Grains Research Update, Adelaide, February 2020, pp. 251-256.

Garland G, Edlinger A, Banerjee S, Degrune F, Garcia-Palacios P, Pescador DS, Herzog C, Romdhane S, Saghai A, Spor A, Wagg C, Hallin S, Maestre FT, Philippot L, Rillig MC, van der Heijden MGA (2021) Crop cover is more important than rotational diversity for soil multifunctionality and cereal yields in European cropping systems. *Nature Food* **2**, 28–37. doi:10.1038/s43016-020-00210-8

Harries M, Flower KC, Scanlan CA (2021) Sustainability of nutrient management in grain production systems of south-west Australia. *Crop and Pasture Science* **72(3**), 197-212.

Harris RH, Armstrong RD, Wallace AJ, Belyaeva ON (2016) Effect of nitrogen fertiliser management on soil mineral nitrogen, nitrous oxide losses, yield and nitrogen uptake of wheat growing in waterlogging-prone soils of south-eastern Australia. *Soil Research* **54(5)**, 619-633.

Hochman Z, Horan H (2018) Causes of wheat yield gaps and opportunities to advance the water-limited yield frontier in Australia. *Field Crops Research* **228**, 20–30. doi:10.1016/j.fcr.2018.08.023

Hunt JR, Celestina C, Kirkegaard JA (2020) The realities of climate change, conservation agriculture and soil carbon sequestration. *Global Change Biology* **26(6)**, 3188–3189. doi:10.1111/gcb.15082

Kopittke PM, Dalal RC, Finn D, Menzies NW (2017) Global changes in soil stocks of carbon, nitrogen, phosphorus, and sulphur as influenced by longterm agricultural production. *Global Change Biology* **23(6)**, 2509–2519. doi:10.1111/gcb.13513

Lawes R, Chen C, Whish J, Meier E, Ouzman J, Gobbett D, Vadakattu G, Ota N, van Rees H (2021) Applying more nitrogen is not always sufficient to address dryland wheat yield gaps in Australia. *Field Crops Research* **262**, 108033.



Macdonald BCT, Chang YF, Nadelko A, Tuomi S, Glover M (2016) Tracking fertiliser and soil nitrogen in irrigated cotton: uptake, losses and the soil N stock. *Soil Research* **55(3)**, 264–272. doi:10.1071/SR16167

Macdonald LM, Farrell M, Baldock JA (2020) Soil organic matter – what the science tells us. Proceedings GRDC Grains Research Update, Barellan, March 2020, pp. 28–35.

Macdonald LM, Wilhelm N, Fraser M, Moodie M, Trengove S, Desbiolles J, Saunders C, Whitworth R, da Silva R, Llewellyn R, McBeath T (2021) Targeted amelioration in Mallee sands to maximise crop water use. Proceedings GRDC Grains Research Update, Adelaide, February 2021, pp. 37-42.

Meier EA, Hunt JR, Hochman Z (2021) Evaluation of nitrogen bank, a soil nitrogen management strategy for sustainably closing wheat yield gaps. *Field Crops Research* **261**, 108017. doi:10.1016/j. fcr.2020.108017

Norton RM (2016) 'Nutrient performance indicators from southern Australian grain farms.' (GRDC, Canberra).

Peoples MB, Brockwell J, Herridge DF, Rochester IJ, Alves BJR, Urquiaga S, Boddey RM, Dakora FD, Bhattarai S, Maskey SL, Sampet C, Rerkasem B, Khan DF, Hauggaard-Nielsen H, Jensen ES (2009) The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis* **48(1-3)**, 1–17.

Peoples MB, Swan AD, Goward L, Kirkegaard JA, Hunt JR, Li GD, Schwenke GD, Herridge DF, Moodie M, Wilhelm N, Potter T, Denton MD, Browne C, Phillips LA, Khan DF (2017) Soil mineral nitrogen benefits derived from legumes and comparisons of the apparent recovery of legume or fertiliser nitrogen by wheat. *Soil Research* **55(6)**, 600–616. doi:10.1071/SR16330

Powlson DS, Stirling CM, Jat ML, Gerard BG, Palm CA, Sanchez PA, Cassman KG (2014) Limited potential of no-till agriculture for climate change mitigation. *Nature Climate Change* **4**, 678–683. doi:10.1038/nclimate2292

Robertson M, Macdonald B, Farrell M, Norman H, Macdonald L, Vadakattu G, Taylor J (2022) What can science offer the proponents of Regenerative Agriculture practices? Farm Policy Journal, accepted.

Sanderman J, Creamer C, Baisden WT, Farrell M, Fallon S (2017) Greater soil carbon stocks and faster turnover rates with increasing agricultural productivity. *Soil* **3**, 1–16. doi:10.5194/soil-3-1-2017

Sanderman J, Farquharson R, Baldock JA (2010) Soil carbon sequestration potential: a review for Australian agriculture. CSIRO Sustainable Agriculture Flagship, Adelaide, Australia.

Smith CJ, Hunt JR, Wang E, Macdonald BCT, Xing H, Denmead OT, Zeglin S, Zhao Z (2019) Using fertiliser to maintain soil inorganic nitrogen can increase dryland wheat yield with little environmental cost. *Agriculture Ecosystems* & Environment **286**, 106644. doi:10.1016/j. agee.2019.106644

Viscarra Rossel RA, Webster R, Bui EN, Baldock JA (2014) Baseline map of organic carbon in Australian soil to support national carbon accounting and monitoring under climate change. **Global Change Biology 20(9)**, 2953–2970. doi:10.1111/gcb.12569

#### **Contact details**

Mark Farrell CSIRO Agriculture & Food Locked Bag 2, Glen Osmond SA 5064 08 8303 8664 mark.farrell@csiro.au @inverted\_soil



## Early learnings from multi-site, multi-system assessment of new long-coleoptile genetics for deep sowing of wheat

## Greg Rebetzke<sup>1</sup>, John Kirkegaard<sup>1</sup>, Therese McBeath<sup>2</sup>, Belinda Stummer<sup>2</sup>, Bonnie Flohr<sup>2</sup>, Andrew Fletcher<sup>3</sup>, Sarah Rich<sup>3</sup>, Michael Lamond<sup>4</sup>, Barry Haskins<sup>5</sup>, Rachael Whitworth<sup>5</sup>, Kathryn Bechaz<sup>6</sup>, Lee Gullifer<sup>6</sup>, Darren Aisthorpe<sup>7</sup>, Andrew Ware<sup>8</sup> and Rhaquelle Meiklejohn<sup>8</sup>.

<sup>1</sup>CSIRO Agriculture and Food, Canberra ACT; <sup>2</sup>CSIRO Agriculture and Food, Adelaide SA; <sup>3</sup>CSIRO Agriculture and Food, Floreat WA; <sup>4</sup>SLR Agriculture, York WA; <sup>5</sup>AgGrow Agronomy and Research, Griffith NSW; <sup>6</sup>Kalyx Australia, Griffith NSW; <sup>7</sup>DAF, Emerald QLD; <sup>8</sup>EPAG Research, Port Lincoln SA.

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#### Keywords

■ coleoptile, dwarfing gene, establishment, sowing depth.

#### Take home messages

- Long coleoptile wheats have potential to remove risk and uncertainty with dry sowing and provide successful establishment from deep sowing into subsoil moisture.
- Yield was largely unaffected by deep sowing to 12cm in long coleoptile Mace<sup>(b)</sup>18 whereas yield penalties of up to 34% were observed with deep sowing of shorter coleoptile Mace<sup>(b)</sup>.
- Soil type influenced establishment of short coleoptile wheat when sown deep. On dry, sandier soils, leaf growth continued slowly upward to permit some seedling emergence. However, on heavier-textured, compacted and/or crusted soils, leaf growth was restricted to slow and commonly prevented seedling emergence.

#### Background

Timely and successful plant establishment is critical to crop productivity in rainfed farming systems. Early emergence combined with optimal phenology increases yield potential due to a longer duration for root, tiller and crop growth while ensuring conditions are suitable for growth and flowering, and during grain-filling. Well-established crops also provide ground cover to protect ameliorated soils, reduce water loss through soil evaporation, and increase crop competitiveness with weeds.

Changing weather patterns are associated with proportionally greater summer rainfall and increasingly later sowing breaks (Flohr et al. 2021; Scanlon and Doncon 2020). As a result, many crops are sown dry to accommodate large sowing programs. There is increasing interest in deep sowing at depths exceeding 10cm to utilise summer rainfall and ensure earlier germination and establishment (Rich et al. 2021; Flohr et al. 2022). However, the shorter coleoptiles (65-95mm) associated with the green revolution *Rht1* and *Rht2* dwarfing genes in current wheat varieties limits sowing depths to less than 10cm and commonly 3 to 5cm. Coleoptile length is a key consideration with sowing depth as the coleoptile elongates from the seed through the soil, protecting the elongating sub-crown internode and crown.

Alternative dwarfing genes have been identified with potential to reduce plant height and increase yields while increasing coleoptile length by 50-80%



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(Rebetzke et al. 2022). Some of these dwarfing genes (for example, *Rht8* and *Rht18*) have been used commercially overseas but have not been assessed for use in Australia. Improved establishment and grain yield in a grower-led trial in 2020 highlighted the potential for long coleoptile *Rht18* wheats for earlier, deep sowing to make use of summer-stored, subsoil moisture (Rebetzke et al. 2021). This paper reports on a series of subsequent experiments conducted across Australia examining deep sowing of long coleoptile wheats. A separate pot study investigated the influence of sowing depth on shoot and root growth in contrasting soil types.

#### Methods

Multi-location experiments were designed to investigate the potential for emergence with deep sowing of long coleoptile, Rht18 breeding lines bred at CSIRO from an Italian durum wheat variety, 'Icaro', into the semidwarf variety 'Mace<sup>(b)</sup>'. Both Mace<sup>(b)</sup> and the Rht18-containing Mace<sup>(b)</sup>, 'Mace<sup>(b)</sup>18', were grown together with the older, tall variety 'Halberd' (released in 1969) and two current semi-dwarf varieties, 'Scepter<sup>(b)</sup>' and 'Calibre<sup>(b)</sup>', at two depths (4 and 12cm) at four sites in WA (Latham, Holt Rock, Hines Hill, Beacon). MaceA and MaceA18 are closely related, differing in the presence of the coleoptilereducing Rht2 and coleoptile-increasing Rht18 dwarfing genes. Separate experiments containing many of the same entries were sown at Cootra (SA), Tabbita and Griffith (NSW). Plant number was recorded at 200°Cd and crops harvested at maturity for grain yield.

A separate pot experiment was conducted in a temperature-controlled glasshouse to investigate the influence of soil type on emergence and plant growth with deep sowing. Both Mace<sup>(h)</sup> and Mace<sup>(h)</sup>18 were sown at 4cm and 12cm depth in replicated deep pots (n = 8 reps) containing either a coarse-textured, sandy soil from Cootra (SA) or a heavy-textured, red-brown earth from Griffith (NSW). Plant growth measurements were undertaken at two times: an early sampling at 300°Cd post-sowing (1.5 leaves) and a later sampling at 600°Cd post-sowing (3.5 leaves). Seed used in all experiments was produced in the same environment and graded to the same size (40mg) to avoid confounding maternal effects on seedling vigour.

#### Results and discussion

#### Sowing depth field experiments

Conditions were generally favourable at sowing and throughout the season across the different field sites in 2021. Establishment was excellent for shallow sowings with high emergence rates and final plant numbers at all sites (Figure 1). Overall, plant number was reduced by an average 26% with deep sowing compared with shallow sowing. The largest reduction in plant number with deep sowing was at Beacon (WA) and Griffith (-32%), and the smallest reduction at Holt Rock (WA) (-17%) and Cootra (-20%). Across WA sites, percentage reduction in plant number with deep sowing was 54% and 3% for Mace<sup>(b)</sup> and Mace<sup>(b)</sup>18, respectively, and 38% and 21% for Scepter<sup>()</sup> and Calibre<sup>()</sup>, respectively (Figure 1). Plant number for Mace<sup>(b</sup>18 was not statistically different from Halberd, while the ranking for plant number for the different wheat varieties was consistent across all four WA sites. Plant heights of Mace<sup>(b)</sup> and Mace<sup>(b)</sup>18 were not different (data not shown), yet the coleoptile length of Mace<sup>(b</sup>18 (131mm)) is significantly longer than Mace<sup>()</sup> (76mm), while Halberd and Mace<sup>(b</sup>18 have similar coleoptile lengths (Rebetzke et al. 2021). The moderately-longer coleoptile length of Calibre<sup>()</sup> was associated with greater plant number with deep sowing compared with other shorter coleoptile Rht2 varieties Mace<sup>(b)</sup> and Scepter<sup>()</sup> (Figure 1).

Site mean grain yield ranged from 0.68t/ha at Hines Hill (WA) (where crops were frosted) to 4.56 and 4.62t/ha at Tabbita and Griffith in SNSW, respectively, where the latter sites received up to 550mm of rain in 2021. Shallow-sown Mace<sup>(b)</sup> ranged in yield from 0.40t/ha at Hines Hill to 5.78t/ ha at Griffith. In shallow sowings, Mace<sup>()</sup> produced significantly (P<0.05) greater average yield than Mace<sup>(b</sup>18 (4.08 and 3.81t/ha, respectively). However, when sown deep, grain yields decreased to 3.11t/ ha (-20%) for Mace<sup>(b)</sup> but only to 3.80t/ha (-0.5%) for Mace<sup>(b)</sup>18. The largest yield reduction with deepsown Mace<sup>(b)</sup> was at Griffith (-34%), with the smallest reduction at Cootra (-2%). These yield reductions appeared to reflect plant number with deep sowing at each of the sites assessed.





**Figure 1.** Mean numbers of plants per m<sup>2</sup> at four WA sites for shallow-sown (4cm) and deep-sown (12cm) Mace<sup>b</sup> *Rht2* and *Rht18* NILs  $\blacksquare$ , tall, long coleoptile variety Halberd  $\blacksquare$ , and commercial *Rht2* dwarfing gene varieties Scepter<sup>b</sup> and Calibre<sup>b</sup>  $\blacksquare$ . Lsds were 8, 16, 6 and 6 plants per m<sup>2</sup> for Latham, Holt Rock, Beacon and Hines Hill, respectively.

#### Sowing depth pot experiments

As reported, the Cootra and Griffith sites contrasted significantly (P<0.05) in plant establishment with deep sowing which was thought to be related to soil type. Pot experiments were designed to carefully examine seedling emergence and early seedling growth under controlled conditions in contrasting soils. In the early seedling assessment (at 300°Cd), coleoptile lengths were significantly (P<0.05) greater at 12cm sowing depth and were longer for Mace<sup>(b</sup>18 than Mace<sup>(b)</sup> (Table 1). At 4cm sowing depth, number of leaves per plant, and shoot and root length were similar for Mace<sup>(b)</sup> and Mace<sup>(b)</sup>18, and for both soil types. With deeper sowing to 12cm depth, the sandy Cootra soil was associated with significantly (P<0.05) greater numbers of longer leaves, longer roots and fewer below-ground shoots than the stronger Griffith soil (Table 1). Elongation of the first leaf to the soil surface is typically slow and restricted by soil type and factors including crusting and soil compaction.

A soft, dry soil, such as the Cootra soil, allows for leaf elongation and emergence even with shorter coleoptile wheats sown deep, provided moisture at depth is adequate for germination. This contrasts with Mace<sup>(b)</sup> in the Griffith soil where significant (P<0.05) shoot biomass was recorded below the soil surface (Table 1). There was a significant (P<0.05) variety × soil depth × soil type interaction with Mace<sup>(b)</sup>18 producing a larger number of longer leaves, and greater root length than Mace<sup>(b)</sup>, particularly in the stronger Griffith soil. The reduced below-ground shoot growth for Mace<sup>(b)</sup>18 reflected the long sub-crown internode and positioning of the Mace<sup>(b)</sup>18 crown immediately below the soil surface (data not shown).

Plants were predictably much larger with sampling at the later (600°Cd) seedling growth stage (Table 2). For example, average numbers of leaves more than doubled from 1.5 to 3.5 leaves from the earlier (300°Cd) seedling harvest (Tables 1 and 2).



## **Table 1.** : Seedling growth characteristics at 300°Cd for the Mace<sup>(h)</sup> and Mace<sup>(h)</sup>18 near-isogenic lines (NIL) sown at 4 and 12cm depths in a sandy Cootra and red-brown Griffith soil. All means are expressed on a single-plant basis.</sup></sup>

Seed	NIL	Coleopti (m	le length ım)	Number (r	of leaves 10)	Above- shoot ler	ground ngth (mm)	Average r (m	oot length Im)	Below- shoot ler	ground igth (mm)
ueptii		Cootra	Griffith	Cootra	Griffith	Cootra	Griffith	Cootra	Griffith	Cootra	Griffith
4cm	Mace	43	43	2.2	0.8	52	23	28	08	0	25
	Mace <sup>(b</sup> 18	53	50	1.8	1.3	49	30	30	15	4	19
12cm	Mace	79	77	1.8	0.6	32	09	30	10	11	83
	Mace <sup>(1)</sup> 18	115*	121*	1.3	1.8*	38	43*	30	30*	34*	11*

\*Mace<sup>(b)</sup> and Mace<sup><math>(b)</sup>18 means are statistically different at P = 0.05.</sup>

**Table 2.** : Seedling growth characteristics at 600°Cd for the Mace<sup>()</sup> and Mace<sup>()</sup>18 near-isogenic lines (NIL) sown at 4 and 12cm depths in a sandy Cootra and red-brown Griffith soil. All means are expressed on a single-plant basis.

Seed	NIL	Number (I	of leaves n)	Shoot I (n	piomass 1g)	Root b (n	iomass 1g)	Number c (n	rown roots 10)	Number se (n	minal roots o)
ueptii		Cootra	Griffith	Cootra	Griffith	Cootra	Griffith	Cootra	Griffith	Cootra	Griffith
4cm	Mace	3.8	2.6	389	206	301	95	2.6	1.1	6	5.7
	Mace <sup>(b</sup> 18	4.1	3.8*	397	359*	202*	214	2.6	1.8	6	5.8
12cm	Mace	3.1	2.3	160	111	147	70	1.3	1.0	5.1	2.4
	Mace <sup>(b</sup> 18	3.3	3.8*	185	216*	220*	163*	1.6	2.2*	5.9*	4.3*

\*Mace<sup>(1)</sup> and Mace<sup>(1)</sup>18 means are statistically different at P = 0.05.

Numbers of leaves, and both shoot and root biomass were reduced with deeper sowing, with this reduction being greater for deep sowing in the Griffith soil. Numbers of crown and seminal roots were reduced at all depths in the Griffith soil (Table 2). Deep sowing was associated with fewer crown and seminal roots, particularly in the Griffith soil. Improved emergence and greater early seedling growth translated to increased shoot growth in Mace<sup>(b)</sup>18 compared to Mace<sup>(b)</sup> in the Griffith but not Cootra soil. In the Griffith soil, Mace<sup>(b)</sup>18 produced significantly more leaves than Mace<sup>(b)</sup> to increase shoot biomass. Root biomass was also significantly greater than for Mace<sup>(b)</sup> reflecting larger numbers of crown and seminal roots (Table 2). Despite the similar shoot growth for Mace<sup>(b)</sup>18 and Mace<sup>(b)</sup> when sown deep in the Cootra soil, Mace<sup>(b</sup>18 produced greater root biomass and this largely reflected greater numbers of seminal roots when compared with Mace<sup>()</sup> (Table 2).

The improved performance of Mace<sup>()</sup> with deep sowing at Cootra appeared to reflect the observed ability of some short coleoptile wheats to continue growth of leaf one (and sometimes leaf two) in soft, dry soils. Leaves continued to elongate upward until reaching the soil surface, whereupon a crown was formed and tillering commenced. However, the reduction in seminal and crown root number, and reduced root biomass for the deep sown Mace<sup>()</sup> (Table 2) does suggest that leaf growth through a soil might exhaust seed reserves to compromise early root development.

#### Conclusions

Improved plant establishment with deep sowing at 12cm confirmed the benefit of the long coleoptile trait first reported in separate on-farm experiments in 2018 and 2020. The 2021 studies highlighted the potential for increased grain yield with deep sowing for maximising water productivity. Improved performance in heavier soils suggests there may be potential for the long-coleoptile trait to aid in plant emergence and establishment in situations where furrow-fill occurs after sowing from wind or heavy rain, or with transient waterlogging at emergence (M. Lamond pers. comm.). The potential for coleoptile elongation should aid in ensuring emergence with variable depth control on large planters (B. Haskins pers. comm.), and with high soil temperatures when sowing early into warmer soils (Rebetzke et al. 2016).

Germplasm containing the *Rht18* dwarfing gene has been delivered along with selectable molecular markers for use in commercial breeding programs. Populations have been developed and are currently under assessment toward delivery of higher-yielding, long coleoptile wheat varieties for Australian growers.



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#### References

Flohr BM, Ouzman J, McBeath TM, Rebetzke GJ, Kirkegaard JA, Llewellyn RS (2021) Redefining the link between rainfall and crop establishment in dryland cropping systems. *Agricultural Systems* **190**, 103105.

Flohr B, McBeath T, Ouzman J, Davoren B, Shoobridge W, Rebetzke G, Ballard R, Peck D, Llewellyn R, Kirkegaard J, Stummer B (2022) Adaptive sowing strategies to overcome a shifting seasonal break. Adelaide Grains Research Update, February 2022

Rebetzke GJ, Richards RA, Fettell NA, Long M, Condon AG, Forrester RI, Botwright TL (2007) Genotypic increases in coleoptile length improves stand establishment, vigour and grain yield of deepsown wheat. *Field Crops Research* **100**, 10-23.

Rebetzke GJ, Zheng B, Chapman SC (2016) Do wheat breeders have suitable genetic variation to overcome short coleoptiles and poor establishment in the warmer soils of future climates? *Functional Plant Biology* **43(10)**, 961-972.

Rebetzke G, Fletcher A, Micin S, Wesley C (2021) On-farm assessment of new long-coleoptile wheat genetics for improving seedling establishment from deep sowing. Proceedings GRDC Grains Research Update, Perth, February 2021, p. 29.

Rebetzke GJ, Rattey AR, Brooks B, Bovill W, Richards RA, Ellis MH (2022) Transfer and agronomic assessment of the *Rht18* dwarfing gene from durum to bread wheat (*Triticum aestivum* L.). *Crop and Pasture Science* (In press)

Rich S, Oliver Y, Richetti J, Lawes R (2021) Chasing water: deep sowing can increase sowing opportunity across the grain growing regions of Western Australia. Proceedings GRDC Grains Research Update, Perth, February 2021, p. 27.

Scanlon TT, Doncon G (2020) Rain, rain, gone away: decreased growing-season rainfall for the dryland cropping region of the south-west of Western Australia. *Crop and Pasture Science* **71(2)**, 128-133.

#### **Contact details**

Greg Rebetzke CSIRO Agriculture and Food 02 6246 5153 / 0429 994 226 Greg.Rebetzke@csiro.au



## Resilient pastures for low rainfall mixed farms — crop and system benefits provided by legumes

Ross Ballard<sup>1</sup>, Bonnie Flohr<sup>2</sup>, David Peck<sup>1</sup>, Rick Llewellyn<sup>2</sup>, Jeff Hill<sup>1</sup>, Morgan McCallum<sup>1</sup>, Fiona Tomney<sup>1</sup>, Jessica Gunn<sup>1</sup>, Therese McBeath<sup>2</sup>, Elizabeth Meier<sup>2</sup>, Bill Davoren<sup>2</sup>, Willie Shoobridge<sup>2</sup>, Michael Moodie<sup>3</sup> and Roy Latta<sup>3</sup>.

<sup>1</sup>South Australian Research and Development Institute; <sup>2</sup>CSIRO Agriculture and Food; <sup>3</sup>Frontier Farming Systems.

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#### **Keywords**

■ break effect, grain yield, medic, vetch pasture

#### Take home messages

- Mean wheat yield after medic pasture was increased by 1.11t/ha (+44%) and grain protein by 0.7%, compared to a continuous cereal rotation, across four sites.
- A simulation study based on a medium-low rainfall site found that the inclusion of legumes in the rotation can contribute 14—70kg N/ha per year to the nitrogen (N) bank depending on the intensity at which they are grown.
- Despite the upfront establishment costs of a legume phase, gains in subsequent cereal crop yields alone can provide substantial return on investment.
- Medics were most consistent for production and regeneration on neutral/alkaline sandy loam soils, but were less amendable to on-farm seed harvesting than other legumes.
- Common vetch is a good option where a sown legume ley of one year duration is preferred, and a regenerating pasture legume seedbank is not a priority.
- Two new medics and an arrowleaf clover are being developed for commercial release.

#### Background

The Dryland Legume Pasture Systems (DLPS) project is evaluating a range of annual pasture legumes on mixed farms in the low to medium rainfall zone (Ballard et al. 2020). The project aims to:

- provide a critical assessment of the regional performance of existing and potential pasture cultivars
- quantify the benefits provided by pasture legumes to cropping systems.

This paper reports on the findings from four trials targeting neutral and alkaline sandy loams receiving 275 to 400mm rainfall (Table 1). Sites were cropped with wheat in 2020, following i) sown vetch or ii) one year of sown pasture or iii) two years of pasture that had been sown in 2018 and regenerated in 2019. Regenerated pasture treatments were at Lameroo and Minnipa sites only. Legume break effects on wheat grain yield, protein and available soil N are reported, and performance of the different legume species are briefly discussed.



Legume production, benefits to the cereal crop and subsequent legume regeneration have been measured to understand adaptation of different legume species to the environment and farming system such that growers can be confident in their performance and benefits.

#### Results and discussion

#### Crop benefits

The mean medic pasture break effect was substantial, producing an additional 1.11t/ha of grain yield and increasing grain protein by 0.7%, compared to the continuous cereal treatment (Table 1).

At Lameroo, a larger break effect was measured after a second year regenerating medic pasture in 2019 (that is, 2 years of pasture), although the one year medic pasture sown in 2019 still resulted in 57% additional wheat yield. One instance of reduced wheat yield after medic pasture occurred at Minnipa.

Differences in soil mineral N were measured (Table 2). The mean increase in available N was 42kg/ha and 35kg/ha after vetch and medic respectively. The soil N increase was greatest (81kg N/ha) at Piangil. There was a positive relationship between available N and grain yield at Lameroo and Piangil.

## The economic value of crop benefits from investing in legume phase

Using the Lameroo trial site results (see Tables 1 and 2), a return on investment (discounted cashflow) approach was used to evaluate the benefits of various legume phases to subsequent crops. This includes a 2-year 2018 sown medic (Seraph<sup>(b)</sup>); serradella (Margurita<sup>(b)</sup>); Trigonella and rose clover phase with regenerating pasture in 2019; and a single year sown serradella, medic, field peas and brown manure vetch compared to a continuous cereal treatment (wheat-barley-wheat-triticale). Assumed costs (based on PIRSA 2021 Gross Margin Guide) included pasture establishment (\$145/ha), pasture management (\$58/ha), and the opportunity cost (foregone profit) from not growing cereal in the legume years.

In each case, the value of benefits to subsequent cereal yield alone exceeded the costs of the legume phase (Figure 1). Largely due to very high legume break effects on wheat yield 2020, the net present value of including a legume was over \$200/ha for the field pea, brown manure vetch and 2-year medic and serradella phases. It is important to note that the trials were not grazed, so no grazing value was included, nor was the ongoing value of the pasture legume seedbanks that were established. The effect of higher protein on grain price was also not included.

in 2019.							
Trial location	2020 CSP (mm)	Wh	eat grain yield (t	/ha)	Grain protein content (%)		
	2020 05K (IIIII)	Cereal	<sup>1</sup> Vetch	Medic	Cereal	Vetch	Medic
Lameroo, SA	343	3.18	5.67	4.99, 6.19*	9.4	10.2	9.6, 10.1*
Waikerie, SA	210	2.22	2.45	2.31	10.9	10.7	10.8
<sup>2</sup> Minnipa, SA	254	2.91	2.95	2.20*	10.2	11.6	12.2*
Piangil, Vic.	187	1.80	2.68	2.53	10.7	12.7	12.3
Mean of sites	249	2.53	3.44	3.64	10.3	11.3	11.0

## Table 1. Wheat grain yield (kg/ha) and protein content (%) in 2020; following cereal, vetch and medic pasture treatmentsin 2019.

vetch terminated prior to end of season at Lameroo, Waikerie and Piangil, <sup>2</sup>regenerating pasture at Minnipa grazed by sheep. Other sites ungrazed. \*following 2nd year (regenerating) pasture of Seraph<sup>(h)</sup> medic.

### Table 2. 2019 legume and cereal biomass and 2020 soil mineral N preceding the cereal crop. Legume biomass measured16 to 20 Sept. (Lameroo, Waikerie, Piangil), 3 Oct (Minnipa).

Trial location, soil N		2019 biomass (kg/ha)		2020 soil mineral N (kg/ha)			
sampling depth	Cereal	Vetch	Medic	Cereal	Vetch	Medic	
Lameroo (0 to 100cm)	4909	2460	1290, 1640*	50	67	65, 85*	
Waikerie (0 to 100cm)	2350	320	620	91	93	121	
Minnipa (0 to 60cm)	-	2315	1721*	117	186	152*	
Piangil (0 to 100cm)	3100	2310	1800	22	102	103	
Mean of sites	-	1851	1414	70	112	105	

\*Two consecutive years of pasture; sown 2018, regenerating in 2019. All other values for first year sown pasture.





**Figure 1.** Return on investment from one-year (2019) and two-year (2018-19) legume phases (\$/ha cumulative discounted cashflow) relative to continuous cereal sequence at Lameroo 2018-19 based on 2020 and 2021 cereal yield.

Despite the costs of establishment, gains in subsequent crop yields alone can provide substantial return on investment. Major value is also possible as the pasture species is then able to be generated through grazing and the legume seedbank in future pasture phases. The potential to take a long-term approach to legume nitrogen value is explored in the next section.

#### Long term systems modelling

An emerging approach to determining the amount of nitrogen to supply to crops has been coined the "N bank" strategy (Smith et al., 2019; Meier et al. 2021). The approach aims to maintain a level of N in the soil that will not limit cereal production (Meier et al. 2021), though it requires further field validation particularly in medium and low rainfall environments (Farrell et al. 2021; Meier et al. 2021). Through simulation modelling, we aimed to quantify the contribution of legumes in the rotation to the N bank.

APSIM was used to investigate the long-term (1991-2020) N contribution of grain and brown manure legumes (field pea) to the farming system. Soil and meteorological parameters were based on the Lameroo site. Nitrogen fertiliser was only applied to wheat crops in the rotation. All wheat crops received top-up nitrogen fertiliser at sowing to 40kg N/ha if soil mineral N in the surface 1m of soil was less than 40kg N/ha. In N bank scenarios, wheat crops received top-up nitrogen to the amount of the N bank at 65 days after sowing. At Lameroo, the optimal N bank for grain yield was determined as 120kg N/ha using methods of Meier et al. (2021). Grain legume and brown manure legumes were then grown in sequence at increasing intensity to determine the contribution of nitrogen to the N bank and the subsequent cereal crop yield (Table 3).

## **Table 3.** Simulated annual nitrogen fertiliser applied to wheat to maintain the target N bank of 120kg/ha and wheat yield when grown in sequences with different legume intensities. Simulations were run from 1991-2020 and phased such that a grain yield was obtained for each year.

Rotation	Legume intensity in the rotation (%)	Mean N fertiliser applied for target N bank (N kg/ha)	Mean cereal grain yield (kg/ha)
Continuous cereal	0	75	2611
Grain legume	25	61	2452
	33	55	2410
	50	44	2351
	75	37	2275
Brown manure legume	25	57	2641
	33	48	2679
	50	20	2781
	75	5	2808



**Table 4.** Cereal yield response as per cent increase compared to cereal on cereal treatment across four sites: Lameroo, Waikerie, Minnipa and Piangil. Production before wheat and regeneration after wheat (per cent of medic treatment) of five pasture legumes and common vetch on neutral and alkaline sandy loam soils. Seed harvestability (mean two sites) shown as kg/ha and per cent recovered of total seed.

Legume treatment	Cereal yield response % cont. cereal	Legume DM production % of medic	Regeneration after crop % of medic	Legume seed harvestability kg/ha (% total)
Seraph <sup>()</sup> medic	+34	100	100	0 (0)
Margurita <sup>()</sup> serradella	+51	60	50	610 (44)
Bartolo bladder clover	+26	64	53	10 (1)
SARDI rose clover	+29	84	62	5 (1)
Trigonella balansae 5045	+26	57	18	120 (35)
Volga <sup>()</sup> vetch	+35	128	6	1700 (78)

#### Current and future pasture legume options

Cereal yield response was positive for all legumes, in the range of +26 to +51% (Table 4). Vetch was the most productive (mean 1,851kg/ha, range 320 to 2,460kg/ha, 128% compared with Seraph<sup>(b)</sup> and readily harvestable legume (Table 4). Vetch remains the best option on neutral alkaline soils where a sown legume ley of one year duration is preferred. Amongst the pasture legume options, Seraph<sup>(b)</sup> medic was most productive (mean 1414kg/ ha, range 620 to 1,800kg/ha) and the only treatment to consistently regenerate after the cereal crop (mean 489 plants/ $m^2$ , range 277 to 1,279 plants/ $m^2$ ). Whilst differences between the pasture legumes on cereal yield were modest, greater effect is expected longer term as differences in legume regeneration and production accrue.

Although Margurita<sup>(b)</sup> French serradella and Trigonella APG5045 were readily harvestable (providing seed for resowing) compared to Seraph<sup>(b)</sup> medic, they were less productive (Table 4). Margurita<sup>(b)</sup> serradella regenerated at useful numbers at Lameroo (296 plants/m<sup>2</sup>) but not elsewhere. Trigonella failed to regenerate after crop at three of the four trials.

#### Annual medics

The performance of Seraph<sup>(b)</sup> strand medic (formerly known as PM-250) confirms its suitability for neutral and alkaline sandy loams receiving 275 to 400mm rainfall (Ballard et al. 2020). Along with other contemporary medic cultivars, it has hard-seed levels that allow it to persist and regenerate after crop and soft enough to allow consecutive pastures to be grown. At Minnipa and Waikerie, sown and naturalised medics were the only legumes to regenerate at useful numbers after crop. The strand medics are best suited to sandy loam soils and barrel medics for loam-clay loams. Burr medics are best suited to loam-clay soils and tolerate lower soil pH (minimum 4.8 CaCl<sub>2</sub>).

Two spineless burr medic cohorts: one tolerant of boron (B), another tolerant to red legged earth mites (RLEM) are being evaluated. Two lines have been identified with high agronomic performance and RLEM tolerance. Five B tolerant lines have also been shortlisted and it is expected a line will be identified autumn 2022 for cultivar release.

Disc medics are well adapted to deep alkaline sandy soils. Historically, the cultivars Tornafield and Toreador were sold but no cultivar is now commercially available. Disc medics have performed well on sandy sites in DLPS trials. A cohort of disc and strand medics has been developed with increased ability to form effective symbiotic relationships with rhizobia strains that occupy Mallee soils. Early field evaluation is promising.

The DLPS project has found that medic pods can be summer sown to establish medic pastures (refer Flohr et. al, this issue), but the strategy is limited by the ability to harvest sufficient pod (Table 4). In subsequent work, where the medic sward was desiccated early to reduce pod drop, yields of 1,000kg/ha were achieved at one site but, remained around 100kg/ha at a second site. Whilst we have shown that it is possible to harvest medic pods, further work is needed to improve its reliability.

## Hard-seeded French serradella (cultivars Margurita<sup>(b)</sup>, Frano)

French serradella is widely grown on acidic sandy soils in WA and on some acidic soils in NSW. Pods are readily harvested (610kg/ha, refer Table 4) and break up into small segments which can be resown. They have an unusual seed softening process whereby light inhibits seed softening. This allows them to be sown at 20–30kg pods/ha in February at



"1cm depth, soften during autumn and establish with opening rain. In SA and Victoria, French serradella grew poorly on alkaline soils but has occasionally performed very well on deep mildly acidic to neutral sands. Serradella flowers later than medics and therefore may benefit from late rains. Conversely seed set may be low in dry springs. Frano, which was released in 2021, flowers earlier than Margurita<sup>()</sup> and has improved early vigour.

#### Bladder Clover (cultivar Bartolo)

Developed in WA, bladder clover seeds can be harvested where canopy height is adequate and is suitable for February sowing at 20kg hard seed/ha at 0.5 to 1cm depth. This species maintains pasture quality longer, which can decrease the amount of feeding over the dry months. On some neutral pH soils, bladder clover has performed well, particularly in wetter years. At Piangil and Lameroo, pods were unable to be harvested by cereal header due to insufficient canopy height. Bladder clover has high levels of hard-seed in the first autumn and so the establishment year needs to be followed by a crop to allow hard seed to soften for germination in the following year. A new upright hay-type cultivar is being developed in WA.

#### Rose clover (cultivar SARDI Rose)

Developed for the upper mid-north of South Australia, it has been a middle of the road performer on Mallee soils. Production has been moderate and N-fixation lower. It has been inconsistent in its regeneration after crop. No further cultivar development is warranted.

#### Biserrula (cultivar Casbah)

Widely grown in WA and NSW, seed can be harvested and is suitable for summer sowing in NSW but not WA.. However, this species has not performed well on Mallee soils in SA or Victoria. It has high levels of hard-seed in the first autumn and so, the establishment year needs to be followed by a crop to allow these to soften for germination in the following year. Biserrula can cause temporary photosensitisation in grazing sheep and affected animals need to be removed

#### Trigonella (no cultivar currently available)

Trigonella balansae is closely related to annual medic. It is a species of interest because it can hold its pods and about 35% of seed can be harvested with a conventional grain harvester and used to reduce pasture establishment costs. In historic work, APG5045 was identified as having the best agronomic performance, but its hard-seed levels are too low for use as a ley legume pasture and was recommended as a phase pasture option. This hard-seed deficiency was confirmed in this study (18% regeneration after crop, Table 4). Two rounds of selection for increased hard-seed have been completed and the selections have grown well in the field. By end of autumn 2022, hard-seed studies and regeneration counts will be completed, following a 2021 wheat crop. Data will be reviewed to identify a suitable cultivar.

Trigonella is a new species for agriculture and before releasing a cultivar, it needs to pass a grazing study which considers animal performance, animal health and meat quality. This work is led by CSIRO in WA and needs to be completed before a decision is made about cultivar release.

#### Arrowleaf clover (cultivar Cefalu)

A minor species in low rainfall regions, it has shown promise in NSW and recent SA trials. If late spring rainfall occurs, it can produce green feed late in the season, which is valuable in finishing lambs, and seeds can potentially be harvested with grain harvester. The earliest flowering cultivar is Cefalu. Another line with increased winter and spring dry matter and earlier flowering has been developed. Thinner stems have also been selected, for the benefit of livestock production - modelling in the DLPS project has shown that relatively small differences in nutritive value can provide large benefits to livestock. Field evaluation in 2021 has shown that the new line had about 30% increased dry matter compared to Cefalu throughout the year. Hard-seed studies will be completed late autumn 2022 and a decision made on the suitability of the new line for cultivar release.

#### Conclusions

Substantial increases in cereal yield and grain protein were measured after medic pasture or vetch, compared to continuous cereal. Despite the costs of establishment, gains in subsequent crop yields alone can provide substantial return on investment, and is even greater when accounting for seedbank set up and grazing value. On neutral/alkaline sandy loam soils in the low rainfall regions, vetch remains the best option where a sown legume ley of one year duration is preferred. Where a self-regenerating pasture is preferred, annual medics provide the best option. Improved cultivars of burr medic (boron, RLEM tolerance), disc medic (improved N-fixation) and arrowleaf clover are being developed.



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#### References

Ballard R, Peck D, Flohr B, Llewellyn R, Hill J, Scholz N, Tomney F, Gunn J, Richter I, McBeath T, Davoren B, Shoobridge W, Hackney B, Moodie M, Howie J (2020) New pasture opportunities to boost productivity of mixed farms in low/medium rainfall areas. Proceedings GRDC Grains Research Update, Adelaide, February 2020, pp.41-51.

Farrell M, Vadakattu G, Macdonald L (2021) Addressing the rundown of nitrogen and soil organic carbon. Adelaide Grains Research Update, February 2021

Flohr B, McBeath T, Ouzman J, Davoren B, Shoobridge W, Rebetzke G, Ballard R, Peck D, Llewellyn R, Kirkegaard J, Stummer B (2022) Adaptive sowing strategies to overcome a shifting seasonal break. Adelaide Grains Research Update, February 2022, *in-press* 

Meier EA, Hunt JR, Hochman Z (2021) Evaluation of nitrogen bank, a soil nitrogen management strategy for sustainably closing wheat yield gaps. *Field Crops Research* **261**, 108017.

Smith CJ, Hunt JR, Wang E, Macdonald BCT, Xing H, Denmead OT, Zeglin S, Zhao Z (2019) Using fertiliser to maintain soil inorganic nitrogen can increase dryland wheat yield with little environmental cost. *Agriculture Ecosystems and Environment* **286**, 106644.

#### **Contact details**

David Peck SARDI PO Box 397, Adelaide SA 5001 08 8429 0475 david.peck@sa.gov.au

Bonnie Flohr CSIRO Locked Bag 2, Glen Osmond SA 5064 0475 982 678 bonnie.flohr@csiro.au @BonnieFlohr





**Choose all products in the tank mix carefully**, which includes the choice of active ingredient, the formulation type and the adjuvant used.

**Understand** how product uptake and translocation may impact on coverage requirements for the target. Read the label and technical literature for guidance on spray quality, buffer (no-spray) zones and wind speed requirements.

**Select the coarsest** spray quality that will provide an acceptable level of control. Be prepared to increase application volumes when coarser spray qualities are used, or when the delta T value approaches 10 to 12. Use water-sensitive paper and the Snapcard app to assess the impact of coarser spray qualities on coverage at the target.

**Always expect** that surface temperature inversions will form later in the day, as sunset approaches, and that they are likely to persist overnight and beyond sunrise on many occasions. If the spray operator cannot determine that an inversion is not present, spraying should NOT occur.

**Use weather forecasting** information to plan the application. BoM meteograms and forecasting websites can provide information on likely wind speed and direction for 5 to 7 days in advance of the intended day of spraying. Indications of the likely presence of a hazardous surface inversion include: variation between maximum and minimum daily temperatures are greater than 5°C, delta T values are below 2 and low overnight wind speeds (less than 11km/h).

**Only start spraying** after the sun has risen more than 20 degrees above the horizon and the wind speed has been above 4 to 5km/h for more than 20 to 30 minutes, with a clear direction that is away from adjacent sensitive areas.

**Higher booms increase drift**. Set the boom height to achieve double overlap of the spray pattern, with a 110-degree nozzle using a 50cm nozzle spacing (this is 50cm above the top of the stubble or crop canopy). Boom height and stability are critical. Use height control systems for wider booms or reduce the spraying speed to maintain boom height. An increase in boom height from 50 to 70cm above the target can increase drift fourfold.

**Avoid high spraying speeds**, particularly when ground cover is minimal. Spraying speeds more than 16 to 18km/h with trailing rigs and more than 20 to 22km/h with self-propelled sprayers greatly increase losses due to effects at the nozzle and the aerodynamics of the machine.

**Be prepared** to leave unsprayed buffers when the label requires, or when the wind direction is towards sensitive areas. Always refer to the spray drift restraints on the product label.

**Continually monitor** the conditions at the site of application. Where wind direction is a concern move operations to another paddock. Always stop spraying if the weather conditions become unfavourable. Always record the date, start and finish times, wind direction and speed, temperature and relative humidity, product(s) and rate(s), nozzle details and spray system pressure for every tank load. Plus any additional record keeping requirements according to the label.

### How heat tolerant are our wheats?

#### Richard Trethowan<sup>1</sup>, Rebecca Thistlethwaite<sup>1</sup>, Reem Joukhadar<sup>2</sup> and Hans Daetwyler<sup>2</sup> and Daniel Tan<sup>1</sup>

<sup>1</sup>The Plant Breeding Institute, The University of Sydney; <sup>2</sup>Agriculture Victoria, AgriBio, Bundoora.

GRDC project code: US00081

#### Keywords

wheat, heat tolerance, genomic selection, phenotyping, pre-breeding.

#### Take home messages

Many Australian wheat cultivars are heat tolerant. However, new materials developed from extensive diversity using field-based phenotyping and genomic selection show that the heat tolerance of Australian wheat can be significantly improved.

#### Aim

The work was conducted to improve the heat tolerance of Australian wheat. The research aimed to develop heat tolerant wheat germplasm, protocols for high-throughput field-based screening and molecular tools to assist commercial wheat breeders.

#### Introduction

Periods of extreme high-temperature, particularly short periods of heat shock, are a major threat to wheat yield and grain quality throughout much of the Australian wheat belt. Current projections of Australian climate change indicate that heat waves and temperature variability will become more frequent and more intense in the coming decades (CSIRO 2011, Climate Change in Australia. http://climatechangeinaustralia.com.au). It is vital that new wheat germplasm with improved hightemperature tolerance and molecular tags linked to this tolerance are developed and introduced into commercial breeding programs.

Genomic selection is a breeding method that requires a reference population of wheat lines that are phenotyped for the trait of interest and genotyped using many DNA markers distributed across the whole genome. Statistical methods are then used to estimate the effect of each DNA marker on the phenotype; the collection of all these DNA marker effects provides a prediction of genomic breeding value. This information can then be used to predict new plants that are only genotyped and do not have a phenotype. This allows early selection of plants/lines without phenotyping which decreases the breeding cycle leading to increased genetic gain.

#### What did we do?

A highly diverse set of agronomically adapted materials were assembled for phenotyping. These included thousands of new lines developed by the University of Sydney, including crosses with synthetic wheat, emmer wheat collected in warm areas, landraces, adapted germplasm with putative tolerance identified in hot wheat growing areas globally and Australian wheat cultivars and other sources of heat tolerance developed by others.

These materials were phenotyped for various traits including yield using a three-tiered strategy. Firstly, thousands of lines were evaluated in the field in replicated yield plots at Narrabri in northwestern NSW at different time of sowing. Later sown materials were exposed to greater heat stress. Subsets of materials, based on performance in the previous year and estimated genetic values, were sown at sites in Western Australia (Merredin and Cadoux) and Victoria (Horsham) at 2-3 times of sowing to assess the transferability of traits. Each year, high performing lines were retained from the



previous year, intolerant materials removed, and new materials added. Materials identified as heat tolerant in times of sowing experiments were subsequently evaluated in the field using heat chambers set at 4°C above the ambient temperature to induce heat shock during reproductive development and grain filling to confirm heat tolerance. Finally, those lines that maintained heat tolerance in the heat chambers were screened in temperature-controlled greenhouses to assess pollen viability under heat stress. Materials surviving all three stages of testing were considered highly heat tolerant.

All materials (>6,000 lines) phenotyped in time of sowing experiments were genotyped using a 90K SNP platform and these formed the reference population for genomic selection from which all DNA marker effects were estimated. A prediction equation was developed and used to calculate genomic estimated breeding values (GEBVs) on selection candidates which were genotyped but not phenotyped. A genomic selection model that incorporated environmental covariates (e.g. temperature, radiation, rainfall) directly was developed and improved. This allowed the prediction of line performance under high temperature conditions. Environmental covariates were defined for each plot and growth development phase (vegetative, flowering, and grain fill). An in-field validation of GEBV selected lines was then conducted by correlating GEBVs with field trial phenotypes. Various cycles of crosses were made among diverse lines with high GEBVs and progeny subsequently selected for high GEBV. These formed the basis of our new elite heat tolerant materials.

#### What did we find?

Extensive field-based phenotyping over a 6-year period identified lines with superior adaptation to terminal heat stress. Many of the superior materials had high vield under heat stress, low percentage screenings and high kernel weights. However, stay-green was not an advantage and only an intermediate level of glaucousness was linked to higher yield under stress (Tables 1 and 2). (Glaucous leaves are covered with a grey/blue or whiteish waxy coating that is easily rubbed off). Materials with a wide range of GEBVs were identified and recombined in crosses to produce new heat tolerant lines with higher heat tolerance than current cultivars (Figure 1). The prediction accuracy of genomic selection using models trained at Narrabri was assessed in other environments around Australia (Table 3). The predictions were moderate indicating that phenotyping in Narrabri was relevant nationally.

The heat tolerance of lines selected from time of sowing experiments in the field was subsequently confirmed using field-based heat chambers. Both night and daytime temperatures were observed to reduce yield, increase screenings and reduce kernel weights (Table 4).

Lines that performed well in field-based heat chambers were then tested in the greenhouse and those lines with poorer pollen viability under hightemperature ( $35^{\circ}C/22^{\circ}C$ , day/night) and elevated CO<sub>2</sub> (800 ppm) tended to have reduced seed set and lower yield (Figure 2). Control conditions were maintained at  $22^{\circ}C/15^{\circ}C$  and 400 ppm CO<sub>2</sub>.

Table 1. Influence of stay-green on yield in early and late sowing (576 genotypes) at Narrabri.							
Time of sowing	Non-stay green	Stay-green	Probability				
Main season	5.585 °	5.501 <sup>b</sup>	P<0.01				
Late	4.808 ª	4.657 <sup>b</sup>	P<0.001				
Numbers of lines 429 149							

Means in rows followed by different letters are significantly different at the probability indicated.

#### Table 2. Impact of Glaucousness on yield at early and late sowing (576 genotypes) at Narrabri.

Time of couving	Glaucousness				
Time of sowing	Low	Medium	High		
Main season	5.683 a	5.556 b	5.560 b		
Late	4.756 b	4.804 a	4.694 b		
Numbers of lines	71	431	74		

Means in rows followed by different letters are significantly different at P<0.05.





**Figure 1.** Genomic estimated breeding values (GEBVs) for yield of a subset of the most heat tolerant breeding lines and Australian cultivars (approx. 7,000 genotypes). Main season and late sowing (For PBR status of varieties in graph please refer to Table 5).

Table 3. Prediction accuracy of materials trained in Narrabri (2017 – 2020) and validated at Cadoux (WA), Horsham (VIC) and Merredin (WA) for grain yield.						
Environment	Early sowing	Late sowing				
Cadoux 2017	0.31	0.17				
Horsham 2017	0.47	0.59				
Horsham 2018	0.40	0.38				
Horsham 2019	0.22	0.14				
Merredin 2018	0.50	0.26				
Merredin 2019	0.36	0.13				
Merredin 2020	0.38	0.20				

Note: accuracy determined as the correlation between GEBV and yield (environmental covariates not included).

Table 4. Impact of day/night temperature (heat chambers; 20 genotypes).							
	Yield (kg/ha) % Screenings 1000 grain weight (g)						
Heat chamber (day, anthesis)	2925 °	3.423 <sup>b</sup>	38.74 ª				
No chamber (day, anthesis)	3363 <sup>b</sup>	2.369 °	41.75 <sup>b</sup>				
Heat chamber (night, grain fill)	2894 °	4.134 ª	39.21 ª				
No chamber (night, grain fill)	3275 <sup>b</sup>	3.034 <sup>b</sup>	41.28 <sup>b</sup>				

Means in columns followed by different letters are significantly different.



Table 5. Heat tole	erance rating of A	Australian cultivar	Ś.			
Name	Field yield	Chamber yield	Thousand grain weight	Screenings	Pollen viability	Heat tolerance rating
MACE	HIGH	HIGH	HIGH	MODERATE	MODERATE	Т
MUSTANG®	HIGH	HIGH	MODERATE	LOW	MODERATE	Т
DART	HIGH	MODERATE	MODERATE	LOW	MODERATE	Т
SCOUT	HIGH	MODERATE	HIGH	MODERATE	HIGH	Т
SUNCHASER <sup>()</sup>	HIGH	HIGH	LOW	LOW	MODERATE	Т
BORLAUG 100 <sup>(b)</sup>	HIGH		HIGH	MODERATE		MT
SCEPTER®	HIGH	LOW	HIGH	MODERATE	MODERATE	MT
VIXEN <sup>⊕</sup>	HIGH	LOW	HIGH	HIGH	HIGH	MT
CONDO	MODERATE	MODERATE	HIGH	LOW	HIGH	MT
<b>FLANKER</b> <sup>(b)</sup>	MODERATE	MODERATE	MODERATE	MODERATE	HIGH	MT
	LOW	MODERATE	MODERATE	LOW	MODERATE	MT*
<b>HELLFIRE</b> <sup>(b)</sup>	HIGH		HIGH	HIGH		М
<b>RELIANT</b> <sup>(b)</sup>	HIGH		HIGH	MODERATE		М
EMU ROCK <sup>()</sup>	HIGH	LOW	HIGH	MODERATE	LOW	М
SUNTOP <sup>(b)</sup>	HIGH	LOW	MODERATE	MODERATE	MODERATE	М
COOLAH®	HIGH	MODERATE	LOW	MODERATE	LOW	М
SUNTIME <sup>®</sup>	MODERATE	MODERATE	HIGH	MODERATE	MODERATE	М
<b>CUTLASS</b> <sup>(b)</sup>	MODERATE	LOW	MODERATE	LOW	HIGH	М
EGA GREGORY®	MODERATE		HIGH	MODERATE		М
	MODERATE		MODERATE	LOW		М
MITCH <sup>()</sup>	MODERATE		HIGH	MODERATE		М
SPITFIRE®	MODERATE		MODERATE	MODERATE		М
SUNMATE <sup>()</sup>	MODERATE		MODERATE	LOW		М
SUNVALE <sup>()</sup>	MODERATE		LOW	LOW		М
<b>BECKOM</b> <sup>(1)</sup>	MODERATE		LOW	LOW		М
WYALKATCHEM <sup>⊕</sup>	MODERATE		MODERATE	MODERATE		М
PHANTOM®	MODERATE	HIGH	LOW	HIGH	MODERATE	М
VIKING®	HIGH	LOW	LOW	LOW	MODERATE	MS
SUNPRIME <sup>(b)</sup>	MODERATE	LOW	MODERATE	MODERATE	LOW	MS
SUNMAX®	LOW	LOW	MODERATE	MODERATE	HIGH	MS*
	MODERATE		LOW	HIGH		S
	MODERATE		HIGH	HIGH		S
SUNZELL®	MODERATE		LOW	HIGH		S
	MODERATE	MODERATE	MODERATE	HIGH	LOW	S
COBRA®	LOW	HIGH	HIGH	HIGH	LOW	S
ZANZIBAR®	LOW	HIGHI	LOW	HIGH	HIGH	S
DEVIL®	LOW	HIGH	LOW	HIGH	MODERATE	S
	LOW		MODERATE	LOW	LOW	S
ORION	LOW		LOW	HIGH		S
	LOW		LOW	LOW		S
	LOW		MODERATE	MODERATE		S
YITPI®	LOW		MODERATE	HIGH		S

\*Late maturity confounded field-testing

Hear tolerance rating scale: T=Tolerant; M=Moderate; S=Susceptible





Figure 2. Relationship between pollen viability and grain yield at high CO2.

Based on extensive testing in time of sowing experiments, using field-based heat chambers and under controlled glasshouse conditions, the Australian cultivars evaluated between 2016-2020 were rated for heat tolerance (Table 5). Different varieties arrive at heat tolerance in different ways, with some yielding well in the field but more susceptible to high temperature during pollen formation. The rating in Table 4 is indicative only and based on a number of different observations.

The varieties for which we have detailed knowledge of both their genetics (genotype) and behaviour in a range of environments (phenotype) have enabled us to link the field impact and plant behaviour with parts of the genome that code for specific traits. The process used to do this is called genome wide association analysis. This process has been used to identify a number of meta quantitative trait loci (meta-QTL's) or locations on the genome that express as traits with varying levels of expression in different environments. This knowledge will assist wheat breeders to recombine this new diversity into new cultivars for all regions of Australia.

#### Conclusion

Some recent Australian cultivars combine both high yield and heat tolerance. However, new prebreeding materials developed using genomic selection offer commercial wheat breeders' new sources of diversity for both yield and heat tolerance that can be used to mitigate the effects of a warming environment. GEBVs and QTL linked to key traits will allow wheat breeders to integrate this new diversity into their existing genomic selection pipelines.

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#### **Contact details**

Richard Trethowan Ph: 0400 320 558 Email: richard.trethowan@sydney.edu.au

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



## GRDC SOUTHERN Grains Research Update Series

## FEBRUARY 2022 LIVESTREAM PROGRAM

NB. All times are Australian Eastern Daylight Savings Time (AEDT).

#### Program Day 2 – Advances in break crops

#### Wednesday 9 February, 9am AEDT

Start time	Finish time	Торіс	Presented by
9:00	9:05	Welcome/Introduction to day two	GRDC Representative
9:05	9:35	Legume update - what we need to know for 2022	<b>Jason Brand,</b> Agriculture Victoria
9:35	10:05	Increasing Nitrogen fixation - key factors impacting upon rhizobia health	Liz Farquharson, SARDI
10:05	10:35	Crop safety implications for new products in lentils	<b>Jordan Bruce,</b> Trengove Consulting <b>Navneet Aggarwal,</b> SARDI
10:35	10:50	Morning Tea Break	
10:50	11:20	Optimising canola establishment shifting seasonal break	Matthew Nelson, CSIRO
11:20	11:50	Best practice for high yielding canola crops	<b>Rohan Brill,</b> Brill Ag
11:50	12:20	Optimising canola production	Chris Helliwell, CSIRO
12:20	12:50	A review of GM canola's first year in South Australia	Andrew Ware, EPAG Research Rebekah Allen, Hart Field Site
12:50	13:00	Close and evaluation	GRDC Representative





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## Agronomy best practices with pulses – Victoria

#### Jason Brand<sup>1</sup>, Sundara Mawalagedera<sup>1</sup>, James Manson<sup>2</sup>, Michael Moodie<sup>3</sup> and Liz Farquason<sup>4</sup>.

<sup>1</sup>Agriculture Victoria; <sup>2</sup>Southern Farming Systems; <sup>3</sup>Frontier Farming Systems; <sup>4</sup>South Australian Research and Development Institute.

GRDC project codes: PROC: DJP2105-006RTX

#### Keywords

■ faba bean, herbicide tolerance, lentil, nitrogen fixation

#### Take home messages

- Several new lentil varieties will offer growers improved grain yield and yield stability combined with a range of novel herbicide traits.
- Weed management and herbicide traits several new traits in a range of pulse crops will offer alternative weed management strategies in the future.
- Frost in lentil significant variation was observed across varieties, with PBA Hurricane XT<sup>(b)</sup> showing the worst vegetative damage of released varieties and PBA Ace<sup>(b)</sup> showing good tolerance. Generally, standing stubble treatments showed less damage than slashed stubble, and row spacing and sowing direction had little effect). Increased vegetative damage resulted in reduced grain yields.
- Deep ripping in pulses, except lupin grain yield benefits from deep ripping on deep Mallee sands of 100-210%, resulting gross margin gains of \$312-\$668/ha have been recorded.
- Faba beans in the high rainfall zone the greatest grain yield achieved at Vite Vite North in 2021 was 9.2t/ha, with PBA Samira<sup>(b)</sup> sown on April 16 at 28 plants/m<sup>2</sup>. Higher plant numbers increase biomass, but additionally contribute to faba bean grain yield potential by increasing the number of potential pods and seeds, in a similar manner to head number in cereal crops. Chocolate spot management was improved in 2021 with genetic resistance and fungicides, but yield benefits of improved chocolate spot management were not realised with reduced plant density.

#### Potential releases and new varieties

Two new imidazolinone (IMI) tolerant lentils (GIA2002L, GIA2003L), the first imidazolinone (IMI) tolerant lentil with improved tolerance to clopyralid soil residues from a prior crop (GIA1703L) and the first imidazolinone (IMI) tolerant lentil with metribuzin (MET) tolerance (GIA2004L) are potentially available in 2022.

A new high yielding 'Blue' field pea (PBA Noosa<sup>(b)</sup>) and 'Kaspa' type (PBA Taylor<sup>(b)</sup>) are available for production in 2022. In addition, field pea with improved tolerance to common in-crop and residual Group B herbicides is available (GIA2005P).

#### Varietal performance in agronomic trials

In lentils, all the potential new varieties were sown in trials at Curyo (southern Mallee), comparing sowing dates (Table 1), and Propodollah (west Wimmera), comparing soil types (Table 1). GIA2002L had the highest or equal highest grain yield in all trials, highlighting good potential yield stability. GIA2003L was consistently high yielding, but slightly less than GIA2002L. GIA1703L had excellent yields at Curyo, similar to 2020, and on the ripped sand at Propodollah, but was slightly lower on the duplex soil, it is hypothesised this was due to frost damage that occurred in this location adversely affecting this breeding line more than others.



GIA2004L was relatively low yielding in trials this year, and results need to be treated with caution, as some terbuthylazine damage was observed and this breeding line has known increased sensitivity compared with other varieties.

Further details on trials including field peas, seasonal conditions and outcomes will be explored in the presentation.

#### Agronomic research highlights

## Novel herbicide traits, weed management and new herbicides

In lentils, there are a number of potential new varietal releases combining tolerance to the imidazolinone herbicides with tolerance to metribuzin or soil residues of clopyralid. These will offer alternative weed management strategies within the farming system. In 2021, trials in the Wimmera and southern Mallee assessed potential herbicide strategies on vetch control in lentil and field pea varieties utilising novel herbicide resistance traits and any resulting impacts on grain yield. At the point of publication, data from trials is still being analysed, however early observations indicate that in the absence of herbicides, competition from vetch in lentil caused approximately 60% reduction in grain yield. In comparison, a conventional herbicide strategy reduced yield loss from vetch competition to 23%, while a strategy incorporating the use of imidazolinone chemistry over varieties and lines with the tolerance trait showed no yield loss from vetch competition. Despite improvements in relative grain yield, neither conventional nor imidazolinone based strategies completely prevented vetch seed set. Both potential herbicide management strategies utilising tolerance to metribuzin or soil residues of clopyralid showed improved control of vetch.

In faba beans, a new line AF14092, has shown improved tolerance to metribuzin applied postsowing pre-emergent compared with PBA Samira<sup>(b)</sup> in field trials near Horsham. This breeding line showed excellent grain yields throughout Victoria and could provide improved crop safety to metribuzin when applied post-sowing pre-emergent across a range of soil types.

There has been much interest in the new Group 14 herbicide Reflex (240g/L fomesafen) as an

**Table 1.** Grain yield (t/ha) of lentil varieties and breeding lines in 2021 grown in a sowing date trial at Curyo (southern Mallee) and in a soil type comparison trial at Propodollah (west Wimmera) comparing duplex soil (sandy loam topsoil and clay subsoil) with a sand that had been ripped in 2018.

Variaty/Prooding Lina	'Curyo' Sowing Date			'Propodollah' Soil Type	
vallety/breeding Line	Apr 29	Jun 01	Ave	Duplex Flat	Ripped Sand
GIA2002L	2.68	2.39	2.54	2.14	2.19
GIA2003	2.65	2.40	2.53	1.87	1.86
GIA1703L	2.64	2.29	2.47	1.61	1.90
CIPAL2121	2.57	2.35	2.46	2.07	2.10
GIA Leader®	2.55	2.34	2.45	1.84	2.00
PBA Jumbo2 <sup>(b)</sup>	2.38	2.49	2.44	1.87	2.08
PBA HighlandXT $^{(\!\!\!\!D)}$	2.49	2.35	2.42	1.67	1.91
PBA Ace <sup>()</sup>	2.49	2.32	2.41	2.12	1.46
CIPAL2122	2.36	2.35	2.36	1.75	2.01
GIA2001	2.50	2.21	2.36	1.75	1.70
PBA Hurricane XT	2.48	2.23	2.36	1.66	1.24
PBA Hallmark $XT^{(\!\!\!\ D)}$	2.48	2.03	2.26	1.43	1.82
PBA Bolt <sup>(b)</sup>	2.48	2.01	2.25	1.75	1.52
PBA KelpieXT <sup>()</sup>	2.28	2.21	2.25	1.73	1.63
Nipper	2.46	2.02	2.24	1.24	1.37
GIA2004L	1.76	1.33	1.55	0.64*	0.20*
Ave	2.45	2.21	2.33	1.70	1.69
Lsd (P<0.05)	Sow Date = 0.12; Variety = 0.22; Sow Date x Variety = NS			0.42	0.61

\*Trial showed damage related to terbyne. The low yield of GIA2004L was a result of increased sensitivity to terbyne compared with other varieties.



alternative to Group 5 herbicides to assist with preemergent broadleaf weed control in pulse crops. Observations so far indicate that label guidelines to maintain separation between herbicide treated soil and planted seed are critically important when used in lentils grown on sandy soils, such as in the Mallee. There is a high risk of movement of treated soil into the crop row on these soils which can occur through soil throw from excessive sowing speed, collapse of the furrow side wall, soil drift and erosion and rolling. Actions should be taken to mitigate these potential issues, especially in situations where the soil is soft and or has low ground cover such as on deep sandy dunes or where soil amelioration such as deep ripping has recently been completed.

#### Frost in lentil

In lentil trials at Propodollah in 2021, several major vegetative and reproductive frost events occurred. Crop chlorosis and necrosis (yellowing) in response to two vegetative frost events (26 August: -2.2°C and 27 August: -2.9°C) was recorded. Substantial variation was observed across varieties, with PBA Hurricane XT<sup>(h)</sup> showing the worst damage of released varieties and PBA Ace<sup>(h)</sup> showing good tolerance (Figure 1). Generally, standing stubble treatments resulted in less visually observed damage than slashed stubble (Figure 2) and row spacing and sowing direction had little effect (data not shown). Previously it has been suggested that







**Figure 2.** The effect of stubble on frost damage (% crop yellowing), recorded 31 August, in lentil varieties grown in a trial comparing stubble, row space and row direction at Propodollah (west Wimmera) from two vegetative frost events (26 August: -2.2°C and 27 August: -2.9°C).



the vegetive frost symptoms were not related to grain yield, however preliminary analysis from these trials have shown a significant correlation between observed crop damage and reduced grain yield.

In addition, there was a frost event during the reproductive phase events (11 October: -0.8°C and 12 October: -0.8°C) that caused significant flower and seed abortion. Detailed assessments of flower and pod loss showed that the relative effect across a range of varieties was similar (data not shown). While in some varieties flower and pod loss were higher, they respectively set more flowers and pods to compensate.

#### Soil amelioration

Trials located on deep Mallee sands over the past three seasons have demonstrated substantial increases in the grain yields of pulse crops in response to soil amelioration practices such as deep ripping (Figure 3). Chickpea and faba bean were the most responsive pulse crops to deep ripping in summer prior to sowing, with an average yield increase of 210% across all trial sites. Deep ripping providing a mean yield benefit in lentils of 166%. Deep ripping doubled the mean grain yield of field peas and vetch in the first year following deep ripping. In contrast to the other grain legumes, deep ripping provided only a small yield benefit in lupin. Lupins also have the highest establishment risk in sand due to their requirement for shallow seed placement, therefore lupins should not be sown into deep ripped paddocks in the first season post-amelioration.

A gross margin analysis showed that the average yield response observed across the trial sites was highly profitable (Table 2). The average chickpea yield response to deep ripping was 1.1t/ ha and this would have improved gross margin by approximately \$667/ha, after accounting for an annualised cost of deep ripping of \$40/ha. Field pea and faba beans responded to deep ripping treatments with a similar yield boost, which led to more than \$360/ha profit. The average yield response to deep ripping of lentil and vetch was lower at 0.5t/ha, but this still led to approximately \$300/ha gross margin. Lupin was the only pulse crop that did not gain an economic benefit from deep ripping in these trials. The profitability of the farming system is also likely to be improved with subsequent cereal crops benefiting from increased nitrogen supply from the improved pulse biomass production and legacy effects from the deep ripping operation.

While these trials have shown large productivity and profitability benefits, growers considering deep ripping must evaluate operational risks. For example, deep ripping before a pulse phase should be targeted to paddocks with high levels of residual stubble to ensure adequate ground cover is maintained and minimise erosion risk, while care also needs to be taken with pre-emergent herbicides to minimise risk of crop damage. Trafficability of heavy machinery is also an issue that needs to be managed post-ripping, with rolling with heavy steel drum rollers recommended to reconsolidate the surface and provide better flotation for the seeder and self-propelled sprayers.



**Figure 3.** Grain yield of pulse crops grown on deep Mallee sands for non-ripped and deep ripped treatments. Data is a collation of six Mallee trial sites conducted between 2019-2021. All deep ripping treatments used a Tilco A66 tines spaced at 56cm apart with a ripping depth of 400-500mm.



**Table 2.** Partial gross margin of the average deep ripping yield benefit for pulse crops grown on deep sands across six Mallee trial sites from 2019—2021. Prices used in the gross margins are the average January grain price from 2020—2022 for each pulse crop, with gross margins calculated using an annualised cost of ripping of forty dollars per hectare.

Сгор	Average Yield Benefit (t/ha)	Average Grain Price (\$/t)	Gross Margin Benefit (\$/ha)
Lentil	0.5	703	312
Chickpea	1.1	643	668
Narrow Leaf Lupin	0.1	486	7
Field Pea	1.0	427	387
Vetch	0.7	533	333
Faba Bean	0.9	449	364

#### Pulse nitrogen value

The value of pulses in cropping rotations is well documented, with average yield benefits of wheat following a crop legume 1.2t/ha higher than wheat on wheat (Angus et al. 2015). In addition to providing a break option for managing cereal disease and weed control options, they provide N rich crop residues which gradually become available to the following crops.

Figure 4 shows pulse crops, on average, fix between 21(lupin) and 35 (vetch) kg of crop N per tonne of dry matter produced, which equates to \$31-\$52/t dry matter (based on a urea price of \$AU675/t). The total amount of nitrogen fixed by the crop is largely driven by dry matter production and generally farming practices which optimise pulse biomass production will also optimise N-fixation. For example, a 4t lentil crop on average would fix 100kg N/ha compared to an 8t bean crop which would fix in the order of 200kg/ha.

There is significant variation around the average N-fixation values, indicating considerable room for improvement overall. Research continues to improve inoculation and agronomic practices in order to optimise N-fixation in cropping systems.



**Figure 4.** The average crop nitrogen (shoots + roots) per tonne of dry matter (shoots at mid pod fill) for each of six pulse species was estimated using around 1700 data points (n) from field trials conducted in the southern region between 2015-2020 (Farquharson and Ballard, 2022 unpublished). The standard deviation for each of the species is shown. The mean value of nitrogen was calculated based on the 12-month average (2021) urea price of \$AU675/t. The contribution of N in roots was estimated using root factors from Unkovich et al. (2010).



#### Faba beans in high rainfall zone

Grain yields of early-sown faba beans were limited by plant density, not biomass

The highest grain yield from faba bean trials at Vite Vite in 2021, was 9.20t/ha in PBA Samira<sup>(h)</sup> sown 16 April at 28 plants/m<sup>2</sup>. In a sowing date trial comparing a range of varieties, biomass was not related to grain yield in earlier sown treatments (April 16 & 30), but highly correlated at the late sown treatments (May 21; Fig 5). In a related trial investigating the interaction between plant density and sowing date, grain yield of PBA Samira<sup>(b)</sup> increased as plant density was increased from 7 to 28 plants/m<sup>2</sup> for both sowing date of April 16 or April 30. It is therefore hypothesised that the yield potential of early-sown faba beans was limited by plant number, not biomass.







**Figure 6.** The relationship between grain yield and plant density of PBA Amberley and PBA Bendoc managed with (complete DM) and without fungicides (no DM) at Vite Vite, Victoria in 2021. *Significant differences indicated with letters. Percentage reduction in grain yield due to lower plant density in bold.* 



## Lower plant density did not reduce chocolate spot severity

Chocolate spot management was improved in 2021 by use of genetic resistance (+25% grain yield from S to MRMS, no fungicides) and fungicides (+50% grain yield from nil to complete control).

A reduction in plant density reduced chocolate spot symptoms, but also resulted in 30% lower grain yield (Figure 6).

Grain yield benefits of higher plant densities are usually realised when disease is kept under control and/or when the advent of disease occurs in late spring. For instance, in 2021, chocolate spot infection began in late September, around the time of pod emergence, but in 2020 infection began in early August (unusually early). In 2020, grain yield was unaffected by plant density treatments. This would suggest that when chocolate spot is not controlled, benefits to having higher plant density are realised if disease incursions begin in mid-spring (as in 2021, Figure 6), but not realised if disease incursions begin in early spring (as in 2020).

#### Acknowledgements

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#### References

Angus JF, Kirkegaard JA, Hunt JR, Ryan MH, Ohlander L, Peoples MB (2015) Break crops and rotations for wheat. *Crop and Pasture Science* **66(6)**, 523-552.

Unkovich MJ, Baldock J, Peoples MB (2010) Prospects and problems of simple linear models for estimating symbiotic N<sub>2</sub> fixation by crop and pasture legumes. *Plant and Soil 329* (1-2), 75-89. 2022 Victorian Crop Sowing Guide (2021) https://grdc.com.au/resources-and-publications/ all-publications/nvt-crop-sowing-guides/vic-cropsowing-guide

#### **Contact details**

Jason Brand Agriculture Victoria Grains Innovation Park, 110 Natimuk Road, Horsham VIC 3400409 357 076 jason.brand@agriculture.vic.gov.au @JasonBrand



## An overview of research advances to optimise inoculation, nodulation and nitrogen fixation of pulse crops in southern Australia

Elizabeth Farquharson<sup>1, 2</sup>, Judith Rathjen<sup>2</sup>, Ross Ballard<sup>1, 2</sup>, Stephen Barnett<sup>1, 2</sup>, Jason Brand<sup>3</sup>, Penny Roberts<sup>1, 2</sup>, Michael Moodie<sup>4</sup>, Lynnette Schubert<sup>1</sup>, Daniele Giblot-Ducray<sup>1, 2</sup>, Herdina1, Kelly Hill<sup>1, 2</sup>, Maarten Ryder<sup>2</sup>, Matthew Denton<sup>2</sup> and Alan Mckay1<sup>1, 2</sup>.

<sup>1</sup>South Australian Research and Development Institute; <sup>2</sup>School of Agriculture, Food and Wine, University of Adelaide, Waite Campus; <sup>3</sup>Agriculture Victoria Research, Department of Jobs, Precincts & Regions Horsham; <sup>4</sup>Frontier Faming Systems.

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#### Keywords

■ N fixation, legume, rhizobia, P-Pickel T<sup>®</sup>, PREDICTA<sup>®</sup> rNod.

#### Take home messages

- PREDICTA<sup>®</sup> rNod is a DNA test which takes the guess work out of rhizobia numbers in soils and inoculation requirements.
- Increasing inoculant rates can improve nodulation and nitrogen fixation of pulses on responsive sites and under stressful conditions such as dry sowing or acid soils.
- P-Pickel T<sup>®</sup> is toxic to rhizobia and decreased the nodulation of chickpea in the field. Using granular inoculant can reduce the fungicide effect and improve nodulation.
- Herbicide tolerant pulses had good levels of nodulation and nitrogen fixation when treated with a range of broadleaf herbicides.

#### Background

Rhizobia are bacteria that live in soil and form nodules on legume roots where biological nitrogen (N) fixation occurs. There are many species of rhizobia and those which nodulate agricultural legumes are not native to Australia. Many agricultural soils in southern Australia now support large populations of rhizobia following their introduction to favourable soils (via inoculation) and are supported by inclusion of host legumes in cropping rotations. However, rhizobia numbers in individual paddocks vary greatly and can be affected by soil type, legume history and management practices. Where no rhizobia are present, they must be delivered via inoculants applied to the seed or soil at sowing. This paper provides an update on measuring rhizobia in soils using new PREDICTA® rNod DNAbased tests to inform inoculation decisions. When inoculation is required, the impact of inoculation rates and rhizobial incompatibilities with seed chemicals such as P-Pickel T® (PPT) on nodulation are considered. The impact of commonly used herbicides on N fixation is also briefly discussed.

## DNA test takes the guess work out of inoculation

PREDICTA rNod includes three DNA tests that can accurately and rapidly estimate the number of rhizobia in soil for inoculation groups E & F, N and G & S. The relationship between rhizobia species



Tuble 1. Killzobia moculant groups	S delected by FREDICIA INOU.	
Rhizobia	Commercial inoculant group - strain of rhizobia	Legumes nodulated*
Rhizobium leguminosarum bv. viciae	E – SU303	Field pea & vetch (+faba bean & lentil)
	F – WSM1455	Faba bean & lentil (+field pea & vetch)
Bradyrhizobium lupini	G – WU425	Lupin, serradella
	S – WSM471	Serradella, lupin
Mesorhizobium ciceri	N- CC1192	Chickpea

\*Commercial inoculants will nodulate crops in brackets, however the symbioses may be marginally less effective than with the preferred strain.

and legume host is often specific, therefore it is important to distinguish between rNod tests and use the right inoculant group where inoculation is required (Table 1).

The first of three tests was developed to detect Rhizobium leguminosarum bv. viciae (Ballard et al. 2021) and was used by growers for the first time during 2021. This is the species of rhizobia provided in commercial inoculant Groups E (strain SU303) and F (strain WSM-1455). Of the 64 commercial samples assessed in 2021 for Groups E and F rhizobia, around half had ≤1000 rhizobia/g soil and a medium and high inoculation requirement (Figure 1). The remaining 48% of samples contained >1000 rhizobia/g soil and had a low inoculation requirement, allowing growers to consider applying fungicides to seed or dry sowing with negligible risk of compromising legume nodulation. It is anticipated that a larger portion of soils in the southern region will contain lower populations of Group N and Groups G and S rhizobia, as chickpea, lupin and

serradella have been less widely grown in the south, compared to Groups E and F host crops.

PREDICTA rNod is available via PREDICTA B accredited agronomists.

## Increasing inoculation rates to optimise nodulation

Where inoculation is required, nodulation and N fixation can be improved for grain legume crops if rhizobia applied to seed are increased above the recommended rate, particularly where soil conditions are stressful.

Over the past ten years, field trials have examined the benefit of increasing inoculation rate (peat applied on seed) in stressful soil conditions or when the legume is being grown for the first time. Sufficient rhizobia need to be alive on or near the seed at germination to multiply around the root for good nodulation. When soil conditions are unfavourable, increasing application rates of peat



**Figure 1.** PREDICTA rNod Groups E and F rhizobia test results summary 2021. The proportion of samples in each inoculation requirement category for 64 soil samples from South Australia and Victoria.



inoculant on seed increases the likelihood that sufficient rhizobia will survive on the seed until germination occurs. Under dry sowing conditions (i.e. insufficient moisture for seed germination), doubling the rate of peat on seed improved nodulation and N fixation once sufficient rain occurs for crop establishment (Ballard et al. 2019).

Legumes in the E and F and N groups are sensitive to soil acidity ( $pH_{ca}$ <5.5) which can affect the legume growth, rhizobia survival and nodulation process. Figure 2 shows the combined analysis for five faba bean field trials where standard and double peat slurry inoculation rates were compared. Both the nodule weight per plant and total N fixed were increased at the higher inoculation rate.



**Figure 2.** Impact of standard or double rate of peat slurry inoculant applied to seed on the nodulation (measured 10 weeks post emergence) and N fixation (measured at mid pod fill) of faba bean. Results are the mean of five field trials analysed using a multisite spatial analysis. Average soil pHca was 4.7. Treatments differ significantly (P<0.05) where letters above bars differ within the same parameter.

In 2021, three trials across a range of soil types looked at the impact of inoculation rate on chickpea nodulation. All trials were sown into moist soil. Again, doubling the rate of peat slurry inoculant applied to seed significantly increased nodule number per plant above that of standard rate (Figure 3). However, nodule number at the highest rate was still low (20—30 nodules per plant is adequate). Research to improve the nodulation and N fixation of chickpea continues.



**Figure 3.** Impact of rate of peat slurry inoculant applied to chickpea seed on nodulation (measured 10 weeks post emergence). Results are the mean of three field trials analysed using a multi-site spatial analysis. Soil  $pH_{ca}$  ranged from 5.0—7.5. Treatments differ significantly (P<0.05) where letters above bars differ.

In practice, to double the inoculant rate, twice the amount of peat inoculant should be mixed in the same amount of water as for the single rate. A small batch test is strongly advised to avoid seeder blockages, especially with smaller seeded legumes. Granular inoculants may also benefit from increased rates under adverse sowing conditions based on limited research. If multiple stress factors are present, growers should consider options to remove one or more of these factors, for example, if sowing a sensitive legume into acidic soils, avoid dry sowing.

## Overcoming incompatibilities between seed chemical dressings and rhizobia

Chickpea growers are recommended to apply P-Pickel T fungicide (PPT) to control fungal pathogens (Ford et al. 2018). Where there is a requirement to inoculate, rhizobia are best applied after the PPT, shortly before sowing. Laboratory and greenhouse experiments quantified the extent to which PPT is toxic to rhizobia (Rathjen et al. 2020), which may in turn affect nodulation and N fixation.

Field trials were conducted at three sites with low numbers of soil rhizobia. Soil types ranged from loam (Mallala and Ouyen) to clay (Gymbowen). Chickpea seeds were either untreated or coated with PPT; then inoculated with either peat slurry





**Figure 4.** Average nodulation rating (0 to 5) of chickpea plants coated with PPT or not coated and then inoculated with either a peat slurry applied to seed or granular inoculant in furrow. Field trials were conducted at Mallala SA (2019), Gymbowen Vic (2019) and Ouyen Vic (2020). Treatments differ significantly (P<0.05) where letters above bars differ.

over the fungicide-coated seed, or the inoculant separated from the fungicide-coated seed by applying a granular inoculant in furrow. Nodulation rating was measured 12 weeks after sowing (Corbin et al. 1977). All experiments were conducted in small plots with three replications.

All sites were responsive to inoculation (data not shown). Nodulation was reduced when PPT was applied to the seed prior to inoculation with a peat slurry at all sites (Figure 4). Nitrogen fixation was also reduced in the presence of PPT following similar trends to the nodulation data. Peat slurry inoculated treatments at Mallala fixed 213kg/ha when no PPT was applied compared to 141kg/ha when seed had been treated with PPT (data not shown).

No significant reductions in nodule rating were measured between no PPT and PPT applied to seed when granules were used (Figure 4). Application of inoculant as a granule formulation allowed physical separation from seeds coated with PPT. However, it should be noted that nodulation of chickpea was below adequate (rating 3) for all sites and treatments except peat (no PPT) at Gymbowen. As mentioned in the previous section, further research to improve the chickpea symbiosis is under way.

## Herbicide impacts on nodulation and N fixation of herbicide tolerant pulses

Herbicide labels and legume plant back times should always be followed to reduce the chance of legume crop damage and N fixation penalties.

Major developments in both herbicide chemistries and cultivar tolerances led us to assess the impact of contemporary grass and broadleaf herbicides on nodulation and N fixation of various pulse crops and vetch.

All trials discussed below were replicated small plot trials which received a pre-sowing knockdown herbicide (for example, glyphosate + carfentrazoneethyl) across each site prior to sowing. Following this, trial plots only received their treatment herbicide applied as per label directions or were not sprayed (controls) for the remainder of the season.

#### Grass selective herbicides

In 2020, five herbicides mainly used for the control of grass weeds in pulses were assessed (actives/application time: i) carbetamide (IBS), ii) clethodim (post), iii) propyzamide (IBS), iv) pyroxasulfone (IBS) and v) prosulfocarb +



S-metolachlor (IBS)). Herbicides i-iii were assessed on PBA Hallmark XT<sup> $\phi$ </sup> lentil, PBA Samira<sup> $\phi$ </sup> faba bean and Genesis 090 chickpea at Horsham (Vic.), and all herbicides on PBA Hallmark XT<sup> $\phi$ </sup> and PBA Jumbo 2<sup> $\phi$ </sup> lentils at Hart (SA). No negative effects were seen on either nodulation or N fixation relative to the unsprayed control treatments (data not shown).

#### Broadleaf selective herbicides

Five trials were conducted to compare the nodulation and N fixation of herbicide tolerant cultivars of faba bean (PBA Bendoc<sup>(b)</sup>), lentil (PBA Hallmark XT<sup>(b)</sup>) and field pea (GIA Ourstar<sup>(b)</sup>) following applications of four herbicides used to control broadleaf weeds (actives/application time; i) propyzamide (IBS), ii) imazethapyr (PSPE), iii) terbuthylazine(IBS) and iv) imazamox + imazapyr (PSPE\* off label as simulated high residue). Trials were conducted at Horsham (faba bean, lentil), Hart (bean) and Loxton (lentil, field pea) covering a range of climate and soil types. Overall, cultivars nodulated and fixed N well (field pea data pending), with the exception of propyzamide, which significantly reduced N fixation of PBA Bendoc<sup>()</sup> relative to the control at one of two sites (Horsham,109kg N/ha compared with 147kg N/ha, respectively; data not shown).

#### Conclusion

Using PREDICTA rNod to quantify the number of E and F, N and G and S rhizobia in soils will give growers more certainty and flexibility with respect to inoculation decisions. Where inoculation is not required, growers can dry sow or apply seed chemical dressings with minimal risk of compromising nodulation. In contrast, where inoculation is required, growers may consider applying higher rates of inoculant, especially if soil conditions are stressful, and be mindful of potentially harmful impacts of seed dressings such as PPT. In general, separating the seed treated with PPT from the rhizobia by using granules can reduce toxic effects.

Growers can be confident of using registered grass and broadleaf selective herbicides on medium textured soils while maintaining good nodulation and N fixation. The nodulation and N fixation of herbicide tolerant pulse cultivars was satisfactory at recommended rates of herbicide application.

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#### References

Ballard RA, Barnett S, Giblot-Ducray D, Herdina, Hill K, Farquharson E, McKay A (2021) New tool to predict the likelihood of an inoculation response to Group E and F rhizobia. Proceedings GRDC Grains Research Update, Adelaide, February 2021, pp. 57-62.

Ballard RA, Farquharson EA, Ryder M, Denton M, Rathjen J, Henry F, Brand J, Whitworth R, Haskins B, Seymour M, Yates R (2019) Fixing more N – improving the performance of rhizobial inoculants in suboptimal conditions. Proceedings GRDC Grains Research Update, Bendigo, February 2019, pp. 61-67.

Corbin EJ, Brockwell J, Gault RR (1977) Nodulation studies on chickpea (*Cicer arietinum*). Australian Journal of Experimental Agriculture and Animal Husbandry **17(84)**, 126-134.

Ford R, Moore K, Sambasivan P, Mehmood Y, Hobson K, Walela C, Brand J, Davidson J (2018) Why adhering to integrated *Ascochyta rabiei* management strategy is now more important than ever to sustain a profitable chickpea industry. Proceedings GRDC Grains Research Update, Goondiwindi, March 2018, pp. 171-176.

Rathjen JR, Ryder MH, Riley IT, Lai TV, Denton MD (2020) Impact of seed-applied pesticides on rhizobial survival and legume nodulation. *Journal of Applied Microbiology* **129(2)**, 389-399.

GRDC publication: Inoculating Legumes: Practice and Science (https://grdc.com.au)

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

PREDICTA rNod kits available to PREDICTA B accredited agronomists via russell.burns@sa.gov.au



#### **Contact details**

Liz Farquharson SARDI Plant Health and Diagnostics GPO Box 397, Adelaide SA 5001 +61 8 8429 2243 liz.farquharson@sa.gov.au



# Crop safety and broadleaf weed control implications for various herbicides and combinations in lentil

#### Jordan Bruce<sup>1</sup>, Navneet Aggarwal<sup>2</sup>, Stuart Sherriff<sup>1</sup>, Sam Trengove<sup>1</sup> and Penny Roberts<sup>2</sup>.

<sup>1</sup>Trengove Consulting; <sup>2</sup>SARDI.

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#### **Keywords**

■ herbicide efficacy, herbicide tolerance, lentil, sandy soils.

#### Take home messages

- Lentil crop safety varied significantly between acidic and alkaline sands in 2021 trials, with the use of Reflex<sup>®</sup>, diuron, metribuzin and terbuthylazine herbicides, with alkaline sand sites incurring more herbicide damage than acidic sand sites.
- Crop damage with Reflex<sup>®</sup> herbicide on alkaline sands was rate responsive, with yield loss in a trial at Bute increasing from 17% when applied at 0.5L/ha to 54% when applied at 1L/ha.
- Crop damage on alkaline sands was cumulative where Reflex<sup>®</sup> was applied in combination with a group 5 herbicide, such as diuron. In a trial at Alford on an alkaline sand, yield loss to either diuron or Reflex<sup>®</sup> was 20%, increasing to 52% yield loss when applied in combination.
- Seasonal variation, including higher rainfall post-seeding in 2021 may have been a contributing factor in higher level of crop damage in alkaline sandy soils.
- Effective control of broadleaf weeds such as bifora, common sow thistle, Indian hedge mustard, wild turnip and capeweed, including populations resistant to Group 2 imidazolinone herbicides, was achieved with Reflex<sup>®</sup> (Group 14 herbicide).
- Control of various broadleaf weeds was achieved in lentil using Reflex<sup>®</sup> in combination with other registered herbicides including Group 2, 5 and 12 herbicides. However, crop safety to these combinations varied between herbicides and their doses, and soil type.
- Herbicide strategies on high-risk alkaline sandy soil types needs careful planning to balance between avoiding crop damage and achieving adequate weed control. Rate of Reflex may need to be adjusted near the middle of the rate range in some soil types to find the right balance of crop safety and weed control.

#### Background

Reflex<sup>®</sup> (fomesafen 240g/L) herbicide has been recently registered for use in chickpea, narrow leaf lupin, lentil, field pea, faba bean and vetch. Of all the pulse species with a Reflex<sup>®</sup> registration, lentil is the most sensitive, with a maximum rate of 1L/ ha incorporated by sowing (IBS) only, whilst other legume species have a maximum rate of 1.25L/ha

post-sowing and pre-emergence (PSPE) (except vetch, maximum 0.9L/ha PSPE) or 1.5L/ha IBS. Reflex® is registered for control of broadleaf weeds, including wild radish, Indian hedge mustard, sow thistle, prickly lettuce and bifora when used at 0.75-1L/ha in lentils. A new mode of action registered in lentils will provide herbicide rotation options and will be particularly useful where herbicide resistance is developing.



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Effective broadleaf weed management is a major constraint to achieving yield potential in pulse crops. The adoption of herbicide tolerant pulse crops has improved broadleaf weed control options. However, it has resulted in over-reliance on a few modes of action, particularly Group 2 (previously B). The increased reliance on Group 2 imidazolinone (IMI) herbicides carries the risk of the development of herbicide resistant weeds, and therefore raises concerns for the long-term efficacy of this mode of action. The availability of a new mode of action herbicide in Reflex<sup>®</sup> (Group 14, previously Group G) has increased the broadleaf weed control options for both conventional and herbicide tolerant cultivars of pulse crops.

Previous SAGIT projects (TC116, TC119) have investigated crop safety and weed control on sandy soils of the northern Yorke Peninsula for Group 2, Group 5 (previously C) and Group 12 (previously F) herbicides. This work highlighted the heightened risk of crop damage from soil residual herbicides on these soil types, in particular the Group 2 and 5 herbicides (Trengove et al. 2021). SAGIT project TC121 has continued this work, including Reflex<sup>®</sup>, investigating herbicide crop safety on a range of soil types, including differences in soil texture and pH, with 2021 results presented here.

#### Method

A total of four trial sites were established in 2021 to assess herbicide tolerance and weed control on imidazolinone (IMI) tolerant lentils.

Two of these four trials were established at Alford and Bute 1 (northern Yorke Peninsula) on sandy soils with either high or low soil pH to assess crop safety when using Group 2, 5, 12 and 14 pre-emergent and/or post-emergent herbicides (Table 1). Weeds were removed by hand from all plots in these trials to determine herbicide effects in the absence of weeds.

The remaining two trials were established at Bute (2 & 3) to develop strategies for controlling broadleaf weeds (including bifora, Indian hedge mustard and common sow thistle) on loamy soil, and sandy alkaline soils (Table 1). The treatments comprised of herbicide combinations from Group 2, 5 and 14 in a randomised complete block design with three replicates. The background population of broadleaf weeds in the paddock was used for this study.

#### Rainfall conditions in 2021

Two major rainfall events occurred after seeding, with 27.6 mm and 24.0 mm of rainfall received within the first and second week, respectively (Table 4). A total of 278mm was received between seeding and harvest (Figure 4).

#### Trial establishment

Trials were sown using knife points and press wheels between 26 May and 4 June and were sown to PBA Hurricane XT<sup>(b)</sup>. Herbicides were applied using hand boom equipment delivering 100L/ha water volume at a pressure of 200kPa. Plots at the herbicide tolerance sites were rolled post-emergent compared to the weed control trials which were rolled immediately post-seeding.

#### Herbicide properties and application details

The herbicides used in the trials are described in Tables 2 and 3.

Table 1. De	escriptions for the	four trial sites e	established in 2	021.			
Location	Site	0-10 pH (CaCl2)	0-10 pH (H <sub>2</sub> O)	ECEC Cmol/kg	OC (%)	Texture	Weeds assessed
Alford	Alkaline herbicide tolerance	7.7	8.4	11.7	0.94	Sand	Indian hedge mustard (Sisymbrium orientale), burr medic (Medicago polymorpha), common sow thistle (Sonchus oleraceus), and wild turnip (Brassica tournefortii)
Bute 1	Acidic herbicide tolerance	4.7	5.8	3.09	0.76	Sand	As above + Cape weed (Arctotheca calendula)
Bute 2	Loam weed control	7.5	8.1	Not available	1.33	Loam	Bifora <i>(Bifora testiculata)</i> , Indian hedge mustard and common sow thistle
Bute 3	Sand weed control	6.8	8.1	Not available	0.82	Loamy sand	Indian hedge mustard



# **Table 2.** Pre-emergent herbicide properties for products used in the herbicide tolerance trials in 2021(source: GRDC pre-emergent herbicide fact sheet).

	-							
Herbicide (Group)		Solubility (mg/L @ 20°C)	A	dsorption coefficient, Koc value				
Diuron (5)	36	Low solubility	813	Slightly mobile				
Terbuthylazine (5)	7	Low solubility	230	Moderately mobile				
Metribuzin (5)	1165	High solubility	60	Mobile				
Reflex <sup>®</sup> (14)	50	Moderate solubility	228	Moderately mobile				

## Table 3. Herbicide products and application timing/method for the alkaline (Alford) and acidic sand (Bute 1) herbicide tolerance trials in 2021.

Herbicide product	Trial application	Trial rate (product)	Registered use pattern
Diuron (900g/kg)	IBS	830g/ha	830g — 1100g/ha PSPE
Metribuzin (750g/kg)	IBS	180g/ha	180g PSPE
Terbyne® (terbuthylazine 750g/kg)	IBS	750g/ha	1.0 — 1.4kg/ha IBS
Reflex <sup>®</sup> (fomesafen 240g/L)	IBS	1000mL/ha	500 – 1000mL/ha IBS
Intercept® (imazamox 33g/L + imazapyr 15g/L)	Post-emergent	500mL/ha	500 – 750mL/ha Post
Diflufenican (500g/L)	Post-emergent	150mL/ha	100 – 200mL/ha Post

#### Results and discussion

#### Crop safety

Early season herbicide damage scores indicate there were differences between the two herbicide tolerance sites at Alford and Bute 1 (Figure 1). At the alkaline site (Alford), the group 5 herbicides diuron and terbuthylazine caused significant herbicide damage with scores for necrosis reaching 6.2 out of 9 from the application of Terbyne®. Reflex® caused significant damage at this site but in the form of leaf chlorosis rather than necrosis. The combination of the Group 5 and 14 herbicides at these sites did not lead to increased damage at this time. In contrast, at the acidic site (Bute 1), there were only minor symptoms evident in association with the application of diuron and no other herbicide was significantly different from the control treatment. Reflex® also caused stunting in lentil as the rate increased from 500 to 1000mL/ha in weed control trials (Bute 2 & 3) (data not shown) and the effect was more pronounced in alkaline sands than in loamy soils.

At both sites, there was a reduction in leaf necrosis associated with combining diuron and Reflex<sup>®</sup> compared with diuron alone, this requires further investigation.



**Figure 1.** Early season leaf necrosis (left) and chlorosis (right), scored 13 July at Alford (alkaline sand) and 20 July at Bute (acidic sand) (0 = no chlorosis, 9 = death) of PBA Hurricane XT<sup>(b)</sup> for the herbicide tolerance trials in 2021. Lower case letters and upper-case letters denote significant differences for each site, P values = <0.001.



Previous trial work has shown that on these sandy soil types, there is a strong relationship between NDVI (where NDVI is correlated to biomass) and yield for lentil, and this is also the case for the 2021 alkaline sand herbicide tolerance trial (Figure 2). Herbicide damage on this sandy soil resulted in growth and biomass reduction (Figure 1) and led to decreased yields (Figure 2).



**Figure 2.** Relationship for Greenseeker NDVI of PBA Hurricane  $XT^{(1)}$  (recorded on 06-09-2021) and grain yield for the alkaline sand herbicide tolerance trial at Alford in 2021 (y = -5.2444x<sup>2</sup> + 7.3026x - 0.706, R<sup>2</sup> = 0.77).

Grain yield was significantly reduced in response to the application of some herbicide treatments at the alkaline sand trial site, consistent with earlier herbicide damage scores (Figure 3). Diuron and Reflex® treatments both reduced grain yields by 20% when applied alone, and Terbyne® reduced yield by 51%. This contrasts with the acidic sand site where no significant yield differences occurred in response to the application of any individual herbicide.

Where diuron and Reflex<sup>®</sup> were applied in combination, yield loss increased to a 52% reduction in grain yield compared to the untreated control.

Post-emergent herbicides Intercept® and diflufenican (DFF) did not cause yield loss at either site, which is consistent with results of Trengove et al. (2021) for similar soil types. Generally, DFF and Intercept® were also safe to apply following application of either diuron or Reflex® IBS. Where these had caused damage at the alkaline sand site, the post-emergent applied herbicides did not exacerbate the damage. However, the most damaging combination of herbicide at the alkaline sand site was the combination of diuron plus Reflex® applied IBS followed by DFF post-emergent. This treatment resulted in a grain yield reduction of 79%. The addition of Intercept® to this treatment did not increase the level of damage further.

Reflex<sup>®</sup> application rates in the herbicide tolerance trials (Alford, Bute 1) were set at 1000mL/ ha for all treatments. However, in the weed control trials (Bute 2 & 3), rates of 500mL/ha, 750mL/ha and 1000mL/ha were applied. Grain yield loss at



**Figure 3.** Grain yield presented as per cent of untreated for individual herbicide treatments at the acidic (Bute 1) and alkaline sand (Alford) herbicide tolerance sites in 2021, Diu = diuron, Ref = Reflex®, DFF = diflufenican, Inter = Intercept®, fb = followed by. Bars represent LSD at P=0.05



the alkaline sand trial (Bute 3) varied depending on the rate applied with the 500, 750 and 1000mL/ha rates yielding 83%, 76% and 46% of the untreated, respectively (Pr(>F) = <0.001). This indicates that if rates can be reduced and weed control is still maintained, the crop safety margin can be improved.

#### Seasonal effect of crop safety

It is important to note that season and rainfall patterns are likely to influence herbicide movement and activity in soil and the effect this has on the crop. All the above crop safety data is from the 2021 season. Reflex<sup>®</sup> was also included in 2020 trials and, whilst similar herbicide damage symptoms were present on an alkaline sand, this did not translate into any yield loss in 2020. There were no herbicide damage symptoms or yield loss at the acidic sand site in 2020. A reason for the increased herbicide damage in the 2021 season may be due to more rainfall in the weeks following sowing, which may have moved the herbicide further into the soil profile, with June 2021 rainfall receiving 56mm compared to 19mm in June 2020 (Figure 4). Bute sites received 63 mm rainfall in June 2021 (Table 4). Greater spring rainfall in 2020 is also likely to have contributed to better crop recovery.



**Figure 4.** Growing season rainfall recorded at the Alford community weather station.

#### Broadleaf weed control

Reflex<sup>®</sup> was effective in controlling 94-98% of bifora at rates of between 500 and1000mL/ha (Table 5). Application of Intercept<sup>®</sup>, on its own or in combination with Reflex<sup>®</sup>, provided excellent control of bifora, reducing seed set to <1 bifora seed/ m<sup>2</sup> compared to existing pre-emergent herbicide options metribuzin and Terbyne<sup>®</sup> with 323 and 1672 bifora seeds/m<sup>2</sup>, respectively. Similarly, the combination of Reflex<sup>®</sup> + Intercept<sup>®</sup> provided high levels of common sow thistle control at all sites where it was present (Tables 5 and 7).

Intercept® did not provide adequate control of Indian hedge mustard (IHM) and was not significantly different to the untreated control at the clay loam site (Bute 2) (Table 5). Similar results for poor IHM control with Intercept® occurred at the other three sites (Tables 6 and 7). However, wild turnip was effectively controlled with Intercept®. This poor control of IHM may be explained by the increase of IHM populations resistant to imidazolinone herbicides in this area. This suggests that strategic use of IMI herbicides in combination with alternative modes of action is needed to delay the increase of resistant broadleaf weeds or to manage already resistant populations.

Reflex<sup>®</sup> applied at 1000mL/ha IBS was effective at controlling IMI resistant IHM populations at this location. The level of weed control improved with increasing Reflex<sup>®</sup> rates from 500mL/ha (217 IHM pods/m<sup>2</sup>) to 1000mL/ha (24 IHM pods/m<sup>2</sup>) (Table 5). Most of the surviving IHM plants in Reflex<sup>®</sup> treated plots were found in the in-row spaces, from where the applied herbicide was likely moved out by the seeding operation. Where Reflex<sup>®</sup> was applied IBS and followed by a Group 5 herbicide, metribuzin or Terbyne<sup>®</sup> as a PSPE application, the surviving weeds in the in-row area were mostly controlled. Reflex<sup>®</sup> also proved more effective against capeweed (93% control) compared to Intercept<sup>®</sup> (48% control) (Table 7).

Table 4. Daily rainfall received at Bute sites after sowing till June 30, 2021.								
Date	Rainfall received (mm)	Date	Rainfall received (mm)					
7/06/2021	3.3	18/06/2021	1.8					
8/06/2021	19.5	19/06/2021	1.1					
9/06/2021	3.3	20/06/2021	0.1					
10/06/2021	0.3	23/06/2021	1.0					
11/06/2021	1.2	24/06/2021	3.9					
13/06/2021	0.7	25/06/2021	4.7					
15/06/2021	5.4	26/06/2021	0.2					
16/06/2021	0.8	27/06/2021	0.3					
17/06/2021	15.3	28/06/2021	0.1					



Table 5. Effect of herbicides on b	roadleaf weeds a	and their seed	set on clay loam so	ils at Bute	2, 2021.	
Herbicide treatment (commercial product rate)	Rate (Product)	Seed bearing	Bifora plants/m <sup>2</sup> Bifora seeds set/m <sup>2</sup>	IHM pod set/m <sup>2</sup>	Common sow thistle plants/m <sup>2</sup>	Common sow thistle pod set/m <sup>2</sup>
Intercept®	600 mL/ha (Post)	0.1 <sup>de</sup>	0.4 <sup>c</sup>	731ª	1.4b <sup>c</sup>	4d <sup>e</sup>
Metribuzin 200 g/ha (PSPE)		14.3°	323⁵	1d <sup>e</sup>	<b>0</b> <sup>d</sup>	0 <sup>f</sup>
Reflex® 500 ml/ha (IBS)		5.9 <sup>cd</sup>	35 <sup>c</sup>	217 <sup>bc</sup>	2.6 <sup>b</sup>	12 <sup>bcd</sup>
Reflex® 500 ml/ha (IBS) + Intercept® 600 ml/ha (POST)		0 <sup>e</sup>	<b>0</b> <sup>c</sup>	409 <sup>ab</sup>	0.4 <sup>cd</sup>	1 <sup>ef</sup>
Reflex® 500 ml/ha (IBS) + Metribuzin 200 g/ha (PSPE) + Intercept® 600 ml/ha (POST)		0 <sup>e</sup>	0 <sup>c</sup>	24 <sup>de</sup>	Oď	O <sup>f</sup>
Reflex® 500 ml/ha (IBS) + Terbyne® 1000 g/ha (IBS) + Intercept® 600 ml/ha (POST)		0.1 <sup>de</sup>	0.4 <sup>c</sup>	0 <sup>e</sup>	Oď	O <sup>f</sup>
Reflex <sup>®</sup> 750 ml/ha (IBS)		2.0d <sup>e</sup>	<b>7</b> °	64 <sup>cde</sup>	3.1 <sup>b</sup>	15 <sup>abc</sup>
Reflex® 750 ml/ha (IBS) + Intercept® 600 ml/ha (POST)		0 <sup>e</sup>	0 <sup>c</sup>	81 <sup>cde</sup>	0.2 <sup>cd</sup>	1 <sup>ef</sup>
Reflex® 750 ml/ha (IBS) + Metribuzin 200 g/ha (PSPE) + Intercept® 600 ml/ha (POST)		Oe	0°	0°	Oď	O <sup>f</sup>
Reflex® 750 ml/ha (IBS) + Terbyne® 1000 g/ha (IBS) + Intercept® 600 ml/ha (POST)		Oe	0 <sup>c</sup>	10 <sup>de</sup>	Oď	O <sup>f</sup>
Reflex® 1000 ml/ha (IBS)		5.4 <sup>cd</sup>	21 <sup>c</sup>	24 <sup>de</sup>	2.6 <sup>b</sup>	21 <sup>ab</sup>
Terbyne <sup>®</sup> 1000 g/ha (IBS)		52.7 <sup>b</sup>	1672ª	105 <sup>cd</sup>	1.2 <sup>bc</sup>	5 <sup>cde</sup>
Unweeded control		97.2ª	<b>1987</b> ª	836ª	7.3ª	29ª

Table 6. Effect of herbicides on Indian hedge mustard (IHM) and their seed set on sandy alkaline soils at Bute 3, 2021.				
Herbicide treatment (commercial product rate)	IHM/m <sup>2</sup> (120 DAS)	IHM pods/m <sup>2</sup> (135 DAS)		
Diuron 550 g/ha (PSPE)	0.2 <sup>bc</sup>	1 <sup>b</sup>		
Intercept <sup>®</sup> 600 ml/ha (POST)	5.6ª	118ª		
Metribuzin 180 g/ha (PSPE)	0.6 <sup>b</sup>	13 <sup>b</sup>		
Reflex® 500 ml/ha (IBS)	0.6 <sup>b</sup>	5 <sup>b</sup>		
Reflex® 500 ml/ha (IBS) + Diuron 550 g/ha (PSPE)	0 <sup>c</sup>	0 <sup>b</sup>		
Reflex® 500 ml/ha (IBS) + Diuron 550 g/ha (PSPE) + Intercept® 600 ml/ha (POST)	0 <sup>c</sup>	0 <sup>b</sup>		
Reflex® 500 ml/ha (IBS) + Metribuzin 180 g/ha (PSPE)	0 <sup>c</sup>	0 <sup>b</sup>		
Reflex® 500 ml/ha (IBS) + Metribuzin 180 g/ha (PSPE) + Intercept® 600 ml/ha (POST)	0.2 <sup>bc</sup>	5⁵		
Reflex® 750 ml/ha (IBS)	0 <sup>c</sup>	0 <sup>b</sup>		
Reflex® 1000 ml/ha (IBS)	0 <sup>c</sup>	0 <sup>b</sup>		
Unweeded control	6.3ª	154ª		



		saliuy sui a Alkalin	e sand		scuvely, III z	-021.	Acidic sand		
Herbicide treatment (commercial product rate)	Medic	WHI	Wild turnip	Common	Medic	MHI	Wild turnip	Common	Capeweed
	control (%)	control (%)	control (%)	sow thistle control (%)	control (%)	control (%)	control (%)	sow thistle control (%)	control (%)
Ni	0ª	0ª	0ª	0 <sup>a</sup>	0ª	0ª	0ª	0ª	0ª
Diuron 830 g/ha (IBS)	63 <sup>6</sup>	93cd	100 <sup>c</sup>	d6 <sup>b</sup>	<b>38</b> abc	80 <sup>b</sup>	82 <sup>b</sup>	84 <sup>cd</sup>	76 <sup>bcde</sup>
Terbyne® 750 g/ha (IBS)	<b>78</b> bc	96 <sup>cde</sup>	100 <sup>c</sup>	96 <sup>b</sup>	30 <sup>abc</sup>	87 <sup>bc</sup>	<b>78</b> <sup>b</sup>	90cq	87 <sup>defg</sup>
Metribuzin 180 g/ha (IBS)	53 <sup>ab</sup>	74 <sup>ab</sup>	98 <sup>b</sup>	48ª	4 <sup>ab</sup>	73 <sup>b</sup>	76 <sup>b</sup>	57 <sup>b</sup>	62 <sup>abc</sup>
Intercept® 500 ml/ha (POST)	<b>63</b> d	70 <sup>ab</sup>	98 <sup>b</sup>	85 <sup>b</sup>	80 <sup>ef</sup>	0ª	100 <sup>d</sup>	84 <sup>c</sup>	48 <sup>ab</sup>
Diuron 830 g/ha (IBS) + Intercept® 500 ml/ha (POST)	89 <sup>cd</sup>	96 <sup>de</sup>	100℃	d6 <sup>b</sup>	70 <sup>bcde</sup>	70 <sup>b</sup>	₀66	97 <sup>ef</sup>	74 <sup>abcd</sup>
Diflufenican 150 ml/ha (POST)	53 <sup>ab</sup>	1009	100 <sup>c</sup>	93⊳	42 <sup>abcd</sup>	100 <sup>e</sup>	100 <sup>d</sup>	pp0cq	90 <sup>cdef</sup>
Diuron 830 g/ha (IBS) + Diflufenican 150 ml/ha (POST)	58 <sup>6</sup>	1009	<b>36</b> €	100 <sup>b</sup>	90 <sup>efg</sup>	100 <sup>e</sup>	100 <sup>d</sup>	100 <sup>f</sup>	99 <sup>gh</sup>
Diuron 830 g/ha (IBS) + Diflufenican 150 ml/ha (POST) + Intercept® 500 ml/ha (POST)	91 <sup>d</sup>	1009	100 <sup>c</sup>	96 <sup>b</sup>	98 <sup>fg</sup>	100 <sup>e</sup>	100 <sup>d</sup>	100 <sup>f</sup>	99 <sup>gh</sup>
Reflex® 1000 ml/ha (IBS)	54 <sup>ab</sup>	96 <sup>de</sup>	99c	93 <sup>b</sup>	0ª	93 <sup>cd</sup>	94⁰	94 <sup>de</sup>	93 <sup>efgh</sup>
Reflex <sup>®</sup> 1000 ml/ha (IBS) + Intercept <sup>®</sup> 500 ml/ha (POST)	<b>88</b> <sup>cd</sup>	96 <sup>efg</sup>	100℃	100 <sup>b</sup>	80 <sup>cde</sup>	<b>97</b> d	100 <sup>d</sup>	100 <sup>f</sup>	91 <sup>efgh</sup>
Reflex® 1000 ml/ha (IBS) + Diflufenican 150 (POST)	57 <sup>b</sup>	1009	100 <sup>c</sup>	100 <sup>b</sup>	78 <sup>def</sup>	100 <sup>e</sup>	100 <sup>d</sup>	100 <sup>f</sup>	98 <sup>fgh</sup>
Reflex $^{\odot}$ 1000 ml/ha (IBS) + Diflufenican 150 ml/ha (POST) + Intercept $^{\odot}$ 500 ml/ha (POST)	<b>93</b> d	1009	100⁰	100 <sup>b</sup>	1009	100€	100 <sup>d</sup>	100 <sup>f</sup>	100 <sup>h</sup>
Diuron 830 g/ha (IBS) + Reflex® 1000 ml/ha (IBS)	72 <sup>bc</sup>	97 <sup>def</sup>		93 <sup>b</sup>	18 <sup>ab</sup>	96 <sup>d</sup>	97 <sup>c</sup>	<b>91</b> cd	95 <sup>efgh</sup>
Diuron 830 g/ha (IBS) + Reflex $^{\odot}$ 1000 m//ha (IBS) + Intercept $^{\odot}$ 500 m//ha (POST)	<b>87</b> cd	96 <sup>de</sup>	100⁰	96 <sup>b</sup>	88 <sup>efg</sup>	97 <sup>d</sup>	100 <sup>d</sup>	100 <sup>f</sup>	91 <sup>defg</sup>
Diuron 830 g/ha (IBS)+ Reflex® 1000 ml/ha (IBS) + Diflufenican 150 ml/ha (POST)	<b>75</b> bc	1009	100ౕ	100 <sup>b</sup>	66 <sup>cde</sup>	100⁰	100 <sup>d</sup>	100 <sup>f</sup>	4666
Diuron 830 g/ha (IBS) + Reflex® 1000 ml/ha (IBS) + Diflufenican 150 ml/ha (POST) + Intercept® 500 ml/ha (POST)	93 <sup>d</sup>	100 <sup>fg</sup>	100 <sup>c</sup>	100 <sup>b</sup>	86 <sup>efg</sup>	100 <sup>e</sup>	100 <sup>d</sup>	100 <sup>f</sup>	100 <sup>h</sup>
Weed density in nil (weeds/plot)	159	91	56	6	16	119	87	22	39
Weed density in nil (weeds/m <sup>2</sup> )	10.6	6.1	3.7	0.6	1.1	7.9	5.8	1.5	2.6



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Intercept<sup>®</sup> application was the stand-out herbicide for achieving medic control in these trials, particularly at the acidic site where the next best treatment only achieved 38% control. Therefore, to achieve the desired level of broadleaf weed control in lentil, it is important to know the likely weed types, population, and resistance status prior to deciding on herbicide treatment.

The availability of the new Group 14 herbicide Reflex<sup>®</sup> has increased the options for achieving improved broadleaf weed control in lentil, including weeds resistant to IMI herbicides. Careful decisions regarding safe dosage rates of Reflex®, governed by the soil type, and a follow-up application of Group 5 and Group 12 herbicides provide broadspectrum broadleaf weed control in lentil. Group 2 IMI herbicides will continue to be a valuable tool for broadleaf weed control in lentil, especially for weeds that have not evolved resistance to this mode of action, and the weeds such as medics that are not effectively controlled with other herbicides. Using Reflex<sup>®</sup> in conjunction with IMI herbicides, metribuzin, Terbyne<sup>®</sup> or diuron, will diversify the selection pressure for broadleaf weed control in lentil and delay the resistance build up to a specific mode of action.

#### Acknowledgements

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#### References

Trengove S, Sherriff S, Bruce J (2021) Increasing reliability of lentil production on sandy soils. Proceedings GRDC Grains Research Update, Adelaide, February 2021, pp. 99-106.

#### **Contact details**

Jordan Bruce Trengove Consulting jordanpbruce@gmail.com



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

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and training through its Rural Minds program, which is designed to raise mental health awareness and confidence, grow understanding and ensure information is embedded into agricultural and farming communities. WWW.CORES.ORG.AU CORES™ (Community Response to Eliminating

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Suicide) is a community-based program that educates members of a local community on how to intervene when they encounter a person they believe may be suicidal.

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









# **Genetic improvement of canola establishment**

Matthew Nelson<sup>1</sup>, Jose Barrero<sup>2</sup>, Mark Cmiel<sup>2</sup>, Andrew Fletcher<sup>1</sup>, Ian Greaves<sup>2</sup>, Trijntje Hughes<sup>2</sup>, Andrew Toovey<sup>1</sup>, Karen Treble<sup>1</sup>, Alec Zwart<sup>2</sup>, John Kirkegaard<sup>2</sup> and Greg Rebetzke<sup>2</sup>.

<sup>1</sup>MCSIRO Agriculture and Food, Floreat, Perth, Australia; <sup>2</sup>CSIRO Agriculture and Food, Black Mountain, Canberra, Australia.

GRDC project code: CSP1907-001RTX

#### **Keywords**

deep sowing, genetic improvement, hypocotyl length, seedling vigour.

#### Take home messages

- A nationwide survey of canola growers and agronomists identified marginal soil moisture and variable seeding depth as two key factors leading to poor canola establishment.
- Our project is pursuing genetic solutions to improve establishment of canola targeting early vigour and longer hypocotyls to enable deeper sowing to access soil moisture.
- We identified several overseas varieties with enhanced vigour and/or longer hypocotyls, which emerged significantly better from 50mm sowing depth in the field than all five current Australian canola variety controls.
- We have developed rapid and accurate screening methods for breeders to accelerate the development of canola varieties with improved establishment potential.

#### Background

Successful establishment is the foundational phase of any crop lifecycle and necessary to achieve high yield potential and compete effectively with weeds (Kirkegaard et al. 2020). Poor establishment of canola (*Brassica napus* L.) is a widespread problem in Australia and Canada with on average 50-60% of germinable seeds successfully establishing (Harker et al. 2012; Harries et al. 2017; McMaster et al. 2019). The success or failure of canola establishment is influenced by a range of factors including agronomic practices, environmental conditions, seed quality and genetics (Nelson et al. 2022).

Australian growers are increasingly seeking to sow their canola crops early to maximise yield potential. This increased yield potential comes with a trade-off of increased risk of poor crop establishment due to false breaks, poor soil moisture and high soil temperature (Fletcher et al. 2016). Canola has small, oil-rich seeds that typically do not emerge well when sown deep (below 30mm) (Brill et al. 2016) or in soils prone to crusting, so the target seeding depth tends to be shallow (typically around 20mm). Shallow sowing results in a greater likelihood of false breaks and inability to reach stored moisture deeper in the soil profile. Growers are faced with a trade-off when choosing the target sowing depth, which is further complicated by the common use of imprecise seeding equipment leading to variable seed depths. Studies have shown that larger canola seeds emerge better than smaller seeds from deeper sowing (Harries et al. 2017; McMaster et al. 2019; Riethmuller et al. 2003) and hybrids tend to establish better than openpollinated varieties independent of seed size (Brill et al. 2016).

Most research into canola establishment to date has targeted improved agronomy, understanding environmental conditions and seed quality/size aspects. Little is known about the genetic determinants that influence canola establishment and what little is known comes from



studies in Europe and Canada. In 2019, CSIRO and GRDC began a 4-year project to identify international varieties with better genetic potential for establishment, and to develop selection and screening tools to help breeders develop Australian canola varietes with improved establishment potential.

#### Method

In order to learn from grower experiences of canola establishment, we first conducted a survey of Australian growers and agronomists comprising 18 questions designed to understand grower practices, their experiences, and their views on causes and solutions of poor canola establishment. Participants were invited via Twitter and through grower group email lists to participate anonymously in a SurveyMonkey questionnaire, which remained open from January 30 to February 17, 2020. We used these responses, along with a comprehensive review of scientific literature, to build our understanding of the crop traits that must be improved to achieve higher and more consistent establishment rates of canola.

Our genetics approach was as follows:

- For any breeding activity, it is essential to have genetic variation of the target traits and so we assembled a highly diverse set of 100 open-pollinated varieties of Brassica napus comprising mainly oilseed canola but also including vegetable and fodder types. These varieties originated from 18 countries representing the canola growing regions of Europe, Canada and China and included 23 historic Australian varieties. In order to achieve uniform seed quality and limit maternal effects on seedling performance, seed was multiplied in the same field production site at the Ginninderra Experimental Station, Canberra in 2019.
- Efficient and accurate lab-based screening methods were developed to measure seedling vigour at three stages (germination, cotyledon and 4-leaf stages), and hypocotyl length and cross-sectional area. These methods were used to screen the 100 international varieties alongside 28 current Australian varieties (26 hybrids, 2 open pollinated) contributed by breeding companies.

 A subset of 20 international varieties was selected from the lab screens to include the extremes for vigour and hypocotyl traits along with five current Australian varieties were evaluated. These 25 entries were evaluated for establishment from depth (50mm and 20mm) at four field locations in NSW (Boorowa and Griffith) and WA (Bejoording and East Kokeby) in 2021. Fifteen seeds were sown precisely by hand with 6cm separation in 1.2-1.5m rows at 20mm and 50mm sowing depths, with four replicates in a randomised, split-plot design. Field sites were visited on average 10 times each, with photographs taken of each plot which were used to track emergence counts at each sampling date. When the 20mm depth canola reached the 4-leaf stage, the rows were individually harvested, and biomass measured and expressed as dry weight per plant. This was the first year of a 2-year study on field establishment.

#### Results and discussion

#### Canola establishment survey

#### Canola seeding practices

The survey drew 63 responses (47 growers, 15 agronomists and 1 seed company technical lead), from the main canola growing states and representating a wide range of average annual rainfall (280 – 950mm). The 5-year average proportion of canola in their cropping programs was 27%, with the median canola sowing date being 15 April. Of respondents, 41% used only hybrids, 24% used only open-pollinated (OP) varieties and 35% used both. Most respondents using OP varieties (35 out of 37) graded their own seeds, typically using a minimum seed diameter of 1.7mm. Growers predominantly used tyne seeders (82.5%) and, to a lesser extent, disc seeders (11%) to sow canola, while the remaining 6% used both type and disc seeders, or other seeders. The typical seeding rates ranged widely from 1.0 to 5.0kg/ha but most (73%) were in the range 1.6-3.0kg/ha, and 73% of respondents sow into cereal stubble. Of the 47 respondents who provided target plant densities, 83% were in the range 21-50 plants/m2. Most respondents (71%) sow dry 'usually' or 'always' if the break of season has not already occurred.





Figure 1. The views of 63 survey respondents about the factors that limit canola establishment in their experience.

# Causes of poor canola establishment and operational solutions

The survey then asked what the growers and agronomists considered to be the most important factors limiting canola establishment. The two most frequent responses related to marginal soil moisture (76% of respondents) and sowing depth (65%) (Figure 1). Other common responses were poor soil structure/crusting (29%), seed treatments (22%), sowing too fast (17%) and poor seed quality/vigour (16%). Commonly cited solutions to improve canola establishment were largely operational or agronomic in nature: achieve more precise seeding depth (26%), slow down seeding (23%), increase seeding rate (13%), careful choice of wheel pressing/rolling (11%), and use of soil wetting agents (9%).

# Insights to improve establishment potential in canola

When combined with a comprehensive review of the scientific literature, these survey responses provided a clear vision of the genetic improvements required by canola varieties to achieve better and more consistent establishment in Australia:

 Canola varieties capable of emerging from deeper sowing. This would help canola access stored soil moisture and reduce the likelihood of responding to a false seasonal break in the season. This is especially important with the trend towards earlier sowing (Hunt et al. 2019). We identified increased germination vigour and longer hypocotyls as the key target traits to support successful establishment from deeper sowing.

 Rapid post-emergent growth to maximise competitiveness with weeds and to rapidly access moisture deeper in the soil profile.
 We identified two key stages in seedling development to target: the cotyledon stage, which is sustained primarily by seed-stored energy; and the 4-leaf stage when the seedling has transitioned from reliance on stored energy to sustaining growth by photosynthesis.

# Developing selection tools to improve canola establishment

#### Developing efficient selection tools

Our new lab-based screening methods to assess early vigour (at germination, cotyledon and 4-leaf stages) and hypocotyl (length and diameter) traits were very robust with repeatability ranging from 0.71 to 0.96 across the sets of international and current Australian varieties. This indicates these methods can be used with the confidence that they will provide consistently good measures of performance in controlled lab environments. For the three vigour traits, the best international OP varieties matched the best current Australian hybrid varieties, which had the advantage of heterosis (hybrid vigour). This is encouraging for breeders to make further improvements in the additive genetic value of their hybrid parents and even greater vigour in new hybrid varieties.





**Figure 2.** The three best international varieties (yellow bars) had significantly longer hypocotyls than the 28 current Australian varieties (blue bars) tested. Isd = 24.9mm.



**Figure 3.** Field performance of the best three (of 20) international varieties (yellow bars) which had significantly higher emergence rates (A) and/or biomass per plant (B) than the best Australian variety (of 5; blue bars) when sown at 50mm depth. Note that the anonymised varieties shown are not necessarily the same between both charts.



The standout trait, however, was hypocotyl length. The three best international varieties had significantly (p<0.05) longer hypocotyls than the 28 current Australian varieties tested (Figure 2). There is clearly scope for substantial increases in hypocotyl length in current Australian varieties.

#### Ground-truthing lab-based findings in the field

Having identified international varieties with improved vigour and hypocotyl traits in controlled lab conditions, we set out to determine if these traits reflected performance under field conditions. To this end, we conducted four field experiments in WA and NSW in 2021 of which the most insightful was the Boorowa trial. At the 50mm sowing depth, the three international varieties (from 20) with the highest emergence rates had a significantly higher emergence rate than the best Australian variety (from five) (Figure 3A). These three international varieties were identified in lab-based screens as having long hypocotyls or high vigour. Similarly, the three international varieties with the most biomass per plant had significantly higher biomass than the best Australian variety tested (Figure 3B). All three international accessions were identified as having high seedling vigour in lab-based screens. Thus, we had reasonable grounds to expect that the rapid lab-based screening methods are effective to identify varieties with improved establishment potential. However, it should be stressed that this is from one year of field experimental data and the best performing trial. These experiments will be conducted again in 2022 to confirm the repeatability of these field-based results.

#### Conclusion

Guided by a survey of Australian canola growers/ agronomists and a comprehensive literature review, we identified early vigour and long hypocotyls as target traits to improve establishment of canola when it is sown at depth. We developed rapid, lab-based screening tools to identify international varieties with enhanced vigour and hypocotyl lengths. The best international varieties clearly outperformed the best Australian varieties in labbased screening, and this appears to hold up in the first year of field experiments. These results show great promise to enable canola breeders to rapidly develop new canola varieties that can establish better from deeper sowing.

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#### References

Brill RD, Jenkins ML, Gardner MJ, Lilley JM, Orchard BA (2016) Optimising canola establishment and yield in south-eastern Australia with hybrids and large seed. *Crop and Pasture Science* **67(4)**, 409-418.

Fletcher A, Lawes R, Weeks C (2016) Crop area increases drive earlier and dry sowing in Western Australia: implications for farming systems. *Crop and Pasture Science* **67(12)**, 1268-1280.

Harker KN, O'Donovan JT, Blackshaw RE, Johnson EN, Lafond GP, May WE (2012) Seeding depth and seeding speed effects on no-till canola emergence, maturity, yield and seed quality. *Canadian Journal of Plant Science* **92(4)**, 795-802.

Harries M, Seymour M, Bucat J, French B, Sprigg S (2017) Agronomy for early sown canola. Proceedings GRDC Grains Research Update, Perth, February 2017, p. 62.

Hunt JR, Lilley JM, Trevaskis B, Flohr BM, Peake A, Fletcher A, Zwart AB, Gobbett D, Kirkegaard JA (2019) Early sowing systems can boost Australian wheat yields despite recent climate change. Nature Climate Change 9:244-247

Kirkegaard J, Lilley J, Berry P, Rondanini D (2020) Canola. In: Sadras V, Calderini D (eds) Crop Physiology Case Histories for Major Crops. Academic Press

McMaster C, Menz I, Stevenson A (2019) Canola establishment across central NSW. Proceedings GRDC Grains Research Update, Wagga Wagga, February 2019, pp. 229-234.



Nelson MN, Nesi N, Barrero JM, Fletcher AL, Greaves IK, Hughes T, Laperche A, Snowdon R, Rebetzke GJ, Kirkegaard JA (2022) Strategies to improve field establishment of canola: a review. Advances in Agronomy (in press).

Riethmuller GP, Carmody PC, Walton GH (2003) Improved canola establishment, yield and oil with large seed on sandplain soil in Western Australia. "Proceedings of the 13th Australian Research Assembly on Brassicas'. Tamworth, NSW", 8–12 September 2003, pp. 55-59.

#### **Contact details**

Matthew Nelson CSIRO Agriculture and Food Floreat Laboratories 147 Underwood Avenue, Floreat, Perth WA 6014 0490 139 509 matthew.nelson@csiro.au @Matthew67636066





# **SPRAY APPLICATION GROWNOTES<sup>™</sup> MANUAL**





Tom Wolf

GRDC

# SPRAY APPLICATION MANUAL FOR GRAIN GROWERS

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

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

This new manual focuses on issues that will assist in maintaining the accuracy of the sprayer output while improving the efficiency and safety of spraying operations. It contains many useful tips for growers and spray operators and includes practical information – backed by science – on sprayer set-up, including self-

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

propelled sprayers, new tools for determining sprayer outputs, advice for assessing spray coverage in the field, improving droplet capture by the target, drift-reducing equipment and techniques, the effects of adjuvant and nozzle type on drift potential, and surface temperature inversion research.

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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.



# Hyperyielding crops lift canola yield above 6t/ha

Rohan Brill<sup>1</sup>, Darcy Warren<sup>2</sup>, Tracey Wylie<sup>2</sup>, Kat Fuhrmann<sup>2</sup>, Aaron Vague<sup>2</sup>, Max Bloomfield<sup>2</sup>, Kenton Porker<sup>2</sup> and Nick Poole<sup>2</sup>.

<sup>1</sup>Brill Ag; <sup>2</sup>FAR Australia.

GRDC project code: FAR2004-002SAX

#### Keywords

■ canola, hybrid, manure, nutrition.

#### Take home messages

- Grain yield reached well over 6t/ha at Millicent and Wallendbeen in 2021, 1t/ha above the highest yields observed in 2020.
- Yield plateaued from nitrogen application either below or up to 150kg/ha applied N.
- The application of animal manure lifted yield by a further 11—18% above the maximum yield from applied N.
- Variety choice has a major impact on achieving hyperyields, with 45Y95 CL being the standout variety in 2021.
- Further research will determine the mechanisms behind the strong yield response from animal manure and how nutrition can drive hyperyields of canola.

#### Background information

The canola component of the GRDC and FAR Australia Hyperyielding Crops project commenced in 2020 with sites at Gnarwarre, Victoria; Millicent, South Australia; and Wallendbeen NSW. The focus has been on determining the management factors including variety choice, nutrition management, fungicide management and canopy management required to achieve a canola yield of 5t/ha. Variety choice and nutrition were the two most important factors driving canola yield in these high yielding environments in 2020, with fungicide and seeding rate less important. Highest yields were at Wallendbeen, with 5.6t/ha of 45Y28 RR with 225kg/ha N applied. At Gnarwarre, highest yield was 4.8t/ha of 45Y28 RR with 106kg/ha N applied with 5t/ha pig manure. At Millicent, highest yield was 4.6t/ha of 45Y93 CL. All results from 2020 are available at: https://faraustralia.com.au/wp-content/ uploads/2021/04/210325-HYC-Project-2020-Results-Canola-Final.pdf.

#### 2021 Hyperyielding Canola trials

Trials with a similar focus were conducted in 2021 in the same environments as 2020. Yields were higher in 2021 at all sites, with two of the three sites achieving a grain yield of 6t/ha, well above the target yield of 5t/ha (Figure 1). This paper outlines the key management strategies to achieve these very high yields at each site.

#### Methodology

This paper reports on two key trial series (Table 1), the first a Genotype \* Environment \* Management (GEM) trial which were split into separate winter and spring trials with three management strategies (low, medium and high Input) applied to each variety (blocked by herbicide tolerance) at three locations: Gnarwarre, Millicent and Wallendbeen (described in Table 2). The second trial series was a nutrition trial, again split into separate spring and winter trials with six nutrition treatments, focusing on nitrogen management and the addition of animal manure.





Figure 1. Grain yield of the highest yielding canola treatments at three sites in 2020 and 2021.

There were separate fungicide, seeding rate and variety screen trials conducted at each site. Results from these will be presented at GRDC Updates and available on the FAR Australia website on completion of reports.

Table 1. Variety e	Table 1. Variety entries and treatments in a canola GEM trial and			d canola nutrition trial, conducted at three sites in 2021.			
GEM Trial Series			Nutrition Trial				
Spring Varieties	Winter Varieties	Treatments	Spring Variety	Winter Variety	Treatments		
ATR Wahoo $^{(\!\!\!\ D)}$		Low Input: Seed = Maxim <sup>®</sup> XL			0kg/ha N		
HyTTec Trifecta	Hyola 970CL	Xpro <sup>®</sup> 0.8L/ha N = 150kg/ha	_		75kg/ha N		
45Y93 CL		Medium Input: Seed = Maxim XL			150kg/ha N		
45Y95 CL		Xpro 0.8L/ha N = $225$ kg/ha			225kg/ha N		
45Y28 RR		High Input:	45Y28 RR	Hyola Feast CL	300kg/ha N		
Condor TF	Hyola Feast CL	6-Leaf = Prosaro® 0.45L/ha 20% Bloom = Aviator Xpro 0.8L/ha 50% Bloom = Prosaro 0.45L/ha N = 225kg/ha			225kg/ha N + Animal Manure*		

\*Manure applied – 6.7t/ha pig manure at Gnarwarre and Millicent (2.7% N, 1.3%P) and 3t/ha chicken manure at Wallendbeen (3.3% N and 0.7% P).



Table 2. Des	cription of three Hype	eryielding	g Canola s	ites in 2021.					
Location	Region	Average rainfall	Elevation	Soil type	Available N at sowing	Organic Carbon	Colwell P	Applied P	Applied S
Gnarwarre	Southern Victoria	600mm	190m	Sodic Vertosol	70kg/ha (0-100cm)	1.4%	34mg/kg	22kg/ha	30kg/ha
Millicent	South-East SA	710mm	20m	Organosol	173kg/ha (0-10cm)	9.7%	56mg/kg	22kg/ha	30kg/ha
Wallendbeen	South-West Slopes NSW	680mm	540m	Red Ferrosol	340kg/ha (0-90cm)	2.0%	63mg/kg	30kg/ha	30kg/ha

## Table 3. Effect of nutrition (applied N and animal manure) on 45Y28 RR canola yield (t/ha) at three Hyperyielding Canola sites in 2021. Shaded cells denote highest yield in trial.

	Gnarwarre Vic	Millicent SA	Wallendbeen NSW
0	4.0	4.9	4.5
75	4.5	5.6	4.4
150	4.9	5.8	4.6
225	5.1	6.1	4.5
300	5.0	5.8	4.5
225 + Manure	5.9	6.5	5.0
Lsd (p<0.05)	0.36	0.56	0.32

 Table 4. Effect of nutrition (Applied N and animal manure) on Hyola Feast CL canola yield (t/ha) at two Hyperyielding Canola sites in 2021. Shaded cells denote highest yields in the trial.

	Gnarwarre Vic	Wallendbeen NSW
0	3.8	3.8
75	3.9	3.7
150	4.1	3.6
225	4.1	3.8
300	4.0	3.7
225 + Manure	4.7	3.5
Lsd (p<0.05)	0.51	n.s.

#### Results and discussion

#### Nutrition trials

In the spring nutrition trials, yield from the application of N alone (as urea) plateaued at 150kg/ha at Gnarwarre and 75kg/ha at Millicent (Table 3), with no yield increase from applied N at Wallendbeen which had a starting nitrogen of 340kg/ha in the top 90cm. In the winter nutrition trials, there was no yield response from applied N (urea) at either Gnarwarre or Wallendbeen (winter results not yet available for Millicent) (Table 4).

Despite high starting fertility levels and saturated N responses, there were still strong responses to applied animal manure over and above high rates of applied N. This response was observed in all spring trials and one winter trial (Gnarwarre). The yield response from manure in the spring trials ranged from 11% at Wallendbeen to 18% at Gnarwarre and in the winter trials, from not significant to 17.5%.

It is exciting to see such strong yield responses from nutrition above the response from applied N (urea) alone, especially to yield levels above 6t/ ha. The challenge for the project team is to better understand the reason for the strong yield response from animal manure and how that can be replicated cost-effectively across the wider grains industry.

#### GEM trials

There were large differences between varieties in the spring GEM trial, with a small response from management at Gnarwarre and Wallendbeen and no management response at Millicent. At Wallendbeen, there was an average yield response of 0.3t/ha in the high input management versus medium and low input. At Gnarwarre, there was 0.3t/ha higher yield in the high input management compared to low input management.

At Millicent and Wallendbeen, 45Y95 CL was the standout variety with a yield of 6.4t/ha (averaged



across management levels) (Table 5). This yield is 28% higher than the target yield of 5t/ha and highlights what can be achieved with canola when seasons, variety choice and management all align. The addition of manure to improve crop nutrition may raise the bar even higher for canola and this will be tested in the GEM trial in future years. Further sample processing and data analysis will help understand the reasons behind the standout yield of 45Y95 CL at these two sites.

45Y28 RR was the highest yielding variety in the GEM trials at Gnarwarre where Clearfield varieties were not included. However, 45Y95 CL was the highest yielding variety in the adjacent spring screen trial.

In the winter GEM trials, Hyola Feast CL yielded higher than Hyola 970CL at Wallendbeen but there was no yield difference between the two at Gnarwarre (Table 6). There was no yield difference between the management levels in the winter GEM trial at either site.

#### Discussion and conclusion

There were three major stories to emerge from 2021 Hyperyielding Canola trials:

- Yield levels were above even the most optimistic forecasts for canola – 6t/ha should be a commercial target for industry and 7t/ha will be the next frontier for research in these environments.
- Nutrition is not just about applied urea strong responses from animal manure showed the importance of nutrition to push yields to new levels. This needs to be further investigated by the project team to determine if the yield response from manure is due to its slowrelease nature or from nutrients such as phosphorus and potassium that are applied along with nitrogen in animal manure.
- Like 2020, variety choice had a large impact on grain yield outcomes. 45Y95 CL was the standout variety across the three sites in 2021.

### Table 5. Effect of variety choice on grain yield (t/ha, averaged across three input levels) in spring GEM trial at Gnarwarre, Millicent and Wallendbeen in 2021. Shaded cells denote highest yields in the trial.

	Gnarwarre Vic	Millicent SA	Wallendbeen NSW
ATR Wahoo	3.5	3.3	3.6
HyTTec Trifecta	3.9	4.4	5.2
45Y95 CL	*	6.4	6.4
45Y93 CL	*	5.7	5.6
45Y28 RR	4.5	5.1	4.9
Condor XT	3.9	5.1	5.2
Lsd (p<0.05)	0.21	0.34	0.36

## Table 6. Effect of nutrition (Applied N and animal manure) on Hyola Feast CL canola yield (t/ha) at two Hyperyielding Canola sites in 2021. Shaded cells denote highest yields in the trial.

	Gnarwarre Vic	Wallendbeen NSW
Hyola Feast CL	4.3	3.8
Hyola 970 CL	4.0	3.4
Lsd (p<0.05)	n.s.	0.34



#### Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the investment of the GRDC, the author would like to thank them for their continued support. FAR Australia gratefully acknowledges the support of all of its research and extension partners in Hyper Yielding Crops project. These are CSIRO, the Department of Primary Industries and Regional Development (DPIRD) in WA, Brill Ag, Southern Farming Systems (SFS), Techcrop, the Centre for eResearch and Digital Innovation (CeRDI) at Federation University Australia, MacKillop Farm Management Group (MFMG), Riverine Plains Inc and Stirling to Coast Farmers. We would also like to thank our host growers in each state: Chris Gilbertson at Millicent, Ewen Peel at Gnarwarre, and Charlie Baldry at Wallendbeen. Thanks also to technical support from Greta Duff and Nimesha Fernando at Gnarwarre, and Clare Gibbs, Tyler Smith and Alex Price at Wallendbeen.

#### **Contact details**

Rohan Brill rohbri@hotmail.com



# A review of GM canola's first year in SA

#### Andrew Ware<sup>1</sup> and Rebekah Allen<sup>2</sup>.

<sup>1</sup>EP Ag Research; <sup>2</sup>Hart Field-Site Group.

#### Keywords

■ canola, genetically modified, PodGuard<sup>®</sup>.

#### Take home messages

- South Australian growers are generally happy with their first experience growing genetically modified (GM) canola in 2021, with many advisors reporting they expect area planted will increase in 2022.
- Advisors described better than expected weed control (particularly annual ryegrass) in GM canola as the key benefit of growing the crop.
- Other reported benefits included high yielding alternative varieties with different blackleg resistance options, options to manage herbicide residues using varieties with stacked herbicide tolerance, the availability of the PodGuard<sup>®</sup> trait to manage harvest shattering, a smaller than expected price difference to non-GM canola, and good access to receival points.

#### Background

In 2021, South Australian growers had their first opportunity to produce GM canola. Bayer forecast that 11% of the 2021 South Australian canola crop was planted to GM varieties, compared to 37% in WA and 24% in Victoria. This article will explore the key learnings from the 2021 growing season, using trial data and advisor observations from both South Australia and interstate.

#### Advisor Feedback

In preparation for this presentation, we had discussions with a range of agronomists across South Australia about their experiences with GM canola in 2021. A summary of their responses follows:

- GM canola was targeted at paddocks with either high ryegrass populations and/or where ryegrass populations were resistant to clethodim herbicide.
- Weed control generally exceeded expectations, and increased confidence in growing canola as a ryegrass-reducing tool.

- Most growers applied two applications of glyphosate. Planned third applications to TruFlex® varieties proved difficult to fit into the 2021 growing season.
- Ancillary benefits of having access to different major blackleg genes in high yielding varieties and traits such as PodGuard<sup>®</sup> to reduce potential pre-harvest losses were highly valued by many advisors.
- Many advisors are planning to increase the area planted to GM varieties in 2022 and would like to increase use of varieties with stacked herbicide resistance to both glyphosate and imidazolinone chemistry.
- Price differences to non-GM canola and lack of suitable receival points did not appear to impede adoption.

#### Variety Selection

With the removal of the GM moratoria in South Australia, growers and advisors now have access to an additional 21 varieties to plant in 2022 compared to previous seasons. Beyond the 'traditional'



Table 1. Agronomi	c and disea	ise infor	mation f	or current	glyphosa	te-tolerai	nt canola	varieties.			
Variety	Herbicide Tolerance	Туре	Harvest Maturity	Blackleg rating (bare seed)	Blackleg rating (Jockey)	Blackleg rating (ILeVo)	Blackleg rating (Saltro)	Blackleg Group	EPR \$/t	Release	Seed access
BASF 3000TR	TT+ GT (RR)	hybrid	3	MS-S	MR-MS	R-MR	R-MR	В	-	2016	BASF
InVigor <sup>®</sup> LT 4530P	TT + LL	hybrid	4	MR	-	R	-	BF	-	2021	BASF
Hyola <sup>®</sup> Enforcer CT	TT + CL	hybrid	5	R	-	-	R	ADF	-	2020	Pacific Seeds
DG 408RR	GT (RR)	hybrid	4	MS	-	-	-	AC	-	2017	Nutrien
DG Bindo TF	GT (TF)	hybrid	4	R-MR	-	-	-	ABC	-	2021	Nutrien
DG Lofty TF	GT (TF)	hybrid	4	R	-	-	-	ACH	-	2021	Nutrien
Hyola 410XX	GT (TF)	hybrid	4	R-MR	-	-	R	ABD	-	2018	Pacific Seeds
InVigor R 3520	GT (RR)	hybrid	3	MR	-	-	-	Different	-	2017	BASF
InVigor R 4022P	GT (TF)	hybrid	4	MR-MS	-	R	R	ABC	-	2019	BASF
InVigor R 4520P	GT (TF)	hybrid	4	MS	-	R	R	В	-	2020	BASF
InVigor 5520P	GT (RR)	hybrid	5	MR	-	R	-	ABC	-	2016	BASF
Nuseed <sup>®</sup> GT-42	GT (RR)	hybrid	4	R	-	-	-	ABDF	-	2016	Nuseed
Nuseed GT-53	GT (RR)	hybrid	5	R	-	-	-	ABDF	-	2016	Nuseed
Nuseed Condor TF	GT (TF)	hybrid	5	R	-	-	R	ABD	-	2020	Nuseed
Nuseed Emu TF	GT (TF)	hybrid	3	MR-MS	-	-	-	AB	-	2021	Nuseed
Nussed <sup>®</sup> Raptor TF	GT (TF)	hybrid	4	R	-	-	R	AD	-	2019	Nuseed
Pioneer 44Y27 RR	GT(RR)	hybrid	4	MR	R	R	R	В	-	2017	Pioneer
Pioneer 44Y30 RR	GT (RR)	hybrid	4	MR	-	-	-	AB	-	2021	Pioneer
Pioneer 45Y28 RR	GT (RR)	hybrid	5	MR	R	R	R	BC	-	2018	Pioneer
Hyola Battalion XC	GT (TF) + CL	hybrid	4	R	-	-	-	ADF*	-	2021	Pacific Seeds
Hyola Garrison XC	GT (TF) + CL	hybrid	5	R	-	-	R	ADF	-	2020	Pacific Seeds

Harvest maturity key: 3 = early, 4 = early-mid and mid-early, 5 = mid, 6 = mid-late, winter = very late (information provided by seed companies). Technology key: GT = Glyphosate Tolerant, TF = TruFlex, RR = Roundup Ready, LL = Liberty Link® (glufosinate tolerant), \* = Provisional rating. Blackleg resistance rating key: R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, VS = very susceptible. Adapted from: Ware, A (2021) Canola: 2022 South Australian Crop Sowing Guide pp. 53.

Roundup Ready<sup>®</sup> varieties, current varieties now include TruFlex technology, providing an increased window for post-emergent herbicide application, varieties with stacked herbicide tolerance of triazine/ glyphosate and imidazolinone/glyphosate herbicide technology, and varieties with tolerance to triazine and glufosinate and varieties with the PodGuard trait, that has the potential to reduce pre-harvest losses (Table 1).

The current range of GM varieties offers a spectrum of flowering and maturity times that suit most of the canola growing areas in South Australia.

Over the past 3–4 years, in some of South Australia's most intensive canola growing regions, large areas have been planted to cultivars with Group B blackleg resistance. This has placed considerable pressure on the Group B blackleg group, with foliar fungicide applications needed to manage disease levels. Alternative major blackleg resistance genes in high yielding GM varieties have the potential to reduce this pressure and are seen as another consideration factor in variety choice. High canola prices are driving large increases in the area planned to be planted to canola in 2022. This is putting considerable pressure on seed supply for 2022, with seed supply of many popular varieties sold out early.

#### PodGuard

Shattering tolerance is highly valued in many of South Australia's canola growing areas, as they are frequently subject to strong wind events during crop maturity. Windrowing has offered a successful strategy to reduce pre-harvest losses but can be an expensive and time-consuming process at a busy time of the year.

Many canola breeding companies in Australia have selection processes where they select for lines with increased tolerance to shattering, but at the moment BASF is the only company utilising this trait in the form of PodGuard. This trait is currently available in some of their GM canola varieties.





**Figure 1.** Harvested seed yield of four canola varieties near Esperance in 2015, at three harvest timings, with corresponding weather data (Source: M Seymour, DAFWA).

Considerable research, funded by GRDC, in both NSW and WA has found that varieties with the PodGuard trait have superior shattering tolerance to other commercially available varieties (data displayed in Figure 1).

However, research conducted by NSW DPI as part of the GRDC-funded Optimised Canola Profitability Project found that delaying harvest too long beyond maturity will result in losses of grain size (and yield), meaning that timely harvest of canola is still important even when shattering risk is reduced.

#### Herbicides and weed control

To adhere to Bayer's licence stewardship agreement, growers must only use registered formulations of glyphosate at rates and crop growth stage timings that meet label requirements.

To maximise weed control in GM canola, the use of herbicides with other modes of action, beyond just glyphosate, is an important strategy to reduce pressure on glyphosate and ensure escapes of weeds such as annual ryegrass (ARG) are minimised.

This can be done through the use of preemergent herbicides and through the use of postemergent mixtures.

Experience in 2021 demonstrated the importance of these strategies. Wind events during the 2020 harvest, resulted in considerable quantities of

grain being shaken onto the ground and still being present at seeding in 2021. The break of the season was patchy in some parts of the state, leading to staggered canola and annual ryegrass germinations. This resulted in considerable cereal emerging with canola and ARG over a three—four week period.

Application of effective pre-emergent herbicides were able to reduce pressure on post-emergent applications.

The incorporation of tank mixes to GM canola at the 2-4 leaf timing, such as clethodim (Group 1) also provided effective control of ARG weeds and included an additional mode of action into the spray program, reducing the potential for development of metabolic resistance to glyphosate (Group 9) herbicides. Previous research conducted has also shown that many populations of ryegrass can have resistance to either clethodim, glyphosate or both herbicides (Boutsalis et al. 2021). Pot studies conducted showed that tank mixes of 1.15L/ha of Roundup Ready<sup>®</sup> PL and 500mL/ha Clethodim 240 displayed effective control across most populations tested, with control of ARG averaging 95% compared to 73% for standalone glyphosate and 79% for standalone clethodim (Boutsalis et al. 2021).

The wider application window that is possible with TruFlex varieties also proved valuable in 2021; where staggered germination had some plants larger than the 6-leaf at the planned 2nd application



timing, exacerbated by high wind and rainfall events (and hence spraying opportunities) during June/July.

#### Conclusion

Growing GM canola varieties does provide benefits beyond the traditional herbicide tolerance traits that South Australian growers have accessed previously. However, to make the production of GM canola stack up financially against the other herbicide tolerance trait varieties, growers will need to capitalise on the benefits to account for reduced grain prices and technology fees.

#### 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. GRDC funded NVT data will be discussed as part of the presentation, long term yield data from the 2021 growing season wasn't available at the time of writing. The feedback from many South Australian advisors of their observations on GM canola production in 2021 was critical to the writing of this article. The SAGIT funded project: "Variety selection and weed management options for genetically modified canola", will be further discussed as part of the presentation. Thanks to Mark Seymour for providing the harvest loss data from the trial at Esperance. The trial at Esperance was completed as part of GRDC DAW00227. BASF have provided internal data on the PodGuard® trait. Bayer CropScience provided local trial observations and National canola statistics.

#### References

Boutsalis P, Kleeman S, Preston C (2021) Canola technologies and herbicide resistance. 2021 Hart Field Day Guide, 62-65.

The National Variety Trials program (https://nvt.grdc.com.au)

Introducing TruFlex canola (www.roundupreadycanola.com.au)

#### **Contact details**

Andrew Ware EP Ag Research 7 Seaton Ave., Port Lincoln SA 5606 0427 884 272 andrew@epagresearch.com.au @Ware\_AH

Rebekah Allen Hart Field-Site Group 155 Main North Rd., Clare SA 5453 0428 782 470 rebekah@hartfieldsite.org.au



# GRDC SOUTHERN Grains Research Update Series

# FEBRUARY 2022 LIVESTREAM PROGRAM

NB. All times are Australian Eastern Daylight Savings Time (AEDT).

#### Program Day 3 – Latest in weed management

### Thursday 10 February, 9am AEDT

Start Fin time tim	nish ne	Торіс	Presented by
9:00 9:0	05	Welcome/Introduction to day three	GRDC Representative
9:05 9:3	35	Herbicide residues - how do we know what's there?	Mick Rose, NSW DPI
9:35 10:	:05	Advances in weed recognition	<b>Michael Walsh,</b> University of Sydney
10:05 10:	:35	Tackling barley & brome grass head on	<b>Ben Fleet,</b> University of Adelaide
10:35 10:	:50	Morning Tea Break	
10:50 11:2	20	Herbicide tolerant traits for pulses and chemical regulation	Gordon Cumming, GRDC
11:20 11:5	50	Seed destruction when using a stripper front - does it work?	<b>Michael Walsh,</b> University of Sydney
11:50 12:	:20	Putting new pre-emergent formulations through their paces	<i>Chris Preston,</i> University of Adelaide
12:20 12:	:50	Random weed survey & glyphosate management	<i>Peter Boutsalis,</i> <i>Plant Science Consulting</i>
12:50 13:0	:00	Close and evaluation	GRDC Representative





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# Soil and plant tissue testing for herbicide residues – how can it help?

# Michael Rose<sup>1</sup>, Lukas Van Zwieten<sup>1, 2, 3</sup>, Annie Ruttledge<sup>4</sup>, Terry Rose<sup>3</sup>, Kelly Angel<sup>5</sup>, Amanda Cook<sup>6</sup>, David Minkey<sup>7</sup>, Win Win Pyone<sup>8</sup>, Richard Bell<sup>8</sup> and Michael Widderick<sup>4</sup>.

<sup>1</sup>NSW DPI, Wollongbar NSW; <sup>2</sup>Cooperative Research Centre for High Performance Soils (Soil CRC), Callaghan NSW; <sup>3</sup>Southern Cross University, Lismore NSW; <sup>4</sup>QDAF, Toowoomba Qld; <sup>5</sup>Birchip Cropping Group; <sup>6</sup>SARDI, Minnipa SA; <sup>7</sup>WANTFA; <sup>8</sup>Murdoch University.

#### GRDC project code: US00084

#### **Keywords**

■ carryover, herbicide, plant-back, residual.

#### Take home messages

- Herbicide residue levels can be measured in soil, but to interpret what soil analysis results mean for the subsequent crop, information about how the soils were sampled, how the samples were analysed, crop toxicity thresholds, and soil-specific herbicide availability is needed.
- Soil analysis can provide an extra layer of information for decision making prior to sowing, but there will always be uncertainty in interpreting potential crop effects due to in-paddock variation, environmental conditions, and cultivar-specific tolerances.
- Soil analysis for herbicide residues is not a replacement for using herbicides according to label requirements.
- Leaf tissue testing for herbicide residues can also assist in diagnosing potential causes of poor crop performance.

#### Background

Ongoing adoption of new cropping, soil management and herbicide-use practices mean that growers and advisors continue to encounter challenges related to herbicide carryover in soil. New practices include early sowing, which can shorten the window for herbicide break-down; deep-ripping or soil inversion, which can change herbicide mobility and position in the soil profile; and use of new herbicide formulations where there is uncertainty around herbicide behaviour.

Accurate prediction of when herbicide residues will cause crop damage is related to several factors:

 Crop toxicity thresholds, which provides a measured concentration of herbicide in soil (for example, mg herbicide per kg of soil) that causes crop damage, are not well known.

- The bioavailable levels of herbicides (namely, how much the plant roots actually access) will vary from soil to soil, depending on herbicide and soil chemistry, and soil water content. Current soil tests nearly always report total, rather than (bio)available, herbicide residue concentrations.
- Other environmental factors can influence the herbicide toxicity, including weather conditions (for example, frost), soil properties (for example, micronutrient availability) and plant-specific characteristics (for example, cultivar tolerance).
- In most cases, more than one herbicide is usually detected in soil, and synergistic or antagonistic effects of these combinations remain unknown.



#### Considerations for soil analysis

#### Soil sampling

#### Where (and how many)

Determining where to take soil samples, and how many samples should be taken, is a challenge for all soil properties, not just herbicide residues. However, the high cost of herbicide residue analysis, which can exceed \$100-400 per sample, increases the need for a targeted sampling strategy to give the required information. Previous work has shown that herbicide residue concentrations at points across a single paddock often vary by a factor of three and sometimes vary by more than an order of magnitude (see Figure 1 for an example). This is because of differences in soil texture, organic matter, pH, physical properties and slope which influence herbicide breakdown and leaching or lateral movement through the soil.

Therefore, it is recommended that sampling be conducted at a **minimum** of two locations within a paddock. For example, one sample could be taken from an area known to display higher productivity and one from an area known to have lower productivity; or within a dune-swale system, samples could be from dune, swale and seepage areas. Each sample submission to the laboratory should be a composite of at least three subsamples from within the area of interest (Figure 2). Sampling depth should also be considered. Research to date has shown that samples taken from 0-10cm will normally have the highest herbicide concentration. We would currently recommend that samples be taken from three depths: 0-10cm, 10-20cm and 20-30cm. However, leaching to depth may also occur under some circumstances, and if residues at depth are of interest (for example, planning soil inversion to >30cm, sharp texture contrast in soil profile between 30-60cm), then sampling should be designed to target these soil profile sections.

Some additional considerations about where to sample could include location within the crop row or in the inter-row of the previous crop. The concentration may vary depending on which herbicide is of interest, and how it was applied. Some pre-emergence herbicides that are incorporated by sowing, for example trifluralin, may be more concentrated in the interrow of the previous crop, which may have implications if the subsequent crop is to be sown in this zone.

#### When to sample

The timing of sampling is important for decision making. Factors to consider include:

• The time between sampling and sowing, as residue concentrations may decline during this period, particularly if conditions are warm and wet.

	Grid	OC (%)	pH (CaCl <sub>2</sub> )	Imazapyr (ng/g)	Imazapic (ng/g)
	1	1.1	6.1	2.4	5.4
	2	0.66	6.1	tr	3.6
	3	1.2	7.7	<lod< th=""><th><lod< th=""></lod<></th></lod<>	<lod< th=""></lod<>
1	4	0.79	5	1.6	tr

**Figure 1.** Soil organic C (%), pH and herbicide residues in soil samples from 0-10cm depth taken across a paddock in the Victorian Mallee prior to sowing, April 2021. Each sample point was a composite of 3 subsamples. LOD = limit of detection (0.5ng/g); tr = trace levels detected (0.5-1.0ng/g).





**Figure 2.** Suggested **minimum** sampling scheme for measuring soil herbicide residues. Note: actual sampling scheme should be designed to answer questions of interest to grower/advisor, considering spatial and vertical variations in soil/landscape features.

• The turnaround time for sampling, despatch, laboratory analysis and reporting of results. Enough time between sampling and sowing is required to be able to receive results and make decisions about sowing. This may be between 3-6 weeks.

#### Sample handling

Once samples (about 500g) are taken, they should be refrigerated as quickly as possible and then frozen. This minimises changes to herbicide concentration through microbial breakdown. This is particularly important if soil is moist/wet during sampling. Samples should be couriered to the testing laboratory in an esky or styrofoam box with ice bricks to ensure samples are cool during transport.

#### Laboratory analysis

Several laboratories around Australia have the capability to analyse for herbicide residues in soil and plant tissue. NATA accreditation ensures that results are reported based on laboratory procedures that have been certified for accuracy and precision for particular tests. Because of the large number of herbicides in use and potential environmental matrices (for example, soil, grain, leaf, water), it is possible that tests for some herbicide-matrix combinations are not available in Australia. It is worth contacting the laboratory to enquire about some specifics of the testing, including:

- Cost and ability to analyse single herbicide actives; classes of herbicides (for example, all imidazolinone herbicides); or full multi-residue herbicide analysis (namely, many herbicides across multiple classes). Generally, growers/ advisors should have knowledge of the paddock spray history for at least the last two years or have an idea about which herbicide residues are of interest based on previous experience, or physiological symptoms if a post-emergence leaf test is required. This information can be used to inform the laboratory about which herbicide tests are required. Most testing laboratories will have the capability to conduct multi-residue analysis (namely, many herbicides across multiple classes) but this may increase the cost.
- The limit of detection/quantification/reporting of the test. For soil or plants, results will usually be reported in units of mg of herbicide per kg soil/ plant dry weight (mg/kg, which is equivalent to parts per million, or ppm). Note that 0.001mg/ kg = 1µg/kg = 1ng/g. This is important because some laboratories may only report at levels ≥0.01mg/kg, which may be above the toxicity threshold. That is, the laboratory may report 'below limit of reporting' or '<LOR', which does not necessarily mean the herbicide of interest is not present. Some herbicides, including sulfonylureas, imidazolinones and clopyralid,</li>



may be detrimental to certain crops at levels  $\leq 0.001 \text{mg/kg}$ .

 Method 'recoveries'. Some herbicides bind more strongly to soil than others or can be conjugated and unavailable for direct extraction in plant tissues (for example, phenoxy herbicides). It is worth enquiring if the lab will conduct a routine recovery test for a batch of samples, where a known amount of the target herbicide is spiked into the soil and the % recovery reported. This will provide extra confidence that the result reported are a true reflection of the amount of herbicide in the sample.

# Interpretation of results: Toxicity thresholds and bioavailability

Laboratories will generally report 'total' extractable herbicide in a sample. Probably the greatest challenge for growers and advisors is interpreting what this number means in terms of crop growth and yield. Unlike other soil characteristics and nutrition, there is much less publicly available information on herbicide toxicity thresholds. We have recently compiled a register of herbicide dose-response thresholds for major grain crop seedlings in Australia from peer-reviewed studies and toxicology databases, which is currently in review for publication. In addition, we have generated dose-response toxicity curves for several crops exposed to residues of imazapic, imazapyr, diuron, pyroxasulfone and clopyralid in different soil types. This data is currently being used to develop risk models and can be available for assessing potential risk after herbicide residue analysis.

Toxicity thresholds for soil-borne herbicide residues are regulated by the capacity of the soil to bind, or 'tie-up', the residues through a process known as sorption. The extent to which sorption can reduce the bioavailability of herbicide residues is influenced by the herbicide properties, soil properties, soil moisture and plant characteristics. For many herbicides, soil organic matter and clay content will be the major drivers that affect bioavailability, but for other herbicides, pH or soil mineralogy can be the major drivers (Table 1). Thus, when interpreting a laboratory herbicide analysis result, the client should attempt to compare the lab result against a toxicity threshold that was generated in a soil with similar characteristics (primarily soil organic C, pH and % clay) to the field soil that was analysed. Due to the lack of toxicity thresholds available, this will not always be possible. We are currently working on a tool that can help estimate soil-specific thresholds for certain herbicides based on the soil properties listed above or using midinfrared spectroscopy.

# Case-study: diagnosing the cause for poor seedling growth in early sown wheat, northern NSW

#### Background and methods

A number of growers in northern NSW experienced poor growth of early sown winter wheat seedlings in 2021, following chickpea crops in 2020. It was suspected that imazapic used for summer fallow weed control had carried over, despite adherence to label plant-back recommendations. At the case study site, imazapic had been applied at 45g/ha in Oct 2020, and winter wheat was sown in early April 2021 after 350-400mm of rain during this period. Composite soil and leaf tissue samples were taken from three areas of the paddock with healthy crop growth and three areas of the paddock with poor crop growth and analysed for imazapic and other herbicide residues. The soil was a grey vertosol, with pHCaCl2 = 7.5-7.8, OC = 0.5% and clay = 26-29%. Herbicide residues were measured in 5cm increments to 30cm. Results were compared against toxicity thresholds for wheat that had been generated for the Wellcamp soil (Table 1 above).

#### Results

Concentrations of imazapic in the top 0-10cm soil profile from healthy and poor areas were similar, at around 4ng/g (Figure 3). However, imazapic residues in the 10-20cm profile remained at around 4ng/g in

**Table 1.** Imazapic sorption ( $K_d$ ) and toxicity thresholds ( $ED_{20}$ ) for contrasting soil types with different chemical properties. Higher  $K_d$  indicate greater binding to soil. The  $ED_{20}$  is the concentration in soil which causes 20% reduction in seedling biomass.

Soil	pH CaCl₂	Organic Carbon (%)	CEC (cmol/kg)	K <sub>d</sub> (L/kg)	ED <sub>20</sub> (wheat) (ng/g)
Sand	6.6	0.01	1	0.01	11
Applethorpe	6.1	0.6	4.1	0.17	22
Wellcamp	7.8	1.5	72	0.5	26
Kingaroy	5.1	1.8	18	2.19	74



		Healthy			
15	Depth (cm)	Imazapic (ng/g)	Diuron (ng/g)	Simazine (ng/g)	
	0-5	4.1	33.2	8.6	
	5-10	3.7	12.4	5.2	
	10-15	1.3	2.6	0.9	
	15-20	0.5	1.5	3.4	
	20-25	<lod< td=""><td>1.2</td><td>1.8</td></lod<>	1.2	1.8	
	25-30	<lod< td=""><td>1.2</td><td>2.4</td></lod<>	1.2	2.4	
			Poor		
				Cimenting	
	Depth (cm)	Imazapic (ng/g)	Diuron (ng/g)	(ng/g)	
	Depth (cm) 0-5	Imazapic (ng/g) 3.7	Diuron (ng/g) 23.7	(ng/g) 7.3	
	Depth (cm) 0-5 5-10	Imazapic (ng/g) 3.7 4.2	Diuron (ng/g) 23.7 10.7	(ng/g) 7.3	
	Depth (cm) 0-5 5-10 10-15	Imazapic (ng/g) 3.7 4.2 3.5	Diuron (ng/g) 23.7 10.7 3.5	(ng/g) 7.3 5.2 2.4	
	Depth (cm) 0-5 5-10 10-15 15-20	Imazapic (ng/g) 3.7 4.2 3.5 4.7	Diuron (ng/g) 23.7 10.7 3.5 7.9	(ng/g) 7. 5. 2. 3.	
	Depth (cm) 0-5 5-10 10-15 15-20 20-25	Imazapic (ng/g) 3.7 4.2 3.5 4.7 1.7	Diuron (ng/g) 23.7 10.7 3.5 7.9 3.2	Simazine (ng/g) 7. 5. 2. 3. 1.	

**Figure 3.** Photograph of the field showing area of poor and healthy wheat seedling growth (left) and associated herbicide residue concentrations in the soil profiles (right).

the poor soil but declined to an average of 1ng/g in the healthy soil. Nevertheless, the wheat toxicity thresholds for 20% seedling biomass reduction  $(ED_{20})$  in the similar Wellcamp soil type was 26 ng/g, suggesting imazapic per se was not the sole cause for poor growth. Diuron and simazine residues were also found in both healthy and poor areas at similar levels down the profile. A project-generated  $ED_{20}$  value for wheat exposed to soil-borne diuron in the Wellcamp soil was estimated to be 210ng/g, suggesting diuron was also not a primary cause for poor growth. Threshold values for s-triazines have not been a target of our current projects, but two published thresholds for wheat exposed to simazine in a similar alkaline clay soil type were available, with estimated ED<sub>50</sub> values of 10-20ng/g (Kulshrestha et al., 1982). This suggests that simazine may be responsible, at least in part, for the poor wheat growth observed.

Follow-up analysis of wheat leaf tissue confirmed the presence of imazapic and simazine, but not diuron, in wheat plants from both healthy and poor areas (Table 2). Notably, higher concentrations of imazapic and simazine were found in plants taken from the poor area, and simazine was found at significantly higher concentrations than imazapic. This provides further evidence that simazine, rather than imazapic, was a more likely cause for poor wheat growth. The possibility of both actives, and other soil constraints, acting together to cause poor growth cannot be ruled out.

#### Conclusions

Soil and leaf tissue testing for herbicide residues can provide information on plant-back risks and help diagnose the cause for poor crop performance. Careful consideration is required into where and when samples are taken; which herbicides should be analysed and to what levels of detection; and how results are interpreted. Results should be preferably compared to crop toxicity thresholds developed for the crop species and soil of interest; however, this is seldom possible given the scarcity of publicly available thresholds. This project is continuing to develop these thresholds and tools for assessing bioavailability, with information on priority herbicides (imazapic, imazapyr, diuron, clopyralid, and pyroxasulfone) likely available by the end of 2022.

Table 2. Concentration of herbicide residues (ng/g) in wheat leaf tissue sampled from healthy and poor areas of the affected paddock. LOD = limit of detection (1ng/g).						
Wheat plant	Imazapic	Diuron	Simazine			
Healthy	3.7	<lod< td=""><td>135</td></lod<>	135			
Poor	7.4	<lod< td=""><td>610</td></lod<>	610			



#### Acknowledgements

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#### References

Kulshrestha G, Yaduraju NT, Mani VS (1982) The relative toxicity of the S-triazine herbicides - trazine and simazine to crops. *Journal of Environmental Science and Health Part B* **17(4)**, 341-354.

Herbicide behaviour (https://grdc.com.au/ resources-and-publications/resources/herbicidebehaviour)

Herbicide residues in soil – what is the scale and significance? (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/02/herbicide-residues-in-soil-what-is-the-scale-and-significance)

Residue Watch: How do I know if herbicide residues are breaking down before sowing (https://grdc.com.au/resources-and-publications/ grdc-update-papers/tab-content/grdc-updatepapers/2021/07/residue-watch-how-do-i-knowif-herbicide-residues-are-breaking-down-beforesowing)

Soil CRC Webinars (https://soilcrc.com.au/ webinars/)

#### **Contact details**

Michael Rose NSW DPI 1243 Bruxner Hwy, Wollongbar NSW 2477 (02) 6626 1117 mick.rose@dpi.nsw.gov.au @Mick\_T\_Rose



# Advances in weed recognition: the importance of identifying the appropriate approaches for the development of a weed recognition algorithm for Australian cropping

#### Michael Walsh, Asher Bender and Guy Coleman.

University of Sydney.

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#### **Keywords**

■ machine-learning, site-specific weed control, SSWC, weed recognition.

#### Take home messages

- Effective in-crop weed recognition requires many tens of thousands to millions of annotated images of weeds in crop scenarios.
- Weed-AI enables the open-source publication and compilation of annotated weed images.
- A large publicly available annotated weed image database enables the development and introduction of alternative weed control technologies for Australian grain production systems.

#### Background

Widespread herbicide resistance has reinforced the need for alternative weed control techniques in Australian cropping systems. Apart from HWSC (Walsh et al. 2013), there has been a general lack of development of alternative weed control practices suitable for use in conservation cropping systems. Critically, herbicides remain the only option for incrop use during the important early post-emergence phase where weed control is essential for yield preservation. A recent comparison of weed control techniques highlighted the unacceptably high energy requirements of alternative practices when used as conventional "blanket" treatments (Coleman et al. 2019). This research did, however, highlight that there were equivalent energy requirements for chemical and non-chemical techniques when they were applied site-specifically to weed targets. Incrop site-specific weed control (SSWC) does require the development of accurate weed recognition.

Advances in weed recognition capability have created the potential for in-crop SSWC in Australian grain cropping systems. In particular, substantial improvements in computational power and machine-learning (ML) performance have resulted in the development of potentially highly effective RGB camera-based weed recognition systems (Fernández-Quintanilla et al. 2018). These systems are well suited to the complex task of accurate incrop weed recognition that subsequently enables the in-crop site-specific delivery of weed control treatments (Wang et al. 2019). The availability of suitably accurate in-crop weed recognition creates the opportunity to selectively target weeds with non-selective physical and thermal weed control treatments, thereby expanding the options for incrop weed control. Depending on the weed density, a SSWC approach enables growers to reduce inputs of weed control treatments, chemical and nonchemical, by up to 90%, and to lower the agronomic and environmental risks associated with some weed



control treatments (Timmermann et al. 2003). The opportunity for substantial cost savings and the introduction of a wide range of novel control tactics are driving the future of weed management towards site-specific weed control (Keller et al., 2014).

ML-based weed recognition relies on the availability of suitably collected and annotated weed images for the development of recognition algorithms. The performance of in-crop weed recognition algorithms is completely reliant on an appropriate image database of the target weeds in the relevant crops. At present, commercial development of weed recognition algorithms by weed control companies in Australia (for example, Autoweed, Bilberry, Alterratech) necessitates the independent collection and annotation of images of individual weeds for specific crops. It is estimated that, for each of these scenarios, between 10 000 and 1 000 000 suitably annotated images may be required for suitably accurate weed recognition algorithms. The larger and more visually diverse (for example, weather, lighting, growth stage, plant health) the dataset, the better the likelihood that the algorithm will recognise weeds in diverse field conditions. Given that preliminary efforts on Australian grain crop weed recognition algorithm development have achieved only modest levels of accuracy (60%) for simple scenarios, such as brassica weeds in cereals, it is expected annotation requirements will be at the mid to upper end of this estimate (Su et al. 2021). The development of weed recognition capability is an onerous task and a major impediment to individual weed control companies looking to implement site-specific weed control technologies in Australia.

The aims for this research were to:

- develop and evaluate weed recognition algorithms for annual ryegrass (Lolium rigidum), turnip weed (Rapistrum rugosum) and sowthistle (Sonchus oleraceus) in wheat and chickpea crops
- establish an open-source weed recognition library to facilitate the introduction of weed recognition technologies for Australian cropping.

#### Methods

#### Image collection

Approximately 2000 images of wheat and chickpea were collected in Narrabri and Cobbitty (NSW) during the winter growing seasons of 2019 and 2020 with FLIR Blackfly 23S6C and 70S7C cameras. The dataset spans two growing seasons, variable backgrounds, lighting conditions (natural and artificial illumination) and growth stages. The images were annotated with bounding boxes to identify annual ryegrass and turnip weed. The algorithms were trained on 80% of the data with 20% reserved for testing.

#### Algorithm training

To demonstrate cutting-edge object recognition algorithms in weed recognition tasks, we selected three state-of-the-art architectures, You Only Look Once (YOLO) v5 (June 2020), EfficientDet (June 2020) and Faster R-CNN (2015). Object detection algorithms provide both weed location within the image by a box around the weed and the species of weed.

The algorithms were tested on the three data scenarios.

The leading algorithm architecture out of that testing, YOLOv5, was tested at two image resolutions (640 x 640 and 1024 x 1024) and two algorithm sizes (YOLOv5-S and YOLOv5-XL). YOLOv5-S has 7.3 million parameters and YOLOv5-XL has 87.7 million parameters. The theoretical advantage of larger networks is their ability to learn richer and more subtle structures from the data. The practical disadvantage is that these algorithms require more data to train and more memory and computations to execute. As a result, we were unable to train the YOLOv5 XL algorithm on the 1024 x 1024 image size from lack of available memory.

It is important to draw conclusions about network size and image resolutions amongst comparable algorithms. The architecture of an object detector can have an impact on its 'efficiency' of performance. The Faster R-CNN object detector with a ResNet-50 backbone is the second largest algorithm with 41.5 million parameters. Despite having a theoretical size advantage, five years of research and algorithm innovations have produced more compact networks with higher performance, such as YOLOv5.

#### Understanding weed recognition performance

Determining the performance of recognition algorithms is a nuanced task, not simply a case of measuring the number of times the algorithm correctly finds a weed. In cases where weeds are extremely rare, a classifier that never detects any weeds will be right most of the time and measure as highly accurate, where accuracy is how many correct detections are made. Yet, this classifier will produce false negatives wherever weeds are missed. Conversely, if an algorithm always detects





**Figure 1.** Diagrammatic explanation of intersection over union (IoU) metric that is used to identify the localisation accuracy performance of a recognition algorithm.

weeds, it will never miss a weed but it will produce many false positives, where the background is incorrectly labelled as a weed, resulting in poor accuracy. Algorithms that are more sensitive and label all objects as weeds will have a high recall (lots of false positives) but because they are incorrect much of the time, will have low precision. On the other hand, models that are less sensitive and miss more weeds and only pick out clear examples will have a low recall (lots of misses) but will likely have very high precision. Knowing both of these values helps describe how well an algorithm is working.

Measuring performance in object detection is complicated further by the requirement to give a position of the weed within the image. Whilst accuracy, precision and recall measure the performance of correct-vs-incorrect classifications (namely, weed vs. no weed), they do not measure how well the algorithm has located the weed within the image. The performance of localisation is measured using intersection over union (IOU) (Figure 1). This measures the similarity between the location of a ground-truth weed bounding box and a predicted bounding box.

Bringing precision, recall and IoU together, mean average precision (mAP) is used as a more robust way of determining algorithm performance. This is done by calculating the precision and recall of the object detector at various localisation (IoU) thresholds and returning an averaged result. Note that although mAP rather misleadingly implies that only precision is accounted for, both precision and recall are used within the calculation. In short, mAP measures how well an object detector generates relevant detections (balanced precision and recall) and how well these detections are localised. The measure ranges from 0 to 1, with state-of-the-art algorithms producing a mAP of up to 0.5 on difficult datasets.

#### Results and discussion

Weed type, background crop type, algorithm size and image size influenced algorithm performance (Table 1). The best performance across all three classes in the combined dataset was YOLOv5 S 1024 x 1024 with a mAP of 0.310. It is likely the YOLOv5 XL trained on 1024 x 1024 images would have outperformed this algorithm based on an S vs XL comparison at the 640 x 640 image size, however, memory constraints meant training this algorithm was not possible. YOLOv5-XL (640 x 640) had a higher performance than YOLOv5-S (640 x 640) in all datasets. The performance advantage across the datasets is minor in most cases, despite YOLOv5-XL being twelve times as large as YOLOv5-S.

With the dataset containing more images of weeds in wheat crops, better performance in detecting annual ryegrass was achieved in the wheat and the mixed wheat/chickpea datasets than the chickpea only dataset. Although annual ryegrass looks very similar to wheat, most of the wheat images were taken in early growth stages where the canopy had not closed. This provided scenes with low background clutter and occlusions. Chickpeas have a sprawling habit with lots of fine leaf structures. This phenotype produces cluttered scenes capable of obscured targets, making object detection more difficult. These two factors contributed to lower annual ryegrass performance in the chickpea dataset.

Changing the size of the image being passed through the object detector network has a bigger effect on performance than algorithm size. In



**Table 1.** Results from YOLOv5 XL, YOLOv5 S, Faster R-CNN ResNet-50 and EfficientDet-D4 deep learning architectures at two different image resolutions, 640 x 640 and 1024 x 1024. Each algorithm was trained on three scenarios, weeds in wheat, weeds in chickpea and weeds in both wheat and chickpea. Mean average precision (mAP) results are reported with inference speed in frames per second (FPS). Cells coloured green indicate better performance. Bolded text indicates highest performance in that scenario. Cells coloured red indicate worse performance and are relative to each dataset.

Context	Algorithm	Image resolution	Approx. parameters (M)	All	Annual ryegrass	Turnip weed	Latency (FPS)
Annual ryegrass and	YOLOv5 XL	640 x 640	87.7	0.28	0.079	0.640	39.5
turnip weed in wheat	Faster R-CNN ResNet-50	640 x 640	41.5	0.178	0.048	0.471	10.6
	EfficientDet-D4	1024 x 1024	19.5	0.184	0.024	0.506	-
	YOLOv5 S	1024 x 1024	7.3	0.300	0.080	0.600	47.0
	YOLOv5 S	640 x 640	7.3	0.273	0.077	0.634	62.7
Annual ryegrass	YOLOv5 XL	640 x 640	87.7	0.136	0.036	0.116	39.5
and turnip weed	Faster R-CNN ResNet-50	640 x 640	41.5	0.058	0.010	0.034	10.6
in chickpea	EfficientDet-D4	1024 x 1024	19.5	0.055	0.011	0.015	-
	YOLOv5 S	1024 x 1024	7.3	0.130	0.050	0.084	47.0
	YOLOv5 S	640 x 640	7.3	0.084	0.023	0.062	62.7
Annual ryegrass,	YOLOv5 XL	640 x 640	87.7	0.288	0.069	0.577	39.5
and turnip weed	Faster R-CNN ResNet-50	640 x 640	41.5	0.139	0.023	0.330	10.6
in wheat and	EfficientDet-D4	1024 x 1024	19.5	0.169	0.020	0.437	-
chickpea	YOLOv5 S	1024 x 1024	7.3	0.310	0.076	0.590	47.0
	YOLOv5 S	640 x 640	7.3	0.264	0.077	0.527	62.7

all cases, YOLOv5-S with 1024 x 1024 inputs outperformed YOLOv5-S with 640 x 640 inputs. YOLOv5-S with 1024 x 1024 was also able to outperform YOLOv5-XL with 640 x 640 inputs in two-thirds of the datasets. This indicates that, for a given network architecture, increasing the image size may have greater benefits than increasing the network size for weed recognition.

#### Development of Weed-Al

Access to a shared repository of suitably labelled in-crop weed imagery with standardised metadata reporting would fast-track the development of weed recognition algorithms for Australian grain cropping systems. Further, it would provide opportunities for machine learning researchers around the world to develop new architectures based on Australian weeds. A close look at currently available open databases and repositories in a wide field of subject areas with varying modes of contribution, access and management were used towards identifying a suitable open-source platform design for weed imagery. This information enabled the definition of data requirements and recommendations for the Weed-Al platform.

# Weed-AI: an open-source platform for annotated weed imagery

Weed-Al fills the data access and metadata standardisation gap, operating on an open-source platform, allowing upload, browsing and download of datasets. Anyone can contribute to the platform, and importantly, the datasets are maintained under the Creative Commons CC-BY 4.0 license with the license held by whoever is specified during the upload process. A major advancement in the standardisation of metadata reporting was the development of the AgContext information, a whole of dataset file that provides information on key attributes (Table 2). Datasets are searchable and indexed by a large selection of the AgContext information. The individual weeds annotated in each image are linked to a scientific name and standardised common name. Weed-Al also supports higher level taxonomical groupings of weed classes to cater for more general categories such as 'grasses' or 'broadleaves'. Often, determining the specific species of a weed is difficult when annotating and weeds are instead grouped at the genus or family level. Together, these tools help standardise contributions of images and annotations.


**Table 2.** Details of the AgContext metadata standard that is required for every dataset uploaded to WeedID. This information is on a whole-of-dataset level and should be filled out as representative of the averages for each field for the entire dataset. The web form can be accessed here: https://weed-ai.sydney.edu.au/editor

AgContext JSON ID	Entry Options	Description
crop_type	Grain crop (one of 18 pre-filled options)	Details the dominant crop type in the images uploaded.
	Other crop	
	Not in crop (pasture or fallow)	
bbch_growth_range	Minimum to maximum growth stage range	Two values that describe the crop growth stage.
	using the BBCH scale.	
soil_colour	not visible, black, dark brown, brown, red brown,	Generalised description of the visible soil colour in the images based
	dark red, yellow, pale yellow, white, grey	on the Mansell scale.
surface_cover	Cereal, oilseed, legume, cotton, black plastic,	Background surface cover and type visible behind any plants. Where
	white plastic, woodchips, other, none.	a stubble is present, select a likely crop (for example, cereal, oilseed
		or legume).
surface_coverage	Per cent cover:	An estimate of the per cent cover of the soil/background by the
	• 0–25%	surface_cover variable provided above.
	• 25–50%	
	• 50–75%	
	• 75–100%	
weather_description	Describe key features of the weather during	Sunlight and shadows can have large impacts on image data.
	collection. Include details such as:	Capturing this information is important to cover all different
	• Time of day	detection conditions.
	• Sunlight (cloudy, intense, overcast)	
location_lat	Latitude – decimal degrees	Location of where the dataset was collected including the latitude,
		longitude and the datum used.
location_long	Longitude – decimal degrees	
location_datum	EPSG code for the spatial reference system used.	
camera_make	Free text	Include details on the make/model of the camera used in collection.
		For phone cameras, include the phone type/brand as well.
camera_lens	Free text	Include details on camera lens make/model.
		Phone cameras should have lens information available online. If not
		available, simply include phone make/model.
camera_lens_focallength	Integer	Focal length of the camera/lens.
camera_height	Integer	Image collection height in millimetres (mm) above ground.
camera_angle	Integer	Image collection angle (degrees from horizontal). For example, a
camera pointing straight do	wn would be 90 degrees.	
camera_fov	Integer (1 – 180)	A number representing the angle captured by the camera across the
		diagonal of an image, measured in degrees.
photography_description	Free text	Provide a general description of the data collected. Any important
		information that would be useful or is critical to the dataset that
		was missed.
cropped_to_plant	True/False	Are the images cropped to every plant?

Contributing to Weed-AI is straightforward, with the five-step process listed below (summarised here https://youtu.be/Eg8yxG-mCUc):

- Collect images.
- Annotate images in COCO or VOC format.
- Complete the AgContext file (https://weed-ai. sydney.edu.au/editor).
- Complete the metadata file (https://weed-ai. sydney.edu.au/meta-editor).
- Upload via the Weed-Al uploading tool (https:// weed-ai.sydney.edu.au/upload).

Following successful upload, a review stage helps maintain the quality of the uploaded data. There are currently 12 datasets uploaded covering image classification and bounding box annotations with a



total 18,367 images. Crops include wheat, chickpea, canola, lupins and cotton with weeds such as annual ryegrass, turnip weed, wild radish, blue lupins and sowthistle.

#### Conclusion

The fundamental component of an effective weed recognition algorithm is the quality and quantity of the image data it is provided. Preliminary results for the recognition of annual ryegrass and turnip weed in wheat and chickpea highlight the difficulty of weed recognition in crop scenarios. Weed-Al is an important tool to address this data gap, providing an entirely open-source opportunity for the upload, searching and download of weed image data for the development of Australian-relevant weed recognition algorithms.

#### 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.

#### References

Coleman GRY, Stead A, Rigter MP, Xu Z, Johnson D, Brooker GM, Sukkarieh S, Walsh MJ (2019) Using energy requirements to compare the suitability of alternative methods for broadcast and site-specific weed control. *Weed Technology* **33(4)**, 633-650.

Fernández-Quintanilla C, Peña JM, Andújar D, Dorado J, Ribeiro A, López-Granados F (2018) Is the current state of the art of weed monitoring suitable for site-specific weed management in arable crops? *Weed Research* **58(4)**, 259-272.

Keller M, Gutjahr C, Möhring J, Weis M, Sökefeld M, Gerhards R (2014) Estimating economic thresholds for site-specific weed control using manual weed counts and sensor technology: An example based on three winter wheat trials. Pest Management Science 70:200-211

Su D, Qiao Y, Kong H, Sukkarieh S (2021) Real time detection of inter-row ryegrass in wheat farms using deep learning. *Biosystems Engineering* **204**, 198-211.

Timmermann C, Gerhards R, Kühbauch W (2003) The economic impact of site-specific weed control. *Precision Agriculture* **4(3)**, 249-260. Walsh MJ, Newman P, Powles S (2013) Targeting weed seeds in-crop: a new weed control paradigm for global agriculture. *Weed Technology* **27(3)**, 431-436.

Wang A, Wei X, Zhang W (2019) A review on weed detection using ground-based machine vision and image processing techniques. *Computers and Electronics in Agriculture* **158**, 226-240.

#### **Contact details**

Michael Walsh Werombi Road, Brownlow Hill NSW 2570 0448 847 272 m.j.walsh@sydney.edu.au







### Advances in controlling brome and barley grass

#### Gurjeet Gill and Ben Fleet.

University of Adelaide.

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#### **Keywords**

barley grass, brome grass, herbicide resistance, seed dormancy.

#### Take home messages

- Our research has shown large differences in seed dormancy between brome and barley grass populations. High seed dormancy populations are more difficult to control with pre-sowing knockdown herbicides and delayed crop sowing.
- Brome grass seedbank tends to persist for three years and barley grass for two years. Therefore, single year management programs are unlikely to prevent rebound in populations of these weeds.
- Presence of resistance to group 1 (A) herbicides is still relatively low but in some regions resistant populations have been responsible for control failures.
- Integration of higher crop densities (seed rate) with effective herbicide options has been consistently successful in minimising crop yield loss and reducing weed seed set of brome grass.

#### Aims

- To identify weed traits responsible for increasing incidence of brome and barley grass in cereal crops in southern Australia.
- Quantify benefits of integrating non-chemical tactics such as sowing time and crop density with herbicides to improve weed control.

#### Introduction

Brome grass has climbed to be the fourth worst weed of grain crops in Australia in terms of the area infested, as well as yield and revenue loss (Llewellyn et al. 2016). Barley grass has also increased in importance to become one of the top 10 weeds of Australian cropping. In this survey, barley grass was ranked as the seventh most costly weed to control by the growers in SA and VIC Mallee and Mid-North, Lower Yorke and Eyre Peninsula. Given the increasing importance of these two grass weeds, it is important not only to understand why they have been increasing in grain crops but also to determine how they could be managed more effectively. Research on understanding biological factors responsible for increasing incidence of these weeds has focused on changes in seed dormancy in response to cropping intensity and persistence of their seedbank. Research is currently underway to determine how integration of non-chemical factors could be used to enhance weed control with herbicides.

#### Method

#### Seed dormancy

Barley grass populations from the low rainfall zones in New South Wales, Victoria, South Australia and Western Australia were collected during the summer of 2018. In this random survey, a total of



143 samples were collected from grower paddocks in this region. Seeds of barley grass samples were removed from panicles and sown by weight (2g per tray) into seedling trays filled with potting mix in the first week of April. Seedling trays were placed outdoors at Roseworthy (SA) to experience natural rainfall and temperature conditions. There were 2 replicates of each barley grass population. Weed seedlings were counted and removed throughout the growing season in order to determine seedling emergence pattern (that is, dormancy). Cumulative seedling emergence data were analysed in GraphPad Prism. An identical experimental approach was used to assess differences in seed dormancy between in-crop and non-crop populations of brome grass collected from growers' fields in 2015.

#### Seedbank persistence

Seeds of barley grass and brome grass populations were placed in soil in micro-plots and seedling emergence was recorded regularly in subsequent seasons. Field sites for seedbank persistence were established at Karoonda (low rainfall), Roseworthy (medium rainfall) and Tarlee (high rainfall). Absence of new weed seedling emergence for the whole growing season was considered an indication of complete exhaustion of the weed seedbank.

#### Herbicide resistance

Barley grass populations (n=143) collected from the low rainfall zones in New South Wales, Victoria, South Australia and Western Australia in the summer of 2018 were tested for resistance to all major groups of herbicides used for selective and nonselective weed control. Herbicides were used at the recommended field rate. This included quizalofop and clethodim (group 1 (A)), imazamox + imazapyr (group 2 (B)), glyphosate (group 9 (M)) and paraquat (group 22 (L)). Plants that produced new growth after herbicide treatment were rated as resistant to that herbicide.

#### Brome grass management

Each year since 2018, three field trials have been undertaken to investigate the effect of crop sowing time, seed rate and herbicide treatments on brome grass control, weed seed set and crop yield. In this paper, we have presented results of two field trials were undertaken in SA in 2019 to investigate brome grass management in Razor CL Plus<sup>(b)</sup> Clearfield<sup>®</sup> wheat (Table 1).

#### Results

#### Seed dormancy

Based on extensive research over the last 10 years, it is clear that higher cropping intensities select for greater seed dormancy. Initial evidence for this trend emerged in brome grass collected from fence lines and adjacent cropping fields at Warner Town in SA. Since then, further research has confirmed similar trends in many other brome grass and barley grass populations. Essentially, all weed populations possess individuals with different levels of seed dormancy (that is, genetic variation). Management systems (for example, cropping) that effectively kill early germinating weeds (low dormancy) tend to increase seed dormancy in weed populations. Conversely, systems that allow all individuals to survive and set seed (for example, pastures or fence lines) maintain lower levels of seed dormancy. Results from one of our recent studies can be used to highlight this principle. Recently, we identified two barley grass populations with contrasting seed dormancy from Upper Eyre Peninsula. Population SEP-AC3 came from a paddock with low cropping frequency whereas

Table 1. Management information for brome grass trials undertaken in 2019.					
Detail	Mallala	Riverton			
Crop (variety)	Wheat (Razor CL Plus $^{(1)}$ )	Wheat (Razor CL Plus <sup>()</sup> )			
Sowing date	TOS 1: 16 May 2019	TOS 1: 16 May 2019			
	TOS 2: 31 May 2019	TOS 2: 31 May 2019			
Crop seed rate	100, 150 or 200 seeds/m <sup>2</sup>	100, 150 or 200 seeds/m <sup>2</sup>			
Herbicides	1. TriflurX <sup>®</sup> 2L/ha + Avadex <sup>®</sup> Xtra 2L/ha	1. TriflurX 2L/ha + Avadex Xtra 2L/ha			
	2. Sakura® 118g/ha + Avadex Xtra 2L/ha IBS	2. Sakura 118g/ha + Avadex Xtra 2L/ha IBS			
	3. TriflurX 2L/ha + Avadex Xtra 2L/ha fb	3. TriflurX 2L/ha + Avadex Xtra 2L/ha fb			
	Intervix® 750mL/ha post	Intervix 750mL/ha GS14			
Growing season rainfall (mm)	229	267			

Active ingredients: Sakura = 850g/kg pyroxasulfone; Avadex Xtra = 500g/L

triallate; TriflurX = 480g/L trifluralin; Intervix = 33g/L imazamox + 15g/L imazapyr

time of sowing (TOS); incorporated by sowing (IBS); growth stage (GS); followed by (fb)



SEP-KV2 was from a paddock with high cropping frequency (Figure 1). These populations showed more than three-fold difference in time required for 50% seed germination (13 days vs 46 days). These results clearly show how management practices within a region can have a large influence on seed dormancy of weed populations. From a practical viewpoint, populations with high seed dormancy will have a slow and staggered weed establishment, which will reduce effectiveness of pre-sowing knockdown herbicides and possibly of some preemergent herbicides as well.

As a group, populations from the southern plains of New South Wales (NSP) were the quickest to germinate and emerge due to low seed dormancy  $(t_{50} = 8.9 \pm 1.08 d)$ . This is in contrast to barley grass populations from the Upper Eyre Peninsula in SA (SEP), which had the highest  $t_{50}$  (32.6 ± 3.17d). The average  $t_{50}$  for the other regions ranged from 13.2d for the central plains of New South Wales (NCP) to 18.5d for the populations from the Victorian and SA Mallee. The average  $t_{50}$  for WA populations ranged from 13.8 to 17.7d. Within most of the regions, there were sizable differences between the least and the most dormant populations. Therefore, management practices used in the paddocks where these samples were collected also appears to have influenced the seed dormancy status of barley grass.

#### Seedbank persistence

#### Brome grass

Field studies at three different locations in SA showed that the brome grass seedbank can persist for three years even though most of the seedling establishment occurs within the first year after seed dispersal. Karoonda SA, with sandier soils and a lower rainfall, showed greater persistence of the initial seedbank into the second and third year than sites with greater rainfall and heavier textured soils (Roseworthy and Tarlee SA). Similar pattern of seedbank persistence was observed at Wongan Hills WA. These results are consistent with previous studies which showed that a 3-year effective management program can deplete field populations of this weed species.

#### Barley grass

Seedbank persistence of barley grass was investigated in SA at three field sites (Karoonda, Roseworthy and Tarlee). At the site with the highest rainfall (Tarlee), barley grass emergence only occurred in year one, which indicates that remaining seed had decayed by the second growing season. At Roseworthy (medium rainfall), there was only 0.2% emergence from the initial seedbank in year two and no emergence was observed in year three and four. Karoonda, which has the lowest rainfall out of the three SA sites, showed much greater seedling



**Figure 1.** An example of contrasting seed dormancy in two barley grass populations collected from the Eyre Peninsula of SA in 2018. Time taken to 50% seedling emergence ( $t_{50}$ ) was 13d in SEP-AC3 and 46d in SEP-KV2. Large differences in seed dormancy within the same region are likely to be related to differences in weed management practices between the two paddocks.



emergence in year two (12%) than the other two sites. Even at Karoonda, there were no barley grass plants observed in year three and four of this study. Therefore, the barley grass seedbank in SA appears to be completely exhausted after two years. These results are consistent with the results from WA, where most of the seedlings at these sites emerged in year one. However, there was some barley grass establishment observed in WA trials even after three to four years. These results again highlight the difficulty in completely exhausting weed seedbanks in a single year and the need for a twoyear management program incorporating rotations and herbicides.

#### Herbicide resistance

All populations of barley grass collected in NSW and Victoria were susceptible to the four herbicide groups used in the resistance screening (Figure 2). However, some samples from SA and WA showed resistance to group 1 (A) and 2 (B) herbicides. Resistance to the SU herbicide Atlantis® OD was identified in 16.1% of the populations tested. The presence of resistance to the imidazolinone herbicide Intervix was relatively low (1.4%). Resistance to the FOP herbicide quizalofop (Leopard®) was detected in 4.2% of the barley populations tested. Four of these populations came from the Upper Eyre Peninsula in SA and two from WA. Survivors of this herbicide were vigorous and showed no inhibition in growth. There is no doubt that presence of resistance to group 1 (A) and 2 (B) herbicides in the southern and western region will complicate management of barley grass in break crops and pastures. There was no resistance detected to glyphosate or paraquat in barley grass samples in this survey. However, a subsequent survey in 2021 has identified populations with resistance to paraquat and glyphosate.

Based on resistance testing of barley grass over the last three years, it can be stated that the overall level of herbicide resistance is still low but there are some regions such as Upper Eyre Peninsula where resistance levels are higher than other regions. However, herbicide resistant populations were also detected in WA and VIC. Similarly, herbicide resistance in brome grass remains at a much lower level than in annual ryegrass. However, some populations with resistance to group 1 (A), 2 (B) and 9 (M) have already been identified. Therefore, growers facing unexpected herbicide failures should send their seed samples to commercial laboratories for resistance testing.

#### Brome grass management

A two-week delay in sowing reduced brome grass density by 82% at Riverton as compared to a 38% reduction at Mallala. As both sites received



**Figure 2.** Detection of resistance to different herbicide groups in a random survey of barley grass (n=143). SU = Atlantis OD (group 2 (B)); IMI = Intervix (group 2 (B)); FOP = quizalofop (Leopard, group 1 (A)); Glyphosate = Weedmaster® DST® (group 9 (M)); Paraquat = Para-Ken (group 22 (L)). R = resistant (>20% survival) and DR = developing resistance (6-19% survival).



very similar rainfall during the month of May, the differences in effectiveness of delayed sowing in controlling brome grass are likely to be associated with seed dormancy in these two populations. At Riverton, delay in crop sowing by two weeks reduced brome grass seed set by 76% for TriflurX + Avadex Xtra and 93% for Sakura + Avadex Xtra treatments. TriflurX + Avadex Xtra fb Intervix completely prevented brome grass seed set in both times of sowing (Figure 3a). Similar effects of delayed sowing on herbicide efficacy on brome seed set were also observed at Mallala (P=0.026)



**Figure 3.** The effect of crop sowing time and herbicide treatments on in-crop brome grass seed production at Riverton (a) and Mallala (b). TOS 1 = 16 May and TOS 2 = 31 May. The error bars represent Lsd (P=0.05).



**Figure 4.** The effect of crop sowing time and herbicide treatments on wheat grain yield at Riverton (a) and effect of herbicide treatments on wheat yield at Mallala (b). As there was no interaction between herbicides and sowing time, average yield of the two sowing times is presented for Mallala. TOS 1 = 16 May and TOS 2 = 31 May. The error bars represent LSD (P=0.05).



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(Figure 3b). Considering the current low levels of resistance in brome grass to imidazolinone herbicides (P. Boutsalis, pers. comm.), Clearfield® systems are an attractive option for brome grass management, especially in cereal crops in Australia, and should be carefully integrated into the management plan.

In TOS 1 at Riverton, when Intervix (POST) was applied after TriflurX +Avadex Xtra IBS (2.39t/ha), wheat grain yield increased by 45% to 4.32t/ha (Figure 4a). The comparison of the same treatments in TOS 2 showed only 15% increase in wheat grain yield from 3.42t/ha to 3.93t/ha. The large difference in brome grass plant density in the TriflurX +Avadex Xtra IBS treatment between TOS 1 and TOS 2 (Figure 3) is the most likely reason for these yield responses. As brome grass was almost completely controlled in TriflurX + Avadex Xtra fb Intervix (Figure 2), comparison of TOS 1 and TOS 2 for this treatment provides an indication of the yield penalty from delayed sowing. Wheat yield for this herbicide treatment was 4.32t/ha for TOS 1 as compared to 3.93t/ha for TOS 2, which equates to 9% yield penalty (Figure 4) or 130kg/ha/week.

Herbicide treatments also had a significant effect on wheat grain yield at Mallala (Figure 4b). The treatment of TriflurX + Avadex Xtra produced a wheat yield of only 1.11t/ha, which was significantly lower than the wheat yield in herbicide mixture of Sakura + Avadex Xtra (1.81t/ha). However, when Intervix post-emergence herbicide was used, wheat yield increased further to 2.63t/ha. In this trial, integration of Clearfield<sup>®</sup> technology with preemergent herbicides not only prevented brome grass seed set (Figure 3), but it also produced the highest grain yields (Figure 4b).

#### Conclusion

Our research has shown large differences in seed dormancy between brome and barley grass populations, which can have a large effect on the performance of pre-sowing weed control and success of delayed crop sowing for weed control. Growers are often unaware of seed dormancy status of their weed populations but careful observation of paddocks for weed emergence after the opening rains can be helpful in ranking paddocks for seed dormancy. Other factors that can influence success of weed management include seedbank persistence and herbicide resistance status. A brome grass seedbank tends to persist for three years and barley grass for two years. Therefore, single year management programs are unlikely to prevent rebound in populations of these weeds. Integration

of higher crop densities (seed rate) with effective herbicide options has been consistently successful in minimising crop yield loss and reducing weed seed set of brome grass.

#### Acknowledgements

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#### References

Llewellyn RS, Ronning D, Ouzman J, Walker S, Mayfield A and Clarke M (2016) Impact of Weeds on Australian Grain Production: the cost of weeds to Australian grain growers and the adoption of weed management and tillage practices Report for GRDC. CSIRO, Australia.

#### **Contact details**

Ben Fleet The University of Adelaide Roseworthy Campus, Roseworthy SA 5371 08 8313 7950 benjamin.fleet@adelaide.edu.au



## Seed destruction when using a stripper front – does it work?

#### Michael Walsh<sup>1</sup>, Annie Rayner<sup>2</sup> and John Broster<sup>3</sup>.

<sup>1</sup>MUniversity of Sydney; <sup>2</sup>Kalyx; <sup>3</sup>Graham Centre for Agricultural Innovation (Charles Sturt University and NSW Department of Primary Industries), Charles Sturt University.

GRDC project code: US00084

#### **Keywords**

■ HWSC, stripper front, weed seed collection.

#### Take home messages

- Stripper fronts collect high levels of annual ryegrass seed, similar to draper fronts and therefore their use for cereal crop harvest will not negatively impact HWSC systems.
- The reduced levels of chaff produced during harvest with a stripper front influences the operation of HWSC systems.
- The weed seed collection ability of stripper fronts on other weed species is not yet known.

#### Background

Harvest weed seed control (HWSC) has been developed for use in Australian crop production systems as an alternative weed control technique that targets weed seed during grain harvest. Prompted by the widespread occurrence of herbicide resistance in major weeds of cropping systems, particularly annual ryegrass (Lolium rigidum Gaud.), these HWSC systems have been widely adopted by Australian growers (Walsh et al. 2017; Kondinin-Group 2020). The majority of Australian grain growers are now using a HWSC technique to target weed seeds during harvest. When included in a weed management program, HWSC acts as a preventative weed control practice by targeting weed seeds to reduce weed seed inputs to the seedbank and therefore, future weed problems.

HWSC is effective on weed species where substantial proportions of seed production remain attached to plants at a harvestable height at the time of crop maturity, ensuring that grain harvest is also weed seed harvest. The potential susceptibility to HWSC of a weed species can be assessed by quantifying the degree of seed retention at crop maturity. An initial study assessing HWSC potential in Western Australian (WA) wheat crops identified high seed retention for the major weed species: annual ryegrass (85%), wild radish (Raphanus raphanistrum L.) (99%), brome grass (Bromus spp.) (77%) and wild oats (Avena spp.) (84%) (Walsh and Powles 2014). This geographically wide survey of weed seed retention in commercial wheat crops confirmed that high proportions of the total seed production of these species could potentially be targeted with HWSC systems. A number of studies have subsequently identified seed retention levels for numerous weed species at crop maturity, indicating their HWSC potential (Bitarafan and Andreasen 2020; Borger et al. 2020; San Martín et al. 2021; Schwartz-Lazaro et al. 2021a, 2021b). Seed retention values reported in these studies were based on an assumed crop harvest height where crop (and weed) plant material were collected and processed during grain crop harvest.

The introduction of stripper fronts for, primarily cereal crop harvest, represents a major change in the collection and processing of crop grain (and weed seeds) during harvest. The action of stripper fronts is to collect (pluck) only the grain containing "heads" of cereal crops for subsequent processing



and grain collection. This focus on the collection of grain heads greatly improves the efficiency of harvest by eliminating the need to process straw material that is collected when harvesting with a conventional draper front. With a substantial reduction in collected crop plant material, it is also likely that there is a reduction in weed seed collection and therefore, HWSC efficacy. Therefore, the aim of this study was to identify the level of weed seed collection during cereal crop harvest with a stripper front and the subsequent impact on HWSC.

#### Methods

### Comparison of stripper and draper front weed seed collection

Annual ryegrass seed collection during harvest with stripper and draper fronts during wheat crop harvest was compared at two locations near Marrar, NSW (34.8333°S, 147.3667°E) in December 2017. To determine annual ryegrass seed production, prior to harvest at each location 20 representative annual ryegrass plants were collected. Each plant was harvested by cutting and collecting in a paper bag all plant material above 15cm. Remaining plant material was collected and placed into a separate paper bag. In each collected sample, the number of tillers and the average number of seed on each tiller was determined by threshing then cleaning the sample to separate out the seed which was then counted. For each plant, average total seed production and the percentage retention above 15cm harvest height was determined. Seed retention above 15cm was used as the estimate of weed seed collection when using a draper front operating at a common harvest height of 15cm.

To determine seed collection by stripper fronts, 50 annual ryegrass plants were located within each wheat crop. The number of seed-bearing tillers were counted, and plants were marked with spray-on road paint and the GPS locations recorded. After the area was harvested using Shelbourne<sup>®</sup> stripper front, marked plants were relocated and all remaining annual ryegrass plant material was cut at the soil surface and, along with any tillers on the soil surface, placed in a paper bag. Any plants which were driven over by the harvester wheel were noted. Samples were dried, weighed and the number of viable seeds determined as described above.

#### Chaff production

Six 100m lengths of wheat crop were marked out and, using the same Case® 8240 harvester, the first three lengths were harvested with a Shelbourne® stripper front, and the remaining three with a Case<sup>®</sup> draper front. A large shade cloth bag was attached to the chaff-line chute at the rear of the harvester. As each length of wheat crop was harvested, the chaff produced from each length was collected in the shade cloth bag and then transferred into a wool pack for storage. The average wheat yield obtained in each 100m length was recorded from the yield monitor to correlate with chaff production. The chaff produced from each length was weighed.

As there was a significant site effect (P<0.05), oneway ANOVAs were used to compare the effects of harvester front on annual ryegrass seed collection at each site. Lsds (p=0.05) were used for means comparisons. Due to the unbalanced nature of the design (draper n=20, stripper n=50), an ANOVA was run to try subsetting. However, the results remained unchanged, so subsetting was not used. Analysis of chaff production values was performed using a oneway ANOVA and means were compared using Lsds (p=0.05).

#### Survey of stripper front weed seed collection

Annual ryegrass seed collection during wheat crop harvest with a stripper front was recorded at eight locations near Wagga Wagga, NSW (35.1082°S, 147.3598°E). Prior to harvest, at each location, 20 representative annual ryegrass plants were located within the wheat crop. The number of seed-bearing tillers on each plant were counted, and plants were marked with numbered plastic tags. To collect any seed shed/dislodged during harvest, aluminium trays (20cm x 10cm) were placed around the base of the plant to cover the area of the plant canopy. To determine the average number of seeds per plant, an additional 10 plants were collected by cutting at ground level and placing in a paper bag. These plants were then oven dried at 70°C for 48 hours, seed bearing tillers were collected and counted, then individually threshed with the seed collected and counted.

After crop harvest, where a stripper front was used, marked plants were located and all remaining above-ground plant material was cut at the soil surface and collected, along with any dislodged tillers or branches on the soil, then placed in a paper bag. Material in aluminium trays was collected and sorted to retrieve any annual ryegrass seed. Plant samples were oven dried for two days at 70°C, weighed and the number of viable seeds determined, as described above.

Average seed production per tiller and seedbearing tiller counts were used to estimate the seed production per plant on each of the 20 marked



plants. The post-harvest seed counts per plant were then used to determine the amount and proportion of seed removal during harvest.

#### Results and discussion

### Comparison of stripper and draper front weed seed collection

The use of stripper and draper fronts resulted in similarly high levels of annual ryegrass seed collected from mature plants present in wheat crops at harvest. Annual ryegrass seed collection was high at both Marrar sites for both stripper and draper front harvest (Table 1). At Site 1, there was no difference (P>0.05) in annual ryegrass seed collection between stripper and draper fronts - they both resulted in the collection of 91% of seeds. At Site 2, draper front collection was 94%; however, stripper front collection was lower (P<0.05), at 66%. The difference in seed collection at this site is believed to be due to a higher than 15cm harvest height used during harvest with the stripper front. The grower at this site was using a greater harvest height due to concerns about the presence of rocks during harvest. Higher harvest heights have previously been shown to result in lower weed seed collection (Walsh et al. 2018). Growers should consider harvest height when using stripper fronts as well as draper fronts, as running the front lower will collect more weed seeds.

#### Chaff production

When harvesting a wheat crop with the same harvester, the use of a stripper front produced almost half as much chaff compared to harvesting with a draper front. The observed large difference in chaff production may in part be due to poor harvester setup and operation that resulted in substantial amounts of crop stem and leaf material collected by the draper front exiting in the chaff fraction (Table 1). Regardless of the harvester setup and operation effects, there will likely be reduced amounts of chaff produced by the harvester when a stripper front is used, which will in turn influence HWSC systems.

With reduced amounts of chaff and no straw material collected during harvest with stripper fronts, there will be positive and negative impacts on HWSC, depending on which HWSC option is being used. If a stripper front is used, narrow windrow burning would not be possible due to the remaining standing stubble and the difficulty in burning chaff only windrows. Without straw residues, the use of bale direct systems will also not be possible. Chaff carts may be more efficient when combined with stripper front use, as there will be less chaff to collect, and fewer dumps to make. Although, the burning of these chaff dumps may be more difficult due to the lack of straw and resulting aeration. Use of stripper fronts may reduce chaff lining and chaff tramlining effectiveness. Weed seedling emergence is suppressed with increasing amounts of chaff material concentrated in chaff lines and the equivalent of more than 40t/ha is required to completely prevent emergence (Walsh et al. 2020). Therefore, as stripper fronts will produce less chaff material, the effectiveness of chaff and chaff lining systems in suppressing weed seedling emergence will be reduced. Impact mill operation would be more efficient with a stripper front compared to a draper front. There is a direct relationship between the quantity of chaff and the mill's power requirements (Guzzomi et al. 2017).

#### Survey of stripper front weed seed collection

Wheat crop harvest with a stripper front provided similar levels of annual ryegrass seed collection as when a draper style harvester front was used. Across eight survey sites, high proportions of annual ryegrass weed seed collection were observed when wheat crops were harvested using a stripper front. The proportion of seed collected during harvest averaged 85% and ranged from 65% to 94% (Table 2). These values are equivalent to the seed retention values previously recorded for annual ryegrass in studies where there was an assumed draper front harvest at 15cm height (Walsh and Powles 2014; Borger et al. 2020). Clearly then, the seed collection levels during a stripper front harvest are equivalent to those that occur during harvest when a draper front is used.

**Table 1.** Proportion of annual ryegrass seed production collected at two sites and the amount of chaff production during wheat harvest with stripper and draper fronts at site 1. Different letters indicate significant differences between values within columns (P<0.05).

	Annual ryegrass seed collection		Wheat (Site 1)	
Front	Site 1 (%)	Site 2 (%)	Chaff (t/ha)	Yield (t/ha)
Draper	90.8ª	93.8ª	0.4ª	<b>4.1</b> ª
Stripper	90.9ª	66.1 <sup>b</sup>	0.2 <sup>b</sup>	4.5ª
Lsd (p= 0.05)	8.3	14.5	0.1	0.6



**Table 2.** Annual ryegrass average tiller, seed production on plants in wheat crops at maturity and the proportion of seed collected from these plants during 2020 wheat crop harvest with a stripper front at nine locations near Wagga Wagga, NSW. Numbers in brackets are standard errors for the mean of 20 replicates.

	Annual ryegrass					
Location	Tillers	Seed pr	Seed collection			
	No./plant No./tiller No./plant		No./plant	%		
The Rock	9	67	576	87 (4.2)		
Lockhart	16	35	542	86 (5.0)		
Old Junee	29	134	3885	89 (4.5)		
West Wyalong	8	37	300	65 (7.4)		
Culcairn	5	58	277	88 (6.9)		
Urana	13	31	386	94 (6.9)		
Marrar (1)	14	35	466	87 (8.0)		
Marrar (2)	6	36	223	82 (5.5)		
Average	12.3	54.1	832	85		

#### Conclusion

Assessment of annual ryegrass seed collection during wheat harvest with stripper fronts indicates that there is comparable seed collection to draper front crop harvest. Clearly, at least for annual ryegrass, the use of stripper fronts will not negatively impact the collection of seed during cereal crop harvest. The use of stripper fronts does reduce the amount of chaff material produced during harvest, which will impact on the types and potential efficacy of some HWSC systems. For example, there will be less material for impact mill systems to process that should lead to increased system efficiency. In contrast, lower levels of chaff material will diminish the suppressive effects of chaff lining on weed seedling emergence.

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#### References

Bitarafan Z, Andreasen C (2020) Harvest weed seed control: seed production and retention of *Fallopia convolvulus, Sinapis arvensis, Spergula arvensis* and *Stellaria media* at spring oat maturity. *Agronomy* **10(1)**, 46.

Borger CPD, Hashem A, Gill GS (2020) Comparison of growth, survivorship, seed production and shedding of eight weed species in a wheat crop in Western Australia. Weed Research **60(6)**, 415-424. Guzzomi AL, Ryan M, Saunders C, Walsh MJ (2017) Reducing the integrated Harrington Seed Destructor power requirements through chaff fraction optimization. *Applied Engineering in Agriculture* **33(5)**, 695-701.

Kondinin-Group (2020) Harvest weed seed control — weed seed warriors. Kondinin Group No. 121

San Martín C, Thorne ME, Gourlie JA, Lyon DJ, Barroso J (2021) Seed retention of grass weeds at wheat harvest in the Pacific Northwest. *Weed Science* **69(2)**, 238-246.

Schwartz-Lazaro LM, Shergill LS, Evans JA, Bagavathiannan MV, Beam SC, Bish MD, Bond JA, Bradley KW, Curran WS, Davis AS, Everman WJ, Flessner ML, Haring SC, Jordan NR, Korres NE, Lindquist JL, Norsworthy JK, Sanders TL, Steckel LE, VanGessel MJ, Young B, Mirsky SB (2021a) Seed-shattering phenology at soybean harvest of economically important weeds in multiple regions of the United States. Part 1: Broadleaf species. *Weed Science* **69(1)**, 95-103.

Schwartz-Lazaro LM, Shergill LS, Evans JA, Bagavathiannan MV, Beam SC, Bish MD, Bond JA, Bradley KW, Curran WS, Davis AS, Everman WJ, Flessner ML, Haring SC, Jordan NR, Korres NE, Lindquist JL, Norsworthy JK, Sanders TL, Steckel LE, VanGessel MJ, Young B, Mirsky SB (2021b) Seed-shattering phenology at soybean harvest of economically important weeds in multiple regions of the United States. Part 2: Grass species. *Weed Science* **69(1)**, 104-110.



Walsh M, Rayner A, Ruttledge A, Broster J (2020) Influence of chaff and chaff lines on weed seed survival and seedling emergence in Australian cropping systems. *Weed Technology* **35(3)**, 515-521.

Walsh MJ, Broster JC, Aves C, Powles SB (2018) Influence of crop competition and harvest weed seed control on rigid ryegrass (*Lolium rigidum*) seed retention height in wheat crop canopies. *Weed Science* **66(5)**, 627-633.

Walsh M, Ouzman J, Newman P, Powles S, Llewellyn R (2017) High levels of adoption indicate that harvest weed seed control is now an established weed control practice in Australian cropping. *Weed Technology* **31(3)**, 341-347.

Walsh MJ, Powles SB (2014) High seed retention at maturity of annual weeds infesting crop fields highlights the potential for harvest weed seed control. *Weed Technology* **28(3)**, 486-493.

#### **Contact details**

Michael Walsh Werombi Road, Brownlow Hill NSW 2570 0448 847 272 m.j.walsh@sydney.edu.au



## Pre-emergent herbicide performance in 2021 – how this happened and what to expect in 2022?

#### Christopher Preston.

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

#### Keywords

■ annual ryegrass, crop safety, dry sowing, pre-emergent herbicide.

#### Take home messages

- The late break and cool wet conditions during winter influenced pre-emergent herbicide control in 2021.
- Crop damage occurred through shallow sowing, not adequately separating herbicide from the crop seed and on soil types with low organic matter.
- Less soluble pre-emergent herbicides are safer to use for dry sowing.

#### 2021 – A year of surprises?

2021 was one of those years of surprises. I took more calls about pre-emergent herbicide performance in 2021 than I have for some years. Partly this was due to the widespread use of products that advisors and growers had less familiarity with and part was due to the seasonal conditions that occurred.

Every year is a different, which means that preemergent herbicide efficacy can vary. Several key environmental factors influence the performance of pre-emergent herbicides. The main factors are rainfall patterns, existing soil moisture and temperature. Differences in these from year to year can change how pre-emergent herbicides behave.

### Pre-emergent herbicide performance in 2021

Figure 1 shows weekly rainfall at Snowtown in South Australia, which encapsulates one of the key issues for 2021 across much of South Australia and Victoria. Summer was relatively dry, as was autumn with only a few small rainfall events. This meant that soils were still quite dry coming into seeding. The break was late with the first significant rainfall occurring at the end of May. Through June and July, there was above average rainfall, but spring was dry. The above average rains after the break meant that most pre-emergent herbicides activated well and controlled the first flush of annual ryegrass. The drier than average spring reduced late emerging ryegrass resulting in some excellent control of annual ryegrass with pre-emergent herbicides.

The higher than average rainfall during June and July reduced the performance of some of the more water-soluble herbicides, such as Butisan<sup>®</sup> and Luximax<sup>®</sup>. This is likely due to the herbicides being moved out of the weed root zone.

The dry soil at sowing meant the large rainfall events during June moved pre-emergent herbicides more quickly through the soil profile. This increased the risk of crop damage from pre-emergent herbicides. Selecting the correct herbicides for the soil type and seeding systems is essential in managing this risk. The more water-soluble herbicides with lower crop safety are the most likely to cause damage. Seeding systems where the herbicide is left sitting above the crop seed are also less safe.

Table 1 shows the solubility and soil binding characteristics of pre-emergent herbicides used for annual ryegrass control. Herbicides with higher water solubility and lower binding to soil, such as Butisan, are likely to move further through the







soil with high rainfall events. Those with low water solubility, such as Sakura®, will move less far.

#### What happened with Overwatch® in 2021?

Perhaps the biggest talking point of pre-emergent herbicides 2021 was the behaviour of Overwatch (bixlozone). Overwatch was released in 2021 for the first time and, as often occurs with new herbicides, there was plenty to learn. The most obvious effect of Overwatch was the extensive bleaching of barley crops. Barley is known to be less tolerant of Overwatch than wheat, so more bleaching should be expected. However, environmental conditions in 2021 magnified this effect.

The large rainfall events after sowing moved the herbicide further into the soil profile allowing the barley crop to take up more herbicide. This led to the considerable bleaching observed. To recover from the bleaching, the crop needs to produce new green leaves, as the bleached tissue does not recover. The cool, showery and cloudy conditions through June and July slowed the growth of the crops and it took some weeks for new leaves to emerge. Once some sunny days arrived, most of the barley crops recovered.

Table 1. Behaviour of some pre-emergent herbicides used for grass weed control.					
Dro omorgont horbicido	Trade name	Solubility		K <sub>oc</sub>	
		(mg/L)		(mL/g)	
S-Metolachlor	Dual Gold <sup>®</sup> , Boxer Gold <sup>®*</sup>	480	High	226	Medium
Metazachlor	Butisan	450	High	45	Low
Cinmethylin	Luximax	63	Medium	300	Medium
Bixlozone	Overwatch®	42	Medium	400	Medium
Prosulfocarb	Arcade <sup>®</sup> , Boxer Gold <sup>®*</sup>	13	Low	2 000	High
Propyzamide	Edge®	9	Low	840	High
Triallate	Avadex <sup>®</sup> Xtra	4.1	Low	3 000	High
Pyroxasulfone	Sakura®	3.5	Low	223	Medium
Trifluralin	TriflurX®	0.2	Very low	15 800	Very high

\*Boxer Gold contains both prosulfocarb and S-metolachlor



Where crops did not fully recover, it was often the result of soil types or seeding systems that allowed more herbicide to reach the crop. In particular, crops sown too shallow, those sown too fast with treated soil being thrown into the next furrow, and those sown with disc seeders where herbicide was allowed to remain close to the crop seed were more likely to suffer damage. In addition, crop damage occurred in some soil types with low organic matter and in areas where there was overlap in spray application.

#### What to expect in 2022

2022 is likely to be a different year. The current forecast is for average to above average rainfall for January to March. There is likely to be more moisture present in the soil and the chances of a late break are lower. If the soil profile is damp before herbicides are applied, they are likely to move less in response to rainfall events. Under such conditions, Overwatch will be less damaging to barley crops and we will see less bleaching of the crop. An earlier sowing date will also allow the crop to recover faster from any bleaching that does occur.

What we have learned about Overwatch is that knife points with press wheels is the safest seeding system for barley crops. All other types of seeding systems are likely to result in crop damage. Additional care should be taken in light soils and soil types with low organic matter to make sure the herbicide is kept well away from the crop row.

Mateno<sup>®</sup> Complete (a mixture of pyroxasulfone, aclonifen and diflufenican) will be released in 2022 and will offer an alternative to Boxer Gold and Overwatch for barley. The rate for use in barley will be 750 mL/ha applied IBS. As with Overwatch, knife points and press wheels will be the safest seeding system to use. All the components of Mateno Complete have low water solubility and will tend to stay closer to the soil surface. However, under conditions of dry soil and high rainfall, such as we saw in 2021, the herbicide may be moved into the crop zone and cause damage to barley.

Mateno Complete will be safer to use in wheat than barley. In wheat, it can also be used early post-emergent, at a similar timing to Boxer Gold, to achieve more extended control of annual ryegrass. The lower solubility of the herbicides in Mateno Complete means more rainfall after application is required to activate compared with Boxer Gold. This means the early post-emergent application of Mateno Complete will be most useful in higher rainfall regions.

#### What are the best products for dry sowing?

Using pre-emergent herbicides with dry sowing is challenging as there is no way of predicting when and how much rainfall will occur. A long period between sowing and getting sufficient rainfall to activate the herbicides can lead to some herbicide losses and a shorter period of persistence after the crop emerges. Of more concern is where there is a large rainfall event to start the season. As the soil is dry, large rainfall events will move the herbicides further into the soil profile, increasing the risk of crop damage.

As with all other uses of pre-emergent herbicides, soil type, soil organic matter, herbicide behaviour and seeding system need to be considered when choosing the appropriate pre-emergent herbicide. In terms of herbicide behaviour, trifluralin is the ideal pre-emergent herbicide for dry sowing. It has low water solubility and binds tightly to organic matter (Table 1). This means it has less chance of moving far enough into the soil to cause crop damage. Unfortunately, trifluralin resistance is common in annual ryegrass across South Australia and Victoria. This means the other herbicides with low water solubility, such as Sakura, Avadex Xtra and prosulfocarb, should be used. Herbicides with high water solubility and more mobility in soil, such as Butisan, Boxer Gold and Luximax, are less suited to dry sowing.

Another factor to consider is the tolerance of the crop to the herbicide. Where the crop is less tolerant to the herbicide, the risks increase with dry sowing. For example, the risks of crop damage from Overwatch to barley are much higher than the risks to wheat. Only the safest of herbicides are suitable for dry sowing where disc seeders are used.

The other aspect of dry sowing is managing the risk of the herbicides not activating in time to control weeds. This is most likely to happen with low solubility herbicides like Sakura. A way to manage this is to mix with a herbicide that needs less rainfall to activate, such as trifluralin or Avadex Xtra. Trifluralin requires less moisture as it works as a gas and turns into a gas on contact with water. Avadex Xtra is absorbed by the coleoptile rather than the roots, so does not need to be moved as far through the soil.



#### Useful resources

Soil behaviour of pre-emergent herbicides in Australian farming systems: a reference manual for agronomic advisers (https://grdc.com.au/resourcesand-publications/all-publications/publications/2018/ soil-behaviour-of-pre-emergent-herbicides)

#### **Contact details**

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



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## Annual ryegrass weed management and paraquat resistance

#### Peter Boutsalis<sup>1, 2</sup>, Ben Fleet<sup>1</sup>, Gurjeet Gill<sup>1</sup> and Christopher Preston<sup>1</sup>.

<sup>1</sup>SSchool of Agriculture, Food & Wine, University of Adelaide; <sup>2</sup>Plant Science Consulting P/L.

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#### **Keywords**

■ glyphosate, national random weed survey, paraquat, ryegrass.

#### Take home messages

- According to a recent national weed survey, resistance to pre-emergence herbicides in annual ryegrass is low.
- Paraquat resistance in broadacre paddocks has been confirmed.
- Monitoring for resistance using herbicide resistance testing is important to protect against glyphosate and paraquat resistance increasing.
- Glyphosate should be used strategically, even if glyphosate resistance is present to protect against paraquat resistance.

## National herbicide resistance weed survey 2020-2023

A national weed survey commenced in 2020 through GRDC investment. In a national collaboration between universities, over 1500 paddocks were sampled across WA, SA, Vic, Tas, NSW and Qld in 2020 and 2021. Grower paddock details were supplied by agronomists and each university randomly selected a set number of paddocks in their respective state. After sampling, all the annual ryegrass were sent to the University of Adelaide for testing, barley grass, brome and wild radish to the Australian Herbicide Resistance Initiative (AHRI), wild oats and sowthistle to Charles Sturt University (CSU). Using this approach, the national collection of each species will be tested together. In 2021, the national ryegrass collection was tested with pre-emergence herbicides with the post-emergence testing to be conducted in 2022 (Tables 1 and 2).

The trends in resistance to pre-emergence herbicides in ryegrass supports the findings from previous surveys. The greatest incidence of resistance to trifluralin was detected in SA (38%) followed by Victoria (21%), WA (4%) and 0% in NSW and Tasmania. The only other resistance detected was to Boxer Gold, the highest (9%) in Victoria. No resistance to field rates of Sakura, Propyzamide, Luximax and Overwatch was detected. These results suggest several herbicide options for the pre-emergence control of ryegrass remain.

#### Improving ryegrass weed control

Resistance levels within individuals in a population can vary and, in many cases, a resistant plant can be killed with a robust field rate under optimum spray and growth conditions. This is most common in plants with weak resistance mechanisms, particularly at early growth stages, with herbicides such as clethodim and glyphosate. Young plants possess



**Table 1.** Percent of paddocks detected with resistant ryegrass treated with the recommended label rate of pre-emergence herbicides. Resistance is defined as a sample where  $\geq$ 20% plant survival was detected in the 2021 pot trials.

State	Herbicides					
	Trifluralin	Boxer Gold <sup>®</sup>	Sakura®	Propyzamide	Luximax®	Overwatch™
National	12	2	0	0	0	0
SA	38	1	0	0	0	0
VIC	21	9	0	0	0	0
NSW	0	1	0	0	0	0
WA	4	2	0	0	0	0
TAS	0	0	0	0	0	0

Table 2. Number of paddocks where ryegrass was collected and tested from each state.						
State	Herbicides					
	Trifluralin	Boxer Gold	Sakura	Propyzamide	Luximax	Overwatch
National	1353	1202	1202	1202	1202	1202
SA	279	266	266	266	266	266
VIC	183	179	179	179	179	179
NSW	317	273	273	273	273	273
WA	554	465	465	465	465	465
TAS	20	19	19	19	19	19

thinner cuticles making herbicide entry easier. However, plants with strong resistance mechanisms, such as certain Group 1 (A) and 2 (B) target site resistance, are difficult to control, even at young growth stages. The high frequency of Group 2 (B) target site resistance in certain weed species such as annual ryegrass, explains why this species is sometimes difficult to control with these herbicides. Fortunately, control with alternative diverse mode of action pre-emergence herbicides is possible.

#### Optimising paraquat performance

In order to maximise the efficacy of paraquat consider the below:

- Use high quality paraquat products and surfactants where recommended.
- Since paraquat does not translocate, coverage is more important than for glyphosate. Use nozzles that will ensure uniform coverage at water rates of at least 100L/ha on small seedlings and higher water rates on more advanced growth stages.
- Avoid combining paraquat with too many other active ingredients to reduce the likelihood of antagonism, particularly with low water volumes.
- Avoid using muddy water. (see useful resources at end of paper).

- Avoid applying paraquat during periods of high light and temperature and low humidity, to avoid rapid activation and loss from leaf surfaces, particularly if targeting tillering plants. Application in low light conditions will improve activity.
- Consider using higher label rates if there is considerable shading.
- Maximise application by adhering to lower speeds and using the correct nozzles, pressure and boom height.

#### Glyphosate and paraquat resistance

Across southern Australia, the most important species developing glyphosate resistance is annual ryegrass. It is very important to test for glyphosate resistance to ensure the correct weed control strategies are implemented. Even if glyphosate resistance is confirmed it can still be used strategically. Unlike resistance to some Group 1 (A) and Group 2 (B) herbicides where the level of resistance in an individual can be high, glyphosate resistance often begins with weak resistance in a low number of plants and if left uncontrolled can increase over time, particularly for cross-pollinating species such as ryegrass.

If a resistance test was conducted and it confirmed a high survival rate (for example, 100%



of plants tested resistant), don't panic. If the sampling for resistance was comprised of very few individuals identified in the paddock after the glyphosate application, whether plants (Quick-Test) or seeds (Seed Test) were tested, then the true incidence of resistance is very low. Management in the subsequent season should actively target to control any survivors. That doesn't necessarily imply not to use glyphosate. Over relying solely on paraquat as the only knockdown can impose strong selection pressure for the development of resistance. A double knock approach involving glyphosate (to control the majority of susceptible individuals) followed with a robust rate of paraquat 1—5 days later is ideal (Figure 1). This approach reduces the selection pressure because the number of individuals exposed to paraguat is reduced since glyphosate does most of the 'heavy lifting'. Tank-mixing glyphosate and paraquat is not recommended to avoid strong antagonism. Paraquat resistance was confirmed in the 2017 South-East SA random weed survey in 7% of ryegrass samples. In lucerne and white clover seed crops paraguat alone is commonly used to control ryegrass, as these crops can regenerate from the paraquat burndown. It is, therefore, not surprising that the initial paraguat resistant cases were identified in lucerne and white clover paddocks. A low number of paraguat resistant ryegrass cases have, recently been confirmed in cropping paddocks in South-Western Victoria and South-Eastern SA. Some of these biotypes are also resistant to glyphosate. One of the paraguat resistant sites had been exposed to less than five applications of paraguat, suggesting that the resistance had been brought into the paddock from an outside source. Monitoring for survivors after paraquat use is necessary, with testing recommended to prevent paraquat resistance increasing.



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

The use of an effective pre-emergent herbicide or combination is recommended to control any subsequent germination. With delayed germination becoming more prevalent in some ryegrass biotypes, a resistance test would aid in the identification of whether there were effective postemergent herbicide options available to control potential glyphosate resistance. It is not advisable to grow a GM canola crop unless clethodim/butroxydim is effective, so clethodim/butroxydim (or clethodim + glyphosate) can be used to control ryegrass and glyphosate to control susceptible ryegrass and other target species. The use of atrazine is an important tool as it controls many weed species including ryegrass, with the added benefit of only few cases of resistance detected. Tank-mix combinations of atrazine and clethodim have recently been shown to be antagonistic in controlling ryegrass, therefore separating these two products is recommended to maintain control with either product (Table 3).

Table 3. Increase in control (%) of treatments compared to a Clethodim + Atrazine tankmix on 3-leaf ryegrass in outdoorpot trials. Data is the pooled response of a susceptible and 3 DIM-resistant ryegrass biotypes. The trial was repeated withAtrazine applied followed by the Clethodim treatments and vice versa (second trial). Rates are (1) Clethodim EC240 @500mL/ha and Atrazine WG900 @ 2kg/ha. Hasten and liquid AMS at 1% were included with each treatment. The Clethodim +Atrazine (tank-mix) treatment response was converted to 0 to calculate the improvement in control of the other treatments.

Treatments	Time after first herbicide	% Increase in control over Clethodim + Atrazine tankmix
Clethodim + Atrazine (tank-mix)	0	0
Clethodim only	no atrazine	10
Clethodim-Atrazine sequence	10 min	11
Clethodim-Atrazine sequence	2 days	17
Clethodim-Atrazine sequence	7 days	30







Clethodim with no atrazine provided 10% greater control than Clethodim + Atrazine (tank-mix). Control improved the longer the separation between the first and second treatment.

Crop topping with glyphosate where glyphosate resistance has been confirmed is not advisable as it may serve to sterilise susceptible ryegrass seed and leave resistant plants behind to preferentially cross pollinate and fast-track glyphosate resistance (Figure 2). A seed-sterilisation field trial was conducted in 2016 at a site with confirmed glyphosate resistance. Viability testing of the seed after maturation revealed that the reduction in seed germination was between 9-22%, indicating that at least 80% of the seed remained viable. Glyphosate resistant ryegrass.

Crop rotation with pulses is an option. There are several robust herbicide options available for combatting glyphosate resistance in a pulse crop such as propyzamide, carbetamide, higher Group 1 (DIM) registered rates and crop-topping with paraquat.

#### Conclusion

Several pre-emergent herbicide options remain to control multiple-resistant ryegrass as indicated by recent national weed surveys. There are several factors that can contribute to poor weed control with resistance being only one of them. Optimising application equipment, timing and understanding environmental factors that reduce herbicide efficacy is important. Glyphosate and paraquat can be used strategically, even if resistance is present.

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#### Useful resources

https://grdc.com.au/understanding-post-emergentherbicide-weed-control?utm\_source=website&utm\_ medium=short\_url&utm\_campaign=ICN00016&utm\_ term=National&utm\_content=Understanding%20 post-emergent%20herbicide%20weed%20 control%20in%20Australian%20farming%20systems

https://grdc.com.au/\_\_\_data/assets/pdf\_ file/0018/142542/grdc\_fs\_spray-water-quality\_highres-pdf.pdf

#### **Contact details**

Peter Boutsalis Plant Science Consulting P/L University of Adelaide Waite Campus, Glen Osmond SA 5064 peter.boutsalis@adelaide.edu.au www.plantscienceconsulting.com.au @PBoutsalis





#### **CHAIR - JOHN BENNETT**

Lawloit, VIC



Based at Lawloit, between Nhill and Kaniva in Victoria's West Wimmera, John and his family run a mixed farming operation across diverse soil types. The farming

system is 70 to 80 per cent cropping, with cereals, oilseeds, legumes and hay grown. He wants to see RD&E investments promote resilient and sustainable farming systems that deliver more profit to growers and ultimately make agriculture an exciting career path for young people.

M +61 429 919 223 E john.bennett5@bigpond.com

#### **DEPUTY CHAIR - KATE WILSON**

Hopetoun, VIC



Kate is a partner in a large grain producing operation in Victoria's Southern Mallee region and produces wheat, canola, lentils, lupins and field peas. Kate has been an agronomic

consultant for more than 20 years servicing the Mallee and northern Wimmera. Kate is passionate about producing high quality grain, whilst enhancing the natural ability of the soil. Kate is passionate about research and the extension of that research to bring about positive practice change to growers.

M +61 427 571 360 E kate.wilson@agrivision.net.au

#### ANDREW RUSSELL

Rutherglen, VIC



Andrew is Managing Director and a shareholder of Lilliput AG, and a Director and shareholder of the affiliated Baker Seed Co, a familyowned farming and seed cleaning

business. He manages a 2500ha mixed cropping enterprise south of Rutherglen. Lilliput AG produces wheat, canola, lupin, faba bean, triticale, oats and sub clover for seed and hay. Andrew served on the GRDC's medium rainfall zone RCSN (now National Grower Network) and has held many leadership roles. He holds a Diploma of Rural Business Management and an Advanced Diploma of Agriculture.

M +61 417 401 004 E arussell@lilliput-ag.com.au

#### JON MIDWOOD Inverleigh, VIC



► Jon has worked in agriculture for the past three decades, both in the UK and in Australia. He has managed Grainsearch, a grower-funded

company evaluating European wheat and barley varieties for the high rainfall zone, and his consultancy managed the commercial contract trials for Southern Farming Systems (SFS). Jon was a member of the GRDC's HRZ (RCSN (now National Grower Network) and became a GRDC Southern Panel member in 2015. In 2020 Jon set up an independent consultancy, TechnCrop Services.

M +61 400 666 434 E jon@techcrop.com.au

#### LOU FLOHR



► Lou is a farmer based at Lameroo in the Southern Mallee of South Australia. With her parents and partner, she runs a mixed farming enterprise which includes export oaten hay,

wheat, barley, a variety of legumes and a selfreplacing Merino flock. Prior to returning to the family farm, Lou had a 10-year agronomy career, servicing the Upper South East and Mallee. She is passionate about her industry, particularly in recognising the role that women play in the industry and on the land.

M +61 429 083 927 E flohrlouise@gmail.com

#### ANDREW WARE

Port Lincoln, SA



Andrew is a research agronomist, based at Port Lincoln on SA's Eyre Peninsula. He started his career with the South Australian Research and Development Institute (SARDI) at

the Minnipa Agriculture Centre, and then spent time at CSIRO in Adelaide. Andrew managed the family farm on Lower Eyre Peninsula for 10 years before returning to SARDI in late 2009. In 2019, Andrew started his own research company EPAG Research, delivering applied research across Eyre Peninsula. Andrew received the GRDC Southerm Panel's Emerging Leader award in 2018, and prior to joining the Panel he served on the GRDC's low rainfall zone RCSN (now National Grower Network).

M +61 427 884 272 E andrew@epagresearch.com.au

#### PRU COOK Dimboola, VIC



Pru was raised on a mixed farm at Diapur in Victoria's Wimmera region. She has worked at the Victorian Department of Primary Industries and GRDC, where she implemented

GRDC's first social media strategy. She then worked at Birchip Cropping Group, managing and supporting extension projects. She has recently started her own business focusing on extension, project development and management.

M +61 438 923 258 E pru.cook@gmail.com

#### MICHAEL TRELOAR Cummins, SA



Michael is a third-generation grain grower based at Cummins on South Australia's Eyre Peninsula, where he grows wheat, barley, canola, beans, lupins and lentils on a range

of soil types. He has been involved in the South Australian Grains Industry Trust, the Lower Eyre Agricultural Development Association and the South Australian No Till Farmers Association. He believes research and development underpins profitability in Australian farming systems and the GRDC is pivotal in delivering research outcomes that support growers.

M +61 427 765 034 E mbattreloar@bigpond.com

#### MICHELLE WATT



► In February 2020 Professor Michelle Watt was appointed the Adrienne Clarke Chair of Botany at the University of Melbourne. From 2015 to 2019, she was Director of the Plant

Sciences Institute at the Helmholtz Centre and Professor of Crop Root Physiology at the University of Bonn in Germany. Prior to 2015 Michelle was at CSIRO. She has been in multi-partner projects with Australia, the USA, India, the Philippines, UK and Germany in the under-studied but critical area of plant roots. She is President of the International Society of Root Research and Co-Chair of the Root Phenotyping.

E watt.m@unimelb.edu.au

#### DR NICOLE JENSEN

Canberra, ACT



Nicole is general manager of GRDC's Genetic and Enabling Technologies business group. She brings a wealth of experience in digital agriculture, plant breeding and

genetics from roles she has held in Australia and internationally in the seed industry.

P +61 7 4571 4800 E Nicole.Jensen@grdc.com.au

## **KEY CONTACTS**



#### **SOUTHERN REGION**

ADELAIDE

187 Fullarton Road DULWICH SA 5065 P: +61 8 8198 8400 southern@grdc.com.au

#### OPERATIONS



GENERAL COUNSEL Merryn Cossey Merryn.Cossey@grdc.com.au P: +61 4 2860 1868 SENIOR COUNSEL Claire Connolly-Hay Claire.Connolly-Hay@grdc.com.au M: +614 6030 6003

MANAGER, AGRONOMY,

SOILS, NUTRITION AND

FARMING SYSTEMS

Andrew.Smith@grdc.com.au

**GROWER RELATIONS** 

Randall.Wilksch@grdc.com.au

Andrew Smith

M: +61 413 951 794

Randall Wilksch

M: +61 4 3776 9098

MANAGER

CONTRACT ADMINISTRATOR AND PANEL SUPPORT Claire West Claire.West@grdc.com.au P: +61 & 8198 & 8401

MANAGER WEEDS

Jason.Emms@grdc.com.au

**GROWER RELATIONS** 

Tom.Blake@grdc.com.au

M: +61 4 1889 3186

(NATIONAL)

Jason Emms

MANAGER

Tom Blake

M: +61 4 3954 9950

#### TEAM ASSISTANT

Helene Nielson Helen.Nielson@grdc.com.au P: +61 8 8198 8406

#### APPLIED RESEARCH DEVELOPMENT AND EXTENSION

MANAGER AGRONOMY, SOILS, NUTRITION AND FARMING SYSTEMS Stephen Loss

Stephen.Loss@grdc.com.au M: +61 4 0841 2453

#### GROWER RELATIONS MANAGER

Courtney Ramsey Courtney.Ramsey@grdc.com.au M: +61 4 2827 4018

#### GENETIC AND ENABLING TECHNOLOGIES

SENIOR MANAGER ENABLING TECHNOLOGIES Tom Giles Tom.Giles@grdc.com.au M: +614 1788 9860

#### MANAGER NATIONAL

VARIETY TRIALS Trevor Garnett Trevor.Garnett@grdc.com.au M: +614 5790 6770

#### CONTRACT ADMINISTRATOR

Sarah Marchioro Sarah.Marchioro@grdc.com.au P: +61 8 8198 8400 SENIOR MANAGER NATIONAL VARIETY TRIALS Sean Coffey Sean.Coffey@grdc.com.au

M: +61 4 2865 2226

#### MANAGER OILSEEDS (NATIONAL)

Allison Pearson Allison.Pearson@grdc.com.au M: +61 4 1887 4748 MANAGER NATIONAL VARIETY TRIALS SYSTEMS

Neale Sutton Neale.Sutton@grdc.com.au M: +61 4 3857 9992

#### CONTRACT ADMINISTRATOR

Dianne Wright Dianne.Wright@grdc.com.au P: +61 8 8198 8407

#### CROP PROTECTION MANAGER SOUTH Ruth Peek

Ruth.Peek@grdc.com.au M: +61 4 5553 4040

MANAGER NATIONAL VARIETY TRIALS OPERATIONS Ben O'Connor Ben.O'Connor@grdc.com.au M: +61 4 9988 7749

#### CONTRACT ADMINISTRATOR

Layne Schutt Layne.Schutt@grdc.com.au P: +61 8 8198 8400

CONTENT MANAGER Melanie Hunter Melanie.Hunter@grdc.com.au M: +61 427 189 827

COMMUNICATIONS

#### STRATEGY AND BUSINESS DEVELOPMENT



#### GENERAL MANAGER STRATEGY AND BUSINESS DEVELOPMENT

Ron Osmond Ron.Osmond@grdc.com.au M: +61 4 0000 2640 HEAD OF BUSINESS DEVELOPMENT AND COMMERCIALISATION

Fernando Felquer Fernando.Felquer@grdc.com.au M: +61 4 1351 1412 HEAD OF STRATEGY, PLANNING, INSIGHTS AND PLANNING

Craig Ruchs Craig.Ruchs@grdc.com.au M: +61 4 7771 0813

#### MANAGER COMMERCIALISATION Tim Spencer

Tim.Spencer@grdc.com.au P: +61 8 8198 8400