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CROPPING SYSTEMS AND MANAGEMENT

Front cover photo by Miffy Purslow.

Thanks also Sandy Kimber, Rebekah Allen, Kaidy Morgan, Miffy Purslow & Gabrielle Hall
for other photos used within this publication.

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Hart 2025 calendar

HART FIELD DAY

September 16

Our main Field Day attracts over 500 visitors from all over South Australia and further afield.

Every half hour a block of eight sessions are run simultaneously with highly regarded specialists speaking at each trial. Our comprehensive take-home Field Day Guide is included in your entry fee.

The Hart Field Day is our main event of the year.

Hart AGM

October 2025

Getting The Crop In

March 12

8am – 12:30pm

At this annual seminar, researchers andindustry guest speakers from across the county cover a wide range of topics, all relevant to broadacre cropping.

Winter Walk

July 15

9am – 12pm

An informal guided walk around the trial site; your first opportunity to inspect the site post-seeding with guest speakers presenting their observations on current trials.

They are on hand to answer questions and will also share their knowledge on all the latest cropping systems and agronomic updates.

Spring Twilight Walk

October 21

5pm followed by BBQ

Another informal opportunity to inspect the trial site, this time just prior to harvest. Key researchers and industry representatives again present in the field and answer your questions.

This event is followed by drinks and a BBQ in the shed - a great opportunity to network.

Acknowledgements

The success of our research program could not be achieved without the contribution of a large number of people and organisations.

Supporters

We thank the numerous growers and consultants who provide various contributions, from knowledge and experience through to land and equipment for conducting trials.

Craig Davis
Roger Kimber
Andre Sabeeney
Stuart Sherriff
Andrew Cootes
Kelvin Tiller
Rob & Dennis Dall
Daniel Neill
James Venning
Matt Dare
Rob & Glenn Wandel
Trevor Day
Scott Weckert
Anthony Pfitzner
Glen Wilkinson
Justin, Bradley & Dennis Wundke
Simon Honner
Chris Preston
Peter Baker
Matt Williams
Richard Verner
James Henderson
Wade Hogg
Braydon Keech
Luke Dohnt
Mick Faulkner

We would also like to thank various organisations for the provision of seed and/or products that were trialed in the 2024 research program.

ADAMA
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SARDI Clare
Advanta Seeds
Global Grain Genetics
Agriculture Victoria – field pea breeding program
InterGrain
SARDI Agronomy & Crop Sciences
AGF seeds
Agriculture Victoria – lentil breeding program
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Seednet
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Nufarm
Pacific Seeds
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Agfert
Barenbrug
Pioneer Seeds
Syngenta
BASF
Plant Science Consulting
Bayer Crop Science
Corteva Agriscience
S & W Seeds
RAGT

Thank you also to the following people who volunteer on Hart’s Research Committee.

Rob Dall
Matt Dare
Ash Hentschke
Simon Honner
Simon McCormack
Simon McCormack
Rob Price
Stuart Sherriff
Scott Weckert
Glen Wilkinson
Jana Dixon
Scott Carmichael
Ben McInerney
Nick Longmire

Our guiding principles

OUR PURPOSE

To deliver value to growers and make agriculture better

(in productivity, sustainability & community)

OUR VISION

To be Australia's premier cropping field site, providing independent information and enhancing the skills of the agricultural industry

---

OUR VALUES

Independence

in order to provide unbiased results

Relevance

to issues facing farmers

Integrity

in all dealings

Credibility

through providing reliable, quality information

Professionalism

in the management of the site and presentation of trials

Value for money

low cost of information to farmers

Hart management

Hart board

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Andre Sabeeney (Clare)	Vice-chairman
Sandy Kimber (Clare)	Executive officer
Dale Callary (Clare)	Treasurer
Matt Dare (Marola)	Commercial crop manager, sponsorship
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Scott Weckert (Blyth)	Sponsorship, community engagement
Simon Honner (Blyth)	Board member
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Myfanwy Purslow	Research intern
Sandy Kimber	Executive officer
Robyn Howard	Finance officer
Simone Lawry	Admin support
Gabrielle Hall	Media

Site Management

Hart Field-Site Group:
Rebekah Allen, Kaidy Morgan, Myfanwy Purslow

SARDI, Agronomy Clare:
Patrick Thomas, John Nairn, Sarah Day, Navneet Aggarwal, Dylan Bruce, Trevor Lock, Caitlin Parsons and Hugh Drum.

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Or find out more about us…

HART

SA's premier cropping field site

Hart Field Day

September 16, 2025

www.hartfieldsite.org.au

The Hart site

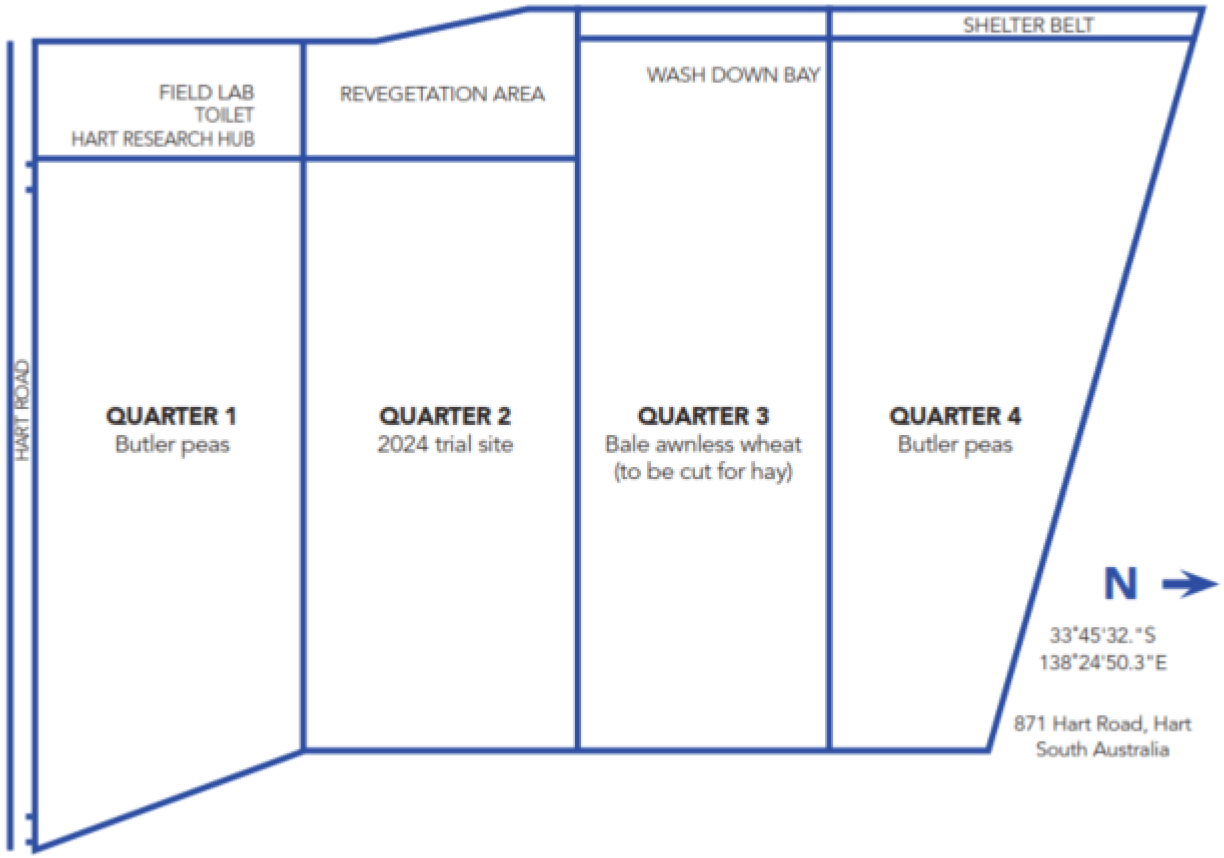
The Hart field site consists of 40 hectares owned by the group.

It is managed as four quarters (shown below) that are rotated each year.

In 2024, our trials were held in Quarter 2.

Quarters 1, 3 and 4 make up our commercial crop:

- Q1 & Q4 were sown to Butler peas
- Q3 to Bale awnless wheat (to be cut for hay in preparation for the following year's trial site).



Facilities at the Hart site also include:

- Field lab – for workspace and sample processing
- Hart Research Hub – for workshops, events & meetings
- Storage shed
- Washdown bay
- Toilet
- Fully fenced re-vegetation area

Hart commercial crop report

Matt Dare

Commercial Crop Manager, Hart Field-Site Group

QUARTERS 1 & 4 – Butler peas

Quarters 1 & 4, a total of 18 ha, were sown to Butler peas in at a rate of 100 kg/ha with 100 kg/ha of MAP fertiliser on May 24, followed by rolling to aid harvesting.

A pre-sowing herbicide mix of 1.2 L/ha trifluralin, 50 ml/ha diflufenican and 100 g/ha metribuzin was applied prior to sowing and incorporated by a knife point and press wheel sowing system.

A post-sowing pre-emergent herbicide mix of 1.0 L/ha propyzamide, 50 g/ha metribuzin and 350 ml/ha chlorpryifos was also applied.

Clethodim was applied for grass weed control in early July.

A frost event on the morning of the Hart Field Day (September 17), in conjunction with severe moisture stress from lack of rainfall, ultimately resulted in the peas yielding well below average.

The pea crop was harvested on October 28, with a final yield of 5.8 tonnes (0.322 t/ha).

A summer weed spray (1.8 L Crucial + 500 ml Starane Advanced) was applied on November 14.

QUARTER 3 – Bale awnless wheat

Bale awnless wheat was sown dry on May 4 in Quarter 3 at 100 kg/ha with 80 kg/ha DAP fertiliser with a plan to cut for hay in September or October in preparation for the 2025 trial site.

Bale wheat was spread with 100 kg/ha of N-Shield Dual (blue urea), in late August.

The wheat was slashed on September 17 rather than cutting for hay as planned, as the crop was dying from moisture stress due to lack of rain.

A summer weed spray (2.0 L Glyphosate540 + 400 ml Fluroxypyr400) was applied on December 18.

THANK YOU

We would like to thank the following people and organisations for supporting Hart's 2024 commercial crop:

- Matt Williams – sowing, rolling, spraying, harvest (Q1, 3 & 4) and slashing (Q3)
- Verner Seeds - Bale seed (Q3)
- Agfert - N-Shield Dual (Q3)

Interpretation of statistical data

The results of replicated trials are presented as either the predicted or average (mean) for each of the replicates within a treatment. When analysing data statistically, authors generally use a REML spatial model or ANOVA, respectively.

In this document we provide an example of ANOVA, in which the means of more than one treatment are compared to each other. The least significant difference (LSD P≤0.05), sometimes seen at the bottom of data tables gives an indication of the treatment difference that could occur by chance. Not significant (NS) indicates that there is no difference between the treatments. The size of the LSD can be used to compare treatment results and values must differ by more than this value for the difference to be statistically significant.

At a 95% confidence interval (p-value ≤0.05) we are 95% confident that observed differences in a trial are due to the treatments, and not by chance (5%).

Interpretation of replicated results: an example only

Below we use an example of a replicated wheat variety trial containing both grain yield and quality data (Table 1). Statistically significant differences were found between varieties for both grain yield and protein. The LSD for grain yield of 0.40 means there must be more than 0.40 t/ha difference between yields before that variety's performance is significantly different to another. In this example Calibre is significantly different to all other varieties as it is the only variety followed by a superscript (^{a}). Scepter, Vixen and Ballista are not significantly different from each other and are all followed by a superscript (^{b}) as they all yielded within 0.4 t/ha of each other.

Similarly, for grain protein, variety performance was only significant from another if there was more than 0.9% difference in protein. In the example, Catapult contained a higher protein level compared to all other varieties which were not different to one another.

Where there are no significant differences between treatments, NS will be displayed as seen in the screenings column below (Table 1).

Table 1. Wheat variety grain yield, protein and screenings from a hypothetical example to illustrate interpretation of p-value and LSD (P≤0.05). Columns with shaded values show the best performing treatments.

Variety	Grain yield (t/ha)	Protein (%)	Screenings (%)
Catapult	3.50^{c}	10.3^{a}	0.2
Ballista	3.98^{b}	8.4^{b}	1.0
Vixen	3.75^{bc}	9.1^{b}	0.5
Scepter	4.05^{b}	8.9^{b}	0.9
Calibre	4.77^{a}	8.4^{b}	0.4
P-value	**0.002**	**<0.001**	**0.062**
LSD (P≤0.05)	**0.40**	**0.9**	**NS**

Disclaimer

While all due care has been taken in compiling the information within this manual the Hart Field-Site Group Inc or researchers involved take no liability resulting from the interpretation or use of these results.

We do not endorse or recommend the products of any manufacturers referred to. Other products may perform as well or better than those specifically referred to.

Any research with un-registered products and rates in the manual does not constitute a recommendation for that particular use by the researchers or the Hart Field-Site Group Inc.

The 2024 season at Hart

Rebekah Allen[1], Myfanwy Purslow[1], Kaidy Morgan[1] and Rohan Kimber[2]

[1]Hart Field-Site Group, [2]South Australian Research and Development Institute (SARDI)

A dry start to the 2024 season challenged our decision-making on all fronts, from crop choice and seeding decisions, to pre-emergent herbicide selection. Hart and surrounding regions received a late break to the season on May 30, with 16.2 mm of rainfall falling across the following three days. Although summer rainfall across January and February was low, above average rainfall in December of 2023 (Figure 1), contributed to some stored soil moisture at Hart.

Seeding at Hart commenced dry on April 18, with crop establishment, pre-emergent herbicide time of sowing and profitable cereal trials. The majority of Hart's program was sown by mid-May, with seeding completed by June 10. Early sown crops emerged six to eight weeks post seeding, with the majority of crops emerging at a similar time in early June. By this time, Hart had only received 21.6 mm of growing season rainfall (GSR), and crops were developing slowly in marginal moisture and cold conditions. Rainfall throughout June was inconsistent, with small, scattered showers totalling 30.6 mm for the month (Figure 2).

Initial Yield Prophet® outputs in July predicted grain yield outcomes for Scepter wheat ranging from 0.7-6.2 t/ha. Total top-dressed nitrogen applied to wheat varieties at Hart was 60 kg N/ha (130 kg urea), however final yield achieved was only 0.56 t/ha. More information can be found in the HART BEAT newsletter for July: https://www.hartfieldsite.org.au/pages/resources/hart-beat-newsletters.php

October received the highest rainfall for 2024, 48.2 mm which included a 25 mm rainfall event on October 18 (Figure 3). In total, Hart received 240.2 mm of annual rainfall (400 mm average) and 176 mm of GSR (300 mm average). Growing season rainfall at Hart placed the region in a Decile 2 for 2024 rainfall records, when compared to the past 100 years.

The dry conditions experienced, particularly across the northern districts, significantly subdued the intensity of pathogen spore dispersal and lowered the abundance of foliar diseases observed in trials at Hart. New pathogen monitoring technology by Bioscout's Spore Scout unit placed within the Hart field site captured this effect, with low numbers of airborne spores detected for botrytis, blackleg, cereal powdery mildew and generic rust. Access to this data is free during the GRDC funded pilot study and can be accessed by registering your interest at https://www.bioscout.com.au/grdc.

The Bioscout Spore Scout units will remain at Hart during the 2025 season, with additional nearby monitoring sites to compare outputs, located throughout the Mid North and upper Yorke Peninsula. Central to these networks are SARDI's Plant Health Surveillance sentinels, working in collaboration with Bioscout to better inform growers on the abundance of airborne plant pathogens. Access to deployments of SARDI sentinels is free at: https://phs.dtfx.com.au/dashboard/previousdeployments

Drought conditions in the Mid North farming region in 2024 resulted in low crop yields, however dry seasons still have value in broadacre cropping research and offer valuable insights and information to learn from. The Hart team hope that trial data and other local research findings in this book provide you with value leading into the 2025 cropping season.

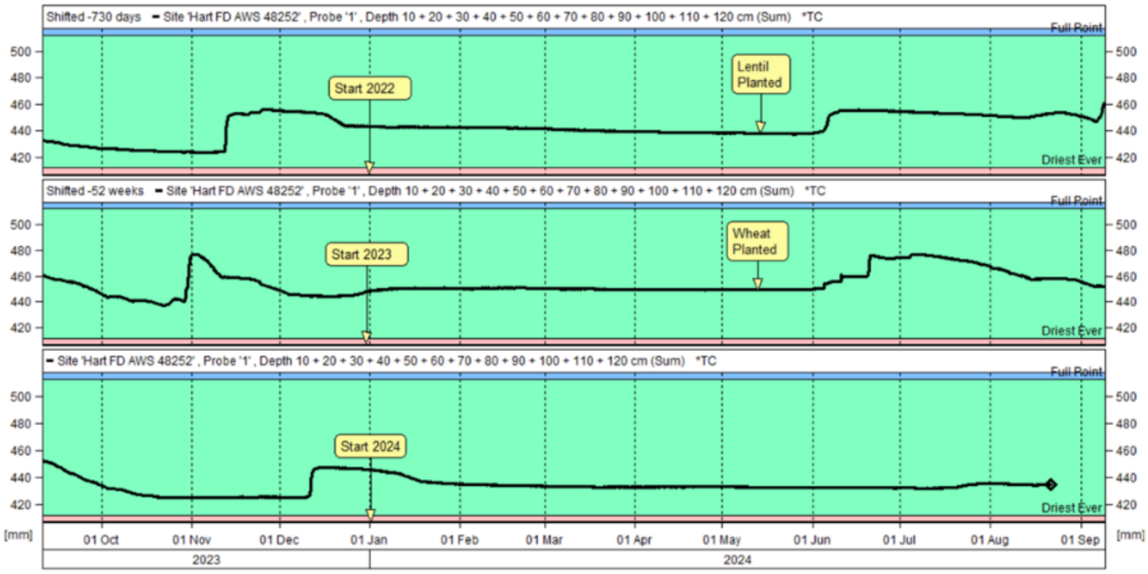


Figure 1. Soil moisture probe summed comparison (120 cm) for 2022 (top), 2023 (middle) and 2024 (bottom) at the Hart field site. This graph shows the fullest and driest points recorded so far (since approximately 2017). Hart soil moisture data is free to view via Agbyte https://www.hartfieldsite.org.au/pages/live-weather/soil-moisture-probe.php

The Hart field site (photo taken August 9, 2024).

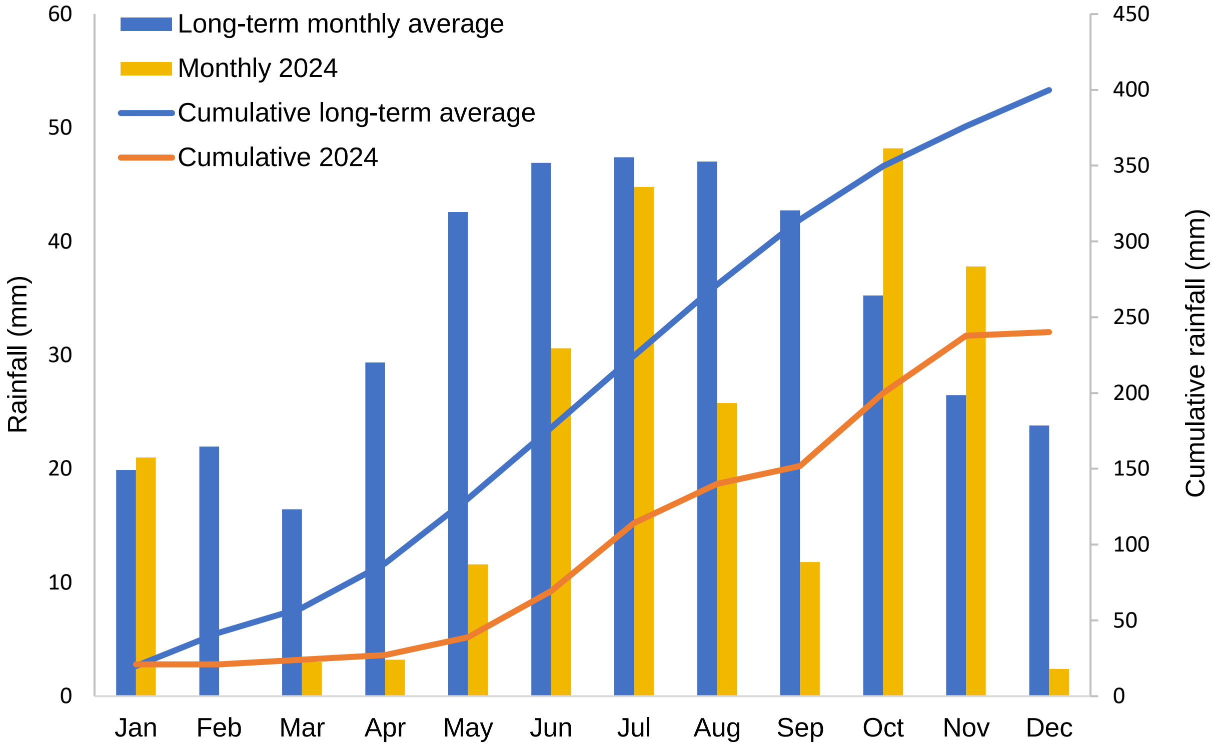


Figure 2. Hart rainfall graph for the 2024 season and long term average. Lines are displayed to present cumulative rainfall for long term average (blue) and 2024 (orange). Current season rainfall data sourced from Mid North Mesonet https://mesonet.com.au/.

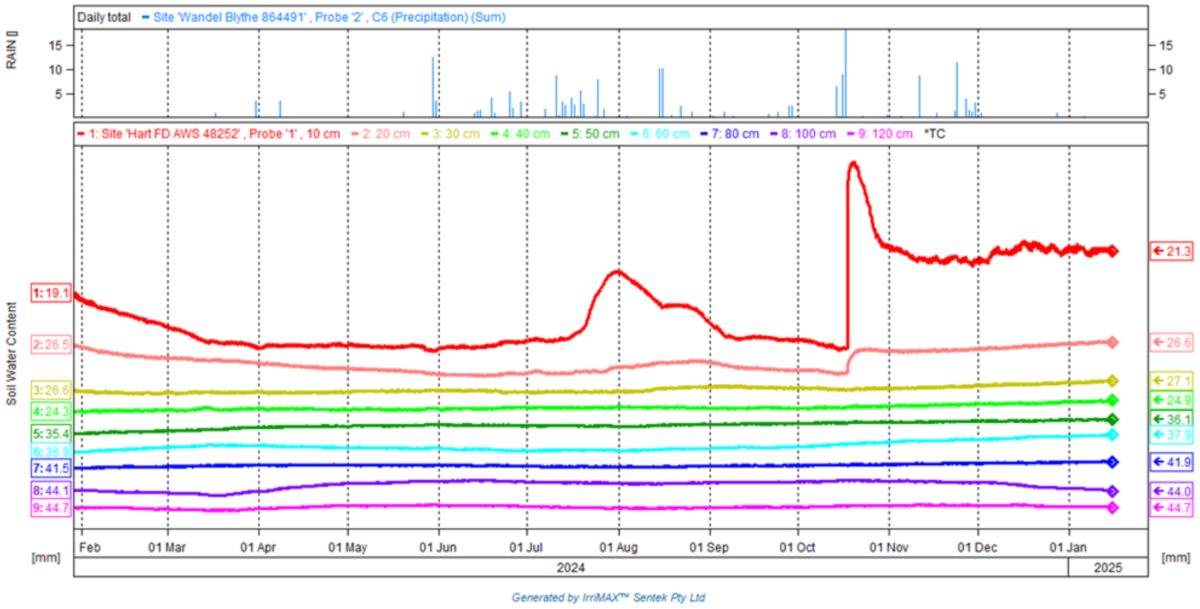


Figure 3. Soil moisture probe stacked sensor for 2024 growing season at the Hart field site. The red peak indicates an October rainfall event at Hart (48.2 mm), infiltrating to approximately 20 cm. Hart's soil moisture data is free to view via Agbyte: https://www.hartfieldsite.org.au/pages/live-weather/soil-moisture-probe.php.

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Growing possibilities

Comparison of wheat varieties and summary of nitrogen decisions

Kaidy Morgan and Rebekah Allen
Hart Field-Site Group

Key findings

- Decile 2 (176 mm) growing season rainfall (GSR) at Hart in 2024 affected yield potential and quality of all wheat varieties tested, with high variability noticed across the trial site.
- Overall, grain yield (t/ha) was similar across most varieties, with all yields achieving <1 t/ha.
- Grain quality was high for screenings (%) and protein (%). Test weight (kg/hL) was not measured due to insufficient sample size.
- A total of 60 kg N/ha (130 kg urea) was applied to wheat varieties. This decision predominately took into account starting soil N, crop yield outcomes across deciles and the seasonal outlook. At the time of key decision making, the likelihood of receiving above average rainfall from August-October was 52%.

Aim

To compare the performance of new and developing wheat varieties alongside current commercial standards.

Methodology

A trial was implemented at Hart, SA to evaluate wheat variety performance (Table 1). The trial was set up as a randomised complete block design with three replicates and 29 bread wheat varieties. New wheat lines trialed at Hart in 2024 include Tomahawk CL Plus (released in 2023) Shotgun (RAC3227), LRPB Major, Boa (LPB19-8035) and coded lines: V14026-054, LPB20-8165, IGW6924, IGW6895, IGW6993 and IGW6955.

This trial was managed with the application of pesticides to ensure a weed, insect and disease-free canopy. All plots were assessed for grain yield (t/ha), protein (%) and screenings (%). Test weight (kg/hL) was not measured in 2024 due to insufficient sample size for testing. Severe water stress in 2024 resulted in a strong edge row effect, therefore all edge rows were removed prior to harvest to improve accuracy of grain yield results. Trial data was analysed using REML spatial model (Regular Grid) with Bonferroni test in GenStat 24th Edition. Due to drought conditions experienced, high variability was noticed across this trial site, therefore interpretation of results presented should consider this.

Table 1. Trial details for 2024 wheat variety comparison at Hart, SA.

Plot size	0.92 m x 10.0 m	**Soil N**	65 kg N/ha
Seeding date	May 14, 2024	**fertiliser**	Seeding: DAP (18:20) Zn 1% + Flutriafol @ 80 kg/ha July 10: 30 kg N/ha (applied as Easy N @ 42.75 kg/ha) August 8: 30 kg N/ha (applied as urea @ 44 kg/ha)
Location	Hart, SA		
Harvest date	November 14, 2024		
Previous crop	Kingbale oaten hay		
Growing season rainfall	Decile 2 (176 mm)		

Pre-seeding available nitrogen (N) (0–105 cm) at Hart was 65 kg N/ha following an oaten hay crop in 2023. In-season N decisions considered existing soil organic N, Yield Prophet® (based on Scepter wheat), Bureau of Meteorology (BoM) climate outlooks and simple economics.

Prior to N application, the site was highly responsive (Figure 1, Graph A), and it was clear that even a Decile 1 season would require significant N input to achieve water-limited yield potential (PYw). As significant N was required to improve our final yield, 30 kg N/ha (65 kg urea) was applied as a top dress application on July 10. This was due to an opportunistic rain event (18.8 mm within 5 days), closing our yield gap (HART BEAT, 2024).

In July, we had a 32% chance that August–October rainfall will fall into a Decile 1–4 category, and 49% chance of falling into Decile 7–10. Combined, this information informed us that the likelihood of receiving above average rainfall from August-October was 52% which was similar to the long-term odds. This is in contrast to 2023, where we saw a strong swing in the odds to drier seasonal outcomes, with only a 22% chance of above average rainfall (HART BEAT, 2024). Based on this information, at the time of follow-up application of N, another 30 kg N/ha was applied, (in-crop total of 60 kg N/ha applied). After this application, there was still a slight to moderate gap between nitrogen and water-limited yield from decile 5 onwards (Figure 1, Graph B).

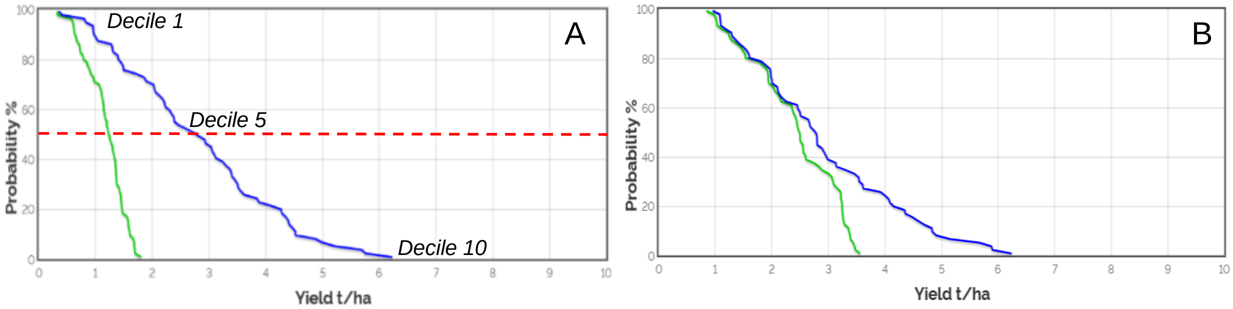

Figure 1. Yield Prophet® Output 1 (Graph A) for the Hart field site on July 10, 2024 for Scepter wheat with no in-crop N applied. This graph shows N responsiveness across all decile outcomes with PYw ranging from 0.5–6.3 t/ha. Yield Prophet® Output 2 (Graph B) shows predicted yields after a total of 60 kg N/ha was applied across two in-crop timings.

Results and Discussion

Grain yield

Decile 2 GSR (176 mm) in 2024 significantly reduced yield potential at Hart. Low stored soil moisture and a late season break received on May 29 increased reliance on late season rainfall to improve yield potential. Below average rainfall for the growing season (April–October) resulted in low yields across all varieties.

In addition to low yield, high variability was noticed across the wheat variety trial site, exacerbated by dry conditions, and impacting results. Therefore, most varieties at Hart performed similarly with no wheat variety achieving above 1 t/ha. Wheat varieties yielded lower than barley this season at the Hart field site, which was unexpected. This result was due to trial location with reduced water availability at the wheat site.

Grain quality

Similarly to grain yield, quality was affected by drought conditions experienced at Hart in 2024. Poor grain fill resulting from water stress caused high protein and also high screenings, with all varieties exceeding the 5% maximum screenings threshold for H1 receival standards.

Summary

Decile 2 (176 mm) GSR at Hart in 2024 resulted in poor and variable yields across the wheat variety trial. High protein and high screenings across all varieties can be attributed to severe water stress during grain fill, leading to higher protein concentration in the small amount of grain present.

Table 2. Wheat grain yield (t/ha) and quality results at Hart in 2024. Test weight (kg/hL) not included as 2024 sample insufficient size for testing.

Quality	Variety	Grain yield (t/ha)	% of site average	Protein (%)	% of site average	Screenings (%)	% of site average
AH	LRPB Anvil CL Plus	0.64^{bc}	115	17.07^{ab}	99	24.15^{a-d}	134
	Ballista	0.59^{bc}	107	16.97^{ab}	98	17.78^{a-d}	99
	Calibre	0.67^{bc}	122	17.91^{ab}	104	31.06^{bd}	173
	Catapult	0.55^{a-c}	99	16.73^{ab}	97	10.36^{a-d}	58
	LRPB Dual	0.45^{a-c}	81	18.75^{ab}	109	16.94^{a-d}	94
	Hammer CL Plus	0.64^{bc}	116	17.12^{ab}	99	23.28^{a-d}	129
	IGW6993	0.58^{a-c}	104	16.69^{ab}	97	13.18^{a-d}	73
	Kingston	0.47^{a-c}	85	16.21^{a}	94	29.57^{cd}	164
	LRPB Matador	0.68^{bc}	122	16.94^{ab}	98	19.8^{a-d}	110
	LRPB Major	0.28^{ab}	51	17.17^{ab}	99	5.83^{a}	32
	Boa (LPB19-8035)	0.65^{bc}	118	15.77^{a}	91	16.94^{a-d}	94
	Reilly	0.71^{bc}	127	16.62^{ab}	96	18.76^{a-d}	104
	Genie	0.35^{a-c}	63	17.51^{ab}	101	15.89^{a-d}	88
	RockStar	0.41^{a-c}	73	17.63^{ab}	102	11.17^{a-d}	62
	Scepter	0.56^{a-c}	101	17.29^{ab}	100	15.47^{a-d}	86
	Shotgun (RAC3227)	0.57^{a-c}	103	18.26^{ab}	106	17.52^{a-d}	97
	Sunblade CL Plus	0.35^{a-c}	64	16.16^{a}	94	18.3^{a-d}	102
	Vixen	0.67^{bc}	120	17.89^{ab}	104	25.85^{a-d}	144
	H1 receival standard			≥ 13		≤ 5	
APW	Brumby	0.57^{a-c}	103	17.05^{ab}	99	12.24^{a-d}	68
	Dozer CL Plus	0.68^{c}	123	17.78^{ab}	103	16.32^{a-d}	91
	Mowhawk	0.19^{a}	35	17.2^{ab}	100	9^{ab}	50
	Soaker	0.67^{bc}	121	16.8^{ab}	97	15.86^{a-d}	88
	Sheriff CL Plus	0.45^{a-c}	82	18.2^{ab}	105	10.13^{a-c}	56
	Tomahawk CL Plus	0.71^{c}	129	16.94^{ab}	98	15.8^{a-d}	88
	APW1 receival standard			≥ 10.5		≤ 5	
Pending quality	LPB20-8165	0.56^{a-c}	101	17.74^{ab}	103	18.46^{a-d}	103
	IGW6895	0.75^{c}	135	16.99^{ab}	98	18.55^{a-d}	103
No further development	IGW6924	0.52^{a-c}	95	19.31^{b}	112	29.06^{bcd}	162
	IGW6955	0.54^{a-c}	98	18.4^{ab}	106	22.02^{a-d}	122
	V14026-054	0.48^{a-c}	87	16^{a}	93	22.06^{a-d}	123
	Site average	0.55		17.3		18.0	

Table 3. Long term wheat variety performance at Hart for 2020–2024 seasons (expressed as a % of trial average).

		% Trial average					Grain yield (t/ha)
Quality	**Variety**	**2020**	**2021**	**2022**	**2023**	**2024**	**2024**
AH	LRPB Anvil CL Plus		105	81	87	115	0.64
	Ballista	95	100	108	106	107	0.59
	Calibre		112	99	108	122	0.67
	Catapult	107	96	105	101	99	0.55
	Devil	109		98			
	LRPB Dual				99	81	0.45
	Grenade CL Plus	93	93	97	96		
	Hammer CL Plus	106	108	89	94	116	0.64
	Kingston		101	95	106	85	0.47
	LRPB Scout	106	86	101	98		
	LRPB Matador				104	122	0.68
	LRPB Major					51	0.28
	Boa (LPB19-8035)					118	0.65
	IGW6993					104	0.58
	Reilly			102	102	128	0.71
	Genie				95	64	0.35
	RockStar	108	80	107	95	73	0.41
	Scepter	101	113	100	108	101	0.56
	Shotgun (RAC3227)					103	0.57
	Sunblade CL Plus		105	111	114	64	0.35
	Valiant CL Plus		93	100	95		
	Vixen	109	130	96	105	120	0.67
APW	Brumby		115	104	104	103	0.57
	Chief CL Plus	113	102	85	95		
	Cutlass	81	76				
	Dozer CL Plus				98	123	0.68
	Denison		86	110	105		
	Mowhawk				100	35	0.19
	Soaker				99	121	0.67
	LRPB Trojan	94	93	105	106		
	Sheriff CL Plus	100	107	96	89	82	0.45
	Tomahawk CL Plus					129	0.71
ASW	Razor CL Plus	98	111	94	98		
Pending	LPB20-8165					101	0.56
	IGW6895					136	0.75
	Trial average yield (t/ha)	**2.50**	**2.03**	**4.40**	**3.75**	**0.55**	
	Sowing date	May 6	May 3	May 5	May 12	May 14	
	April-October rain (mm)	336	232	355	236	176	
	Annual rain (mm)	503	401	519	355	240	

Acknowledgements

The Hart Field-Site Group would like to acknowledge the generous support of our sponsors who provide funding that allows us to conduct this trial. Proceeds from Hart's ongoing commercial crop also support Hart's research and extension program. We would also like to thank InterGrain, AGT, LongReach and Seednet for providing seed to conduct this trial.

This trial is funded by

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Comparison of barley varieties

Myfanwy Purslow and Rebekah Allen
Hart Field-Site Group

Key findings

- Drought conditions at Hart in 2024 contributed to low barley yield and high variability across the site. This should be considered when interpreting results.
- The trial average for all barley varieties was 0.69 t/ha with most varieties performing similarly.
- All varieties exceeded the maximum protein threshold of 12% for Malt 1 receival standards, with an average of 16.93%. Most varieties performed well for grain quality parameters including screenings, retention and test weight.
- Long-term yield data shows that Combat, Minotaur, Compass and Beast continue to perform well across a number of seasons at Hart.

Aim

This trial was conducted to compare the performance of new barley varieties alongside current industry standards.

Methodology

A trial was established at the Hart field site in 2024 to evaluate the performance of new and existing barley varieties. The trial was designed as a randomised complete block design with three replicates and included a total of 20 barley varieties (Table 2). New lines trialed at Hart include Australian Grain Technologies (AGT) PegasusAX (AGTB0667) and Bigfoot CL (AGTB0669), RAGT coded lines RP14033 and RP15034, InterGrain Granite CL (IGB21092T) and coded line 19Y027S-003 from Seednet.

This trial was managed with the application of pesticides to ensure a weed, insect and disease-free canopy. All varieties were assessed for grain yield (t/ha), protein (%) screenings (%) and retention (%). Severe water stress in 2024 resulted in a strong edge row effect. Edge rows were therefore removed prior to harvest to accurately reflect grain yield results achieved in the region. Due to unforeseen issues on site, one of three replicates could not be harvested. Drought conditions experienced at Hart contributed to variability across trial data, so the interpretation of results presented should consider this. All data was analysed using ANOVA in Genstat 24th Edition.

Table 1. Trial details for 2024 barley variety comparison at Hart, SA.

Plot size	0.92 m x 10.0 m	**Fertiliser**	Seeding: DAP Zn 1% + Flutriafol @ 80 kg/ha July 10: Urea (46:0) @ 30 kg/ha August 15: Urea (46:0) @ 30 kg/ha)
Seeding date	May 17, 2024		
Location	Hart, SA		
Harvest date	October 29, 2024		
Previous crop	Kingbale oaten hay		
Growing season rainfall	Decile 2 (176 mm)		

Results and Discussion

Grain yield

The 2024 season at Hart, and more broadly across the Mid North region, experienced dry conditions with rainfall well below average. Hart received 176 mm growing season rainfall (GSR) from April–October (300 mm GSR average) with almost 50 mm of this rainfall received mid-October. Barley grain yields achieved in this trial were below the long-term district average, with only one variety exceeding grain yields of 1 t/ha. This yield outcome has not been observed at the Hart field site since 2008 (204 mm GSR).

The average grain yield achieved for all barley varieties at Hart in 2024 was 0.69 t/ha compared to 4.66 t/ha achieved in 2023 (236 mm GSR). Similarly to wheat varieties at Hart in 2024, yield potential was reduced due to low stored soil moisture and Decile 2 conditions. High variability across the site was observed due to dry conditions, providing little to no difference between barley grain yield results for varieties (Table 2). Long-term yield data shows that Combat, Minotaur, Compass and pending malt accreditation variety Beast, have performed well across a number of seasons at Hart (Table 3).

Grain quality

All barley varieties at Hart achieved protein above the maximum receival standard threshold of 12% (Malt grade 1). This was likely due to low rainfall and low yield increasing protein concentration in grain. All barley varieties had good test weight above 65 kg/hL and 62.5 kg/hL for feed grade barley. Almost all varieties were within their receival standard threshold for screenings and retention, where small differences between varieties are observed.

Photo: Barley variety trial at the Hart field site on October 16, 2024.

Table 2. Barley grain yield (t/ha) and quality results at Hart in 2024.

Quality	Variety	Grain yield t/ha	% of site average	Protein %	% of site average	Test weight kg/hL	% of site average	Screenings %	% of site average	Retention %	% of site average
Feed	Bigfoot CLⓓ (AGTB0669)	0.73^{ab}	1.0	17.0^{ab}	1.0	74.7^{cd}	1.0	2.6^{a}	0.6	84.0^{bc}	1.0
	Combatⓓ	0.96^{ab}	1.3	14.7^{a}	0.8	72.3^{ab}	0.9	2.1^{a}	0.5	80.2^{bc}	1.0
	Graniteⓓ CL (IGB21092T)	0.89^{ab}	1.2	14.5^{a}	0.8	72.6^{abc}	0.9	3.1^{a}	0.8	74.5^{bc}	0.9
	PegasusAXⓓ (AGTB0667)	0.80^{ab}	1.1	17.4^{ab}	1.0	73.8^{abc}	1.0	6.8^{a}	1.7	65.2^{ab}	0.8
Bar 1 Receival Standards				**NA**		**>62.5**		**<15**		**NA**	
Malt	Commodusⓓ CL	0.54^{ab}	0.7	16.8^{ab}	1.0	74.5^{bcd}	1.0	3.5^{a}	0.9	83.4^{bc}	1.0
	Compassⓓ	0.79^{ab}	1.1	17.9^{ab}	1.0	74.3^{bcd}	1.0	2.7^{a}	0.7	87.0^{bc}	1.1
	Maximusⓓ CL	1.30^{b}	1.8	14.5^{a}	0.8	73.8^{abc}	1.0	1.7^{a}	0.4	84.1^{bc}	1.0
	Minotaurⓓ	0.90^{ab}	1.2	15.1^{a}	0.8	74.2^{bcd}	1.0	3.6^{a}	0.9	71.1^{abc}	0.9
	RGT Planetⓓ	0.56^{ab}	0.8	17.8^{ab}	1.0	74.5^{bcd}	1.0	3.5^{a}	0.9	80.9^{bc}	1.0
	Spartacus CLⓓ	0.94^{ab}	1.3	16.8^{ab}	0.9	74.2^{bcd}	1.0	2.7^{a}	0.7	73.3^{bc}	0.9
Malt 1 Receival Standards				**9 - 12%**		**>65**		**<7**		**>70**	
Pending malt accreditation	19Y027S-003	0.44^{a}	0.6	16.1^{ab}	0.9	76.2^{d}	1.0	1.9^{a}	0.5	91.6^{c}	1.1
	Beastⓓ	0.89^{ab}	1.2	16.6^{ab}	0.9	73.3^{abc}	0.9	2.7^{a}	0.7	89.5^{c}	1.1
	Cyclopsⓓ	0.62^{ab}	0.8	17.6^{ab}	1.0	73.3^{abc}	0.9	2.8^{a}	0.7	80.8^{bc}	1.0
	Laperouseⓓ	0.71^{ab}	1.0	17.2^{ab}	1.0	74.0^{bcd}	1.0	3.0^{a}	0.8	73.0^{bc}	0.9
	Neoⓓ	0.49^{ab}	0.7	17.7^{ab}	1.0	73.4^{abc}	1.0	4.6^{a}	1.2	76.3^{bc}	0.9
	Spinnakerⓓ	0.40^{ab}	0.5	20.3^{b}	1.2	71.6^{a}	0.9	13.9^{b}	3.6	48.3^{a}	0.6
	Titan AXⓓ	0.57^{ab}	0.8	16.2^{ab}	0.9	74.4^{bcd}	1.0	2.5^{a}	0.6	89.2^{c}	1.1
*Under evaluation	AGTB0532	0.69^{ab}	0.9	16.6^{ab}	0.9	72.9^{abc}	0.9	4.8^{a}	1.2	73.9^{bc}	0.9
	RP14033	0.33^{a}	0.4	18.7^{ab}	1.1	72.7^{abc}	0.9	2.8^{a}	0.7	76.5^{bc}	0.9
	RP15034	0.33^{a}	0.4	18.7^{ab}	1.1	73.7^{abc}	1.0	5.0^{a}	1.3	73.2^{bc}	0.9
	Site average	**0.69**		**16.9**		**73.7**		**3.8**		**77.8**	

Table 3. Long-term barley variety performance at Hart for 2020–2024 seasons (expressed as a % of trial average).

		% Trial average					**Grain yield (t/ha)**
Quality	**Variety**	**2020**	**2021**	**2022**	**2023**	**2024**	**2024**
Feed	Bigfoot CLᶲ (AGTB0669)					108	0.73
	Combatᶲ			112	110	142	0.96
	Fathomᶲ	112	107	101			
	Granite CLᶲ (IGB21092T)					132	0.89
	Hindmarshᶲ						
	PegasusAXᶲ (AGTB0667)					118	0.80
	Rosalindᶲ	100	105	101	102		
Malt	Commander	95					
	Commodusᶲ CL		100	95	97	80	0.54
	Compassᶲ	99	112	90	101	116	0.79
	La Trobeᶲ	94					
	Leabrookᶲ	107	107	96	98		
	Maximusᶲ CL	95	96	91	93	193	1.30
	Minotaurᶲ		101	107	106	133	0.90
	RGT Planetᶲ	111	86	119	100	82	0.56
	Spartacus CLᶲ	89	83	91	94	139	0.94
Pending malt accreditation	19Y027S-003					65	0.44
	Beastᶲ	99	111	96	105	132	0.89
	Cyclopsᶲ		103	101	96	92	0.62
	Laperouseᶲ	105	112	87	94	105	0.71
	Neoᶲ					72	0.49
	Spinnakerᶲ				98	59	0.40
	Titan AXᶲ			96	102	84	0.57
	Zena CLᶲ			117	98		
Under evaluation	AGTB0532					101	0.69
	RP14033					48	0.33
	RP15034					48	0.33
	Trial average yield (t/ha)	**3.18**	**2.61**	**5.99**	**4.66**	**0.68**	
	Sowing date	**May 16**	**May 3**	**May 5**	**May 12**	**May 17**	
	April-October (mm)	355	232	355	236	176	
	Annual rainfall (mm)	503	401	519	355	240.2	

Acknowledgements

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This trial is funded by

Comparison of lentil and field pea varieties

Myfanwy Purslow[1], Rebekah Allen[1] and Sarah Day[2,3]

[1]Hart Field-Site Group, [2]South Australian Research and Development Institute (SARDI), [3]University of Adelaide

Key findings

- Most lentil varieties performed similarly, with yields ranging from 0.07 t/ha to 0.20 t/ha at Hart in 2024 under dry conditions.
- No yield differences were observed for field pea varieties with a trial average of 0.77 t/ha.
- Pulse disease risk was very low in 2024 due to delayed sowing and extended dry conditions, resulting in majority of pulse crops not reaching full canopy closure.

Aim

To compare the performance of pre-commercial and newly released lentil and field pea lines to current commercial variety options in the medium rainfall zone of South Australia (SA).

Methodology

Two variety trials were established at Hart, SA, to investigate the performance of (1) lentil and (2) field pea varieties (Table 1). These trials have been run at Hart since 2020 to evaluate varieties across multiple seasons. Trials were designed as a randomised complete block design with three replicates.

A total of 14 lentil varieties were evaluated, including three pre-commercial Grains Innovation Australia (GIA) breeding lines; GIA2302L, GIA2301L and GIA2303L. In the field pea variety evaluation, a total of 12 varieties were trialed including one new and three pre-commercial lines: APB Bondi (OZP1903), APB2402, APB2401 and GIA2203P. All varieties received the same agronomic management to ensure a weed, insect and disease-free canopy. Only two replicates could be analysed for lentil grain yield results due to non-random factors affecting one replicate in third bay of trial. Analysis was conducted using ANOVA (Tukey test) in GenStat 24th Edition. Caution should be taken when interpreting results due to the lack of replication. The field pea trial data was analysed using REML spatial model (Regular Grid) with Bonferroni test to separate variety means in GenStat 24th Edition.

Table 1. Site details for the 2024 lentil and field pea variety trials located at Hart field site, SA

Lentil	**Plot size:**	1.75 m x 10 m	**Fertiliser:**	MAP (10:20) + 1% Zn @ 80 kg/ha
	Seeding date:	June 5, 2024		
	Harvest date:	October 30, 2024		
	Previous crop:	Oaten hay		
Field pea	**Plot size:**	2.0 m x 10 m	**Fertiliser:**	MAP (10:20) + 1% Zn @ 80 kg/ha
	Seeding date:	June 5, 2024		
	Harvest date:	October 29, 2024		
	Previous crop:	Oaten hay		

Across all lentil and field pea varieties, yields achieved were well below average, resulting from drought conditions experienced at Hart in 2024. Growing season rainfall (April–October) was 176 mm, compared to the long-term average of 300 mm.

Lentil

Small differences were observed in grain yield between varieties; however, grain yields were low, ranging from 0.07 t/ha to 0.20 t/ha (70–200 kg/ha) at Hart in 2024 (Table 2). PBA Highland XT and PBA Hallmark XT (0.20 t/ha) were higher yielding than ALB Terrier and GIA Leader (0.07 t/ha).

Table 2. Grain yield (t/ha) and maturity characteristics (P = provisional) of lentil varieties at Hart in 2024. Data presented with the same letters are not significantly different (P≤0.05). Lentil maturity characteristics sourced from 2025 South Australian Crop Sowing Guide.

Lentil variety	**Maturity**	**Grain yield (t/ha)**
ALB Terrierᶲ (CIPAL2122)	Mid	0.07^{a}
GIA Leaderᶲ	Mid-late	0.07^{a}
GIA Sireᶲ	Mid	0.09^{ab}
GIA Metroᶲ	Mid-late	0.10^{ab}
GIA2303L	Mid (p)	0.12^{ab}
GIA2301L	Mid (p)	0.12^{ab}
GIA2302L	Early–mid (p)	0.15^{ab}
GIA Lightningᶲ	Mid	0.15^{ab}
PBA Jumbo2ᶲ	Mid	0.15^{ab}
PBA Kelpie XTᶲ	Early-mid	0.16^{ab}
GIA Thunderᶲ	Mid	0.16^{ab}
PBA Hurricane XTᶲ	Mid	0.16^{ab}
PBA Hallmark XTᶲ	Mid	0.20^{b}
PBA Highland XTᶲ	Early-mid	0.20^{b}
Average grain yield (t/ha)		**0.14**
P-value		**0.007**

In a small secondary lentil trial sown at Hart on June 5, GIA Thunder and PBA Highland XT were equally higher yielding than ALB Terrier (Table 3). However, there is only 140 kg/ha difference between the lowest and highest yielding variety due to the dry conditions and coinciding low yield in 2024. Similar trends were observed in the main variety trial shown above (Table 2).

Long-term yield data shows that PBA Jumbo2 and GIA Thunder have consistently performed well across the past four seasons at Hart (Table 4).

Table 3. Lentil variety grain yield and grain weight for secondary trial at Hart in 2024. Data in each column with the same letters are not significantly different (p≤0.05).

Variety	**Grain Yield (t/ha)**	**Grain weight (g/100 seeds)**
GIA Thunderⓑ	0.85^{a}	3.46^{c}
ALB Terrierⓑ	0.73^{b}	3.61^{b}
PBA Highland XTⓑ	0.87^{a}	3.70^{a}
P-value	**<0.001**	**<0.001**

Variety notes

PBA Highland XT is an IMI-tolerant lentil with early flowering and early to mid-maturity with high early vigour and an upright plant type.

GIA Thunder is a broadly adapted IMI-tolerant lentil with mid flowering and mid maturity and has been a high yielding variety at Hart over the past four seasons (Table 4).

PBA Jumbo2 is a high yielding conventional, non-herbicide tolerant, lentil with an excellent disease resistance profile, mid flowering and mid maturity.

ALB Terrier is a new broadly adapted IMI-tolerant lentil with mid-flowering and mid maturity characteristics, and good disease resistance profile.

GIA Leader is an IMI-tolerant variety with mid to late flowering and maturity (2025 South Australian Crop Sowing Guide).

GIA Metro is unique to other lentil varieties due to its dual herbicide tolerance (metribuzin and Imidazolinone). While the dual technology of GIA Metro is a huge benefit in situations where weeds are controlled or non-existent, the dual technology generally results in GIA Metro having lower grain yields when compared to Imidazolinone (IMI) tolerant and conventional lentil varieties (Grains Innovation Australia (GIA) and PB Seeds, 2003). Additionally, GIA Metro is a late flowering and a late maturing variety. When combined with the dry and short growing season of 2024 (Grains Innovation Australia (GIA) and PB Seeds, 2003), to which it is poorly suited, low yield results are not unexpected.

Table 4. Long-term yield data for lentil varieties at Hart 2020-2024.

	% of trial average					**Grain yield (t/ha)**
Variety	**2020**	**2021**	**2022**	**2023**	**2024**	**2024**
ALB Terrierⓓ (CIPAL2122)					52	0.07
GIA2301L					89	0.12
GIA2302L					111	0.15
GIA2303L					89	0.12
GIA Leaderⓓ	98	103	105	99	52	0.07
GIA Lightningⓓ			105	105	111	0.15
GIA Metroⓓ (GIA2004L)			80	81	74	0.10
GIA Sireⓓ (GIA1703L)			80	92	66	0.09
GIA Thunderⓓ (GIA2002L)		113	123	110	118	0.16
PBA Blitzⓓ			90	100		
PBA Boltⓓ			90	104		
PBA Hallmark XTⓓ	95	97	99	97	148	0.20
PBA Highland XTⓓ	100	99	104	100	148	0.20
PBA Hurricane XTⓓ	91	95	105	93	118	0.16
PBA Jumbo2ⓓ	104	110	108	105	108	0.15
PBA Kelpie XTⓓ	106	82	94	103	118	0.16
Average grain yield (t/ha)	**1.62**	**1.30**	**5.42**	**1.81**	**0.14**	
Sowing date	May 18	May 18	June 9	June 1	June 5	
April-October (mm)	355	232	355	236	176	
Annual rainfall (mm)	503	401	519	355	240	

Field pea

There were no observed yield differences across field pea varieties at Hart in 2024 (Table 5). Grain yields ranged from 0.65–0.87 t/ha with a trial average of 0.77 t/ha. Long-term yield data for field pea varieties at Hart can be found in Table 6.

Table 5. Field pea grain yield (t/ha) data at Hart in 2024.

Field pea variety	**Grain yield (t/ha)**
GIA2203P	0.87
APB Bondiⓓ (OZP1903)	0.86
PBA Whartonⓓ	0.82
APB2401	0.80
PBA Ouraⓓ	0.78
GIA Ourstarⓓ	0.77
Kaspaⓓ	0.75
PBA Gunyahⓓ	0.75
APB2402	0.73
GIA Kastarⓓ	0.71
PBA Butlerⓓ	0.70
PBA Taylorⓓ	0.65
Average grain yield (t/ha)	**0.77**
P-Value	**NS**

Table 6. Long-term yield data for field pea varieties at Hart 2020-2024.

% of trial average						**Grain yield (t/ha)**
Variety	**2020**	**2021**	**2022**	**2023**	**2024**	**2024**
APB2401					104	0.80
APB2402					94	0.73
APB Bondiⓑ (OZP1903)					112	0.86
Kaspaⓑ	112	113	106	102	97	0.75
GIA2202P			110	95		
GIA2203P				101	113	0.87
GIA Kastarⓑ	98	88	86	99	93	0.71
GIA Ourstarⓑ	111	93	84	85	100	0.77
PBA Butlerⓑ	94	108	112	101	91	0.70
PBA Gunyahⓑ			93	99	97	0.75
PBA Ouraⓑ	101		101	99	102	0.78
PBA Pearlⓑ			106	103		
PBA Percyⓑ			99	98		
PBA Taylorⓑ			105	110	84	0.65
PBA Whartonⓑ	83	98	99	109	106	0.82
Average grain yield (t/ha)	**1.38**	**1.61**	**3.63**	**2.23**	**0.77**	
Sowing date	May 18	May 18	June 9	June 1	June 5	
April-October (mm)	355	232	355	236	176	
Annual rainfall (mm)	503	401	519	355	240.2	

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Optimising barley biomass production through phenology and plant architecture in mixed farming systems

Brendan Kupke[1,2,3], Mick Faulkner[4], Ben Smith[5], Rhiannon K Schilling[1,2,3]

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Key findings

- At Giles Corner in 2024, grain yield was significantly higher in elite spring grain varieties compared to winter types with Neo CL (5.58 t/ha) and Titan AX (5.44 t/ha) being top performers.
- The yield of simulated grazed plots compared to un-grazed (control) achieved similar grain yields in majority of treatments.
- Improved harvest index in grazed plots helped maintain high grain yields compared to lower harvest index achieved in the un-grazed (control).
- The variety Beast was a top performer for early season DM production and total seasonal forage value compared to other varieties tested.
- The winter type variety Newton had three simulated grazes in the Up to Z (Zadocks) 30 treatment removing a cumulative total of 3.13 t/ha DM, prior to additionally yielding 3.39 t/ha of grain.

Introduction

Barley is a versatile species for mixed farming systems because it offers opportunities for fast feed production for livestock as well as reliable grain production across varied seasons. Previous work has demonstrated the benefits of wheat, and to a less extent barley, in providing dual purpose (graze and grain) crops that maximise gross margins in the medium-high rainfall zones. Other recent work with wheat has shown the value of sowing slower developing winter wheats early. The release of new winter barley phenologies, as well as different canopy architecture types, may provide more opportunities to optimise barley biomass for forage, grain, or opportunistic grain and graze scenarios in different environments. The aim of this SA Discovery Farms and SAGIT co-funded project is to identify opportunities to exploit new barley phenologies and architecture types to further improve mixed farming production across variable growing seasons.

Methodology

A field trial was established at Giles Corner on a red clay loam over rock soil, which was dry sown on May 14 with germination occurring after season breaking rains on June 1. Rainfall for the growing season totalled 232 mm (April-October), which was in the lowest 10% of years for Giles Corner (Decile 1). There was limited heat stress during the growing season, but there were several frost events, with significant ones including: -3.3°C September 13, -3°C September 18, -1.4°C September 26 (measured at 1.2 m by a TinyTag within a Stevenson screen). Weeds, pests and diseases were managed using local grower practice and as to not limit grain yield. Starting soil nitrogen was approximately 125 units on a 2023 bean stubble. At sowing, 100 kg/ha DAP was added and topped up with 100 L/ha UAN across the site on July 30. There were 10 barley varieties that varied for both phenology and plant architecture, with a summary of each in Table 1. Varieties were sown to target 150 plants/m^2 with sowing rate adjusted for seed size. Four different grazing treatments were used to demonstrate different use cases of barley in mixed farming systems. A summary of each treatment is presented in Table 2, where a mower was used to simulate grazing for each grazing treatment.

Table 1: Barley varieties used in the trial with relative plant type, maturity and release year.

Variety	**Plant Type**	**Maturity Group**	**Release year**
Beast ⓓ	Tall	Quick spring	2020
Neo ⓓ CL	Semi-prostrate	Mid spring	2023
Kraken ⓓ	Semi-prostrate	Mid spring	2021
Maximus ⓓ CL	Erect	Quick-mid spring	2020
Newton ⓓ	Prostrate	Slow winter	2023
Titan AX ⓓ	Tall	Mid-slow spring	2022
RGT Planet ⓓ	Semi-prostrate	Mid spring	2017
Cyclops ⓓ	Erect	Quick-mid spring	2022
SEC047	Tall	Very quick spring	Not released
AGTB1007	Semi-prostrate	Winter	Not released

Table 2: Four grazing treatments with the farming system scenario, activities performed and projected outcomes of each. Z30 = Zadoks growth stage 30 (start of stem elongation, Zadoks, 1974).

Treatment	**Scenario**	**Grazing Activity**	**Outcome**
Untreated control (UTC)	Grain	None, managed as a grain crop	Un-grazed grain yield benchmark
Up to Z30	Rotational grazing to Z30 and grain	Multiple grazes before Z30 (springs x2, winters x3 mows), before being left for grain	Value of longer phenological vegetative phase duration of winters and final grain yield
Z30	Graze and grain	Single graze at Z30 (mown once), before being left for grain	Total vegetative biomass production value and final grain yield
Forage	Continuous grazing	Repeated grazing at regular time intervals during the growing season (July 23, August 9, September 3)	Total seasonal biomass/forage production value for each variety (re-growth potential)

The main measurements taken and discussed within this report are growth stage, dry matter (DM) removed from each grazing, harvest index (HI) and grain yield. Quadrat hand cuts were conducted on plots immediately before being mowed, representing the amount of biomass removed per m^2, which was dried at 60°C for DM. Further analysis is still to come on feed/hay quality, tiller counts, grain quality and a financial breakdown of gross margins.

The trial was a split plot design with grazing treatment being the main plot and variety the sub plot with four replicates. Plot size was 5 m x 1.37 m with 6 rows at 22.86 cm spacings, and plot centres 1.8 m. Data was analysed spatially using a linear mixed model (REML) through statistical package GenStat 23rd Edition at the 5% significance level and by multiple comparisons through a Bonferroni test.

Results and Discussion

Varietal differences in grain yield in response to grazing treatments

Grain yield varied considerably across treatments, with there being a significant interaction of grazing by variety ($p<0.001$). Displayed in Table 3, grain yields achieved were reasonable considering the Decile 1 rainfall, with most treatments falling between 3 to 6 t/ha. For the un-grazed grain plots (UTC), all the elite commercial spring phenology varieties performed well, with Neo CL being the standout out at 5.58 t/ha grain yield. Kraken, a spring forage variety was significantly lower yielding, which was to be expected with it being bred mainly for forage production. The very quick developing breeding line SECO47 was also considerably low, which was likely in combination with a severe frost event on September 13 (-3.3°C). Visual observations two weeks post the frost event identified floret sterility on heads and stunted/pinched grains. The winter phenology types, Newton and AGTB1007 were significantly lower yielding than Neo CL in the UTC, likely related to the late seasonal break an establishment occurring in June. However, AGTB1007 was competitive with other elite spring grain varieties, with no significant difference in grain yield to RGT Planet, Cyclops and Beast, indicating that it may have a more flexible sowing window than other winter types.

Table 3: Grain yield of every variety for grain (UTC), as well as grain and graze (Z30 and Up to Z30) treatments. There was a significant grazing x variety interaction, so different letters represent significant differences between treatments.
** SEC047 UTC experienced a significant frost event at flowering, which likely reduced yields, interpret with caution. na = data not available*

Grain Yield (t/ha)	**Grain and Graze Treatment**		
Variety	**UTC**	**Z30**	**Up to Z30**
Beast Ⓓ	4.99^{hi}	4.89^{hi}	5.01^{hi}
Cyclops Ⓓ	5.33^{hij}	5.00^{hi}	4.92^{hi}
Kraken Ⓓ	3.22^{abc}	3.80^{cde}	4.00^{def}
Maximus Ⓓ CL	4.94^{hi}	4.92^{hi}	4.67^{fgh}
Neo Ⓓ CL	5.58^{ij}	5.77^{j}	5.51^{ij}
RGT Planet Ⓓ	5.15^{hij}	5.18^{hij}	4.95^{hi}
Titan AX Ⓓ	5.44^{ij}	5.37^{hij}	5.33^{hij}
SEC047	*3.06^{ab}	3.78^{cde}	na
AGTB1007	4.72^{gh}	3.69^{b-e}	4.16^{efg}
Newton Ⓓ	4.01^{d-g}	2.82^{a}	3.39^{a-d}
P-value (grazing x variety)	**<0.001**		

The influence of grazing on grain yield was minor for all spring types, with all producing no significant reduction in grain yield compared to the UTC. Again, Neo CL was the standout across grazing treatments, even achieving a small non-significant increase in grain yield in response to a single simulated graze at Z30. Newton and AGTB1007 had significant yield reductions from the Z30 treatment compared to the UTC. However, in contrast both varieties did not have a significant reduction in grain yield for the Up to Z30 grazing treatment compared to the UTC. Both varieties received three simulated grazes for this treatment due to them reaching Z30 much later than the spring types. This extended vegetative phase allowed for more time for potential grazing, resulting in more biomass removal before getting locked up for grain. This longer phase and higher biomass grazed off likely resulted in the reduction in grain yield in a dry finish to the season, which will be discussed further below.

Potential for significant grazing prior to Z30 before being left for grain

The addition of winter and spring phenology types in the trial allowed for direct comparisons of the influence of relative vegetative phase duration (time from germination to start of stem elongation) on the potential DM available for grazing without lowering grain yields. The two grain and graze treatments (Z30 and Up to Z30) produced significantly different DM values between varieties for each treatment (Table 4). The Z30 treatment (single simulated graze at approximately Z30) ranged in DM totals of 0.7 t/ha for SEC047, to Newton producing 2.6 t/ha. This is likely linked to the duration of the vegetative phase for each variety, where SEC047 reached the start of stem elongation (and was grazed) on July 23, while Newton reached Z30 on September 3, effectively giving it five weeks of biomass production. For the Up to Z30 treatment (multiple grazes to Z30), the winter types of AGTB1007 and Newton had significantly more DM from repeat grazing during the vegetative phase compared to the spring types (Table 4). Newton also had significantly more DM than AGTB1007. The opposite occurred for grain yield for these treatments, where AGTB1007 significantly out-yielded Newton.

Table 4: Vegetative dry matter (DM) totals removed through simulated grazing for each variety, and the relative timings for each grazing event. The Z30 treatment involved a single simulated graze at the approximate start of stem elongation. The Up to Z30 treatment had multiple simulated grazes at specified graze timings until the start of stem elongation, with the individual totals added together. There was a significant variety interaction within each treatment, so different letters represent significant differences between varieties. na = data not available

Vegetative dry matter removal	**Up to Z30**		**Z30**	
Variety	**DM (t/ha)**	**Graze timings**	**DM (t/ha)**	**Graze timing**
SEC 047	na	na	0.70^{a}	23 July
Cyclops Φ	1.03^{a}	July 23, August 9	1.02^{a}	August 9
Maximus Φ CL	1.04^{a}	July 23, August 9	1.09^{ab}	August 9
RGT Planet Φ	1.14^{a}	July 23, August 9	1.47^{abc}	August 9
Titan AX Φ	1.15^{a}	July 23, August 9	1.21^{abc}	August 9
Kraken Φ	1.34^{a}	July 23, August 9	1.51^{abc}	August 9
Neo Φ CL	1.39^{a}	July 23, August 9	1.40^{abc}	August 9
Beast Φ	1.43^{a}	July 23, August 9	1.96^{cd}	August 9
AGTB1007	2.15^{b}	July 23, August 9, August 22	1.89^{bcd}	August 22
Newton Φ	3.13^{c}	July 23, August 9, September 3	2.56^{d}	September 3
P-value (variety)	***<0.001***		***<0.001***	

The removal of plant biomass prior to Z30 through simulated grazing had no statistically significant reduction in final grain yield across grain and graze treatments compared to the UTC. However, the grazing prior to Z30 did reduce the final dry matter left at crop maturity. Evident in Figure 1, the two grain and graze treatments generally had a lower final dry matter, with some un-grazed varieties producing over 14 t/ha of DM by harvest time. This is important as final DM is positively correlated with grain yield (Figure 1), known as harvest index (HI). However, the grain and graze treatments were able to maintain high grain yields by significantly improving their HI ratio, with some treatments producing a HI of over 0.5. This demonstrates a strong efficiency of converting DM into grain yield at the end of the season for the grazed treated plots. The correlation for the Z30 (r^2=0.85) and Up to Z30

($r^2=0.77$) is even stronger than the UTC ($r^2=0.66$), which may also indicate that they are all responding similarly in their DM recovery post grazing.

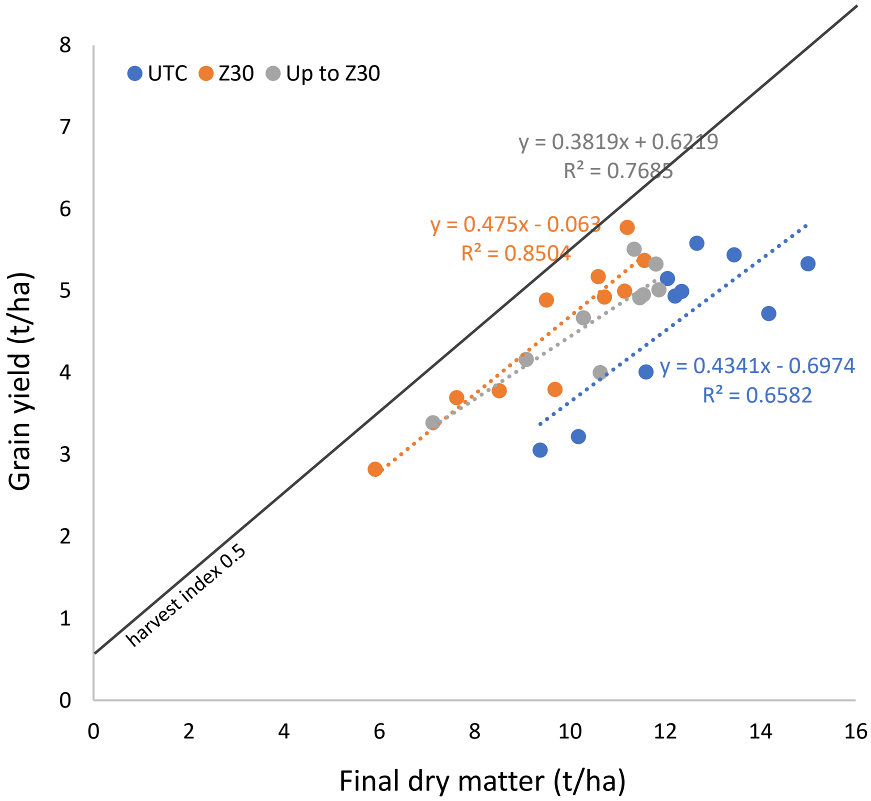

Figure 1: Relationship between grain yield and final dry matter across all barley varieties and individual grazing treatments at Giles Corner in 2024, with the dotted line representing the linear correlation for each grazing treatment. The orange dots are the Z30, grey Up to Z30 treatments, while the blue are the UTC plots. The solid black line is a harvest index ratio of 0.5 that represents a high efficiency of converting biomass into grain yield.

Variety differences in early vigour and total seasonal DM production

The first graze timing on July 23 identified small differences in early DM production between varieties. The top variety, Beast, had 0.77 t/ha of DM was significantly higher than the lowest varieties Maximus CL (0.58 t/ha DM) and Cyclops (0.59 t/ha DM). All other varieties fitted in between and were not significantly different to each other. Even though the differences are small at this time point, any increase in DM would be important for early feed available for livestock, to help address the frequent autumn feed gap in mixed farming systems. Beast performed strongly again following the first simulated graze, also being at the top for the second simulated graze too, with his trend evident (Figure 2). Maximus CL was again significantly lower for DM production post the first graze, with Cyclops performing slightly better, but both still being near the lowest indicating that 'erect' types may not be suitable for early season DM production. Additionally, SEC047 being a very quick developing variety did not produce significantly more DM than other slower developing varieties, suggesting that development speed may not be important for fast early season DM in dry conditions.

The final simulated graze on the September 3 created more variation across varieties due to much more re-growth likely from subsequent rainfall and warmer temperatures. In contrast to previous grazes, Cyclops produced the most DM at 5.01 t/ha compared to Newton being the lowest at 3.6 t/ha DM. For total forage production several varieties grouped together, which included Beast, Kraken, Titan AX, SEC047 and Cyclops, all totalling over 6 t/ha DM cumulative (Figure 2). Maximus remained low for the whole season totalling 4.9 t/ha DM as well Newton dropping off by the last simulated graze at 4.93 t/ha DM. Further seasons data will help in solidifying trends between varieties, as well as potential influences of weed populations with repeat grazing, as there was limited weed pressure in the 2024 trial. However, Beast does initially look to be a strong performer in DM production at Giles Corner, which is consistent with the same trial results from Minnipa in 2024 as well.

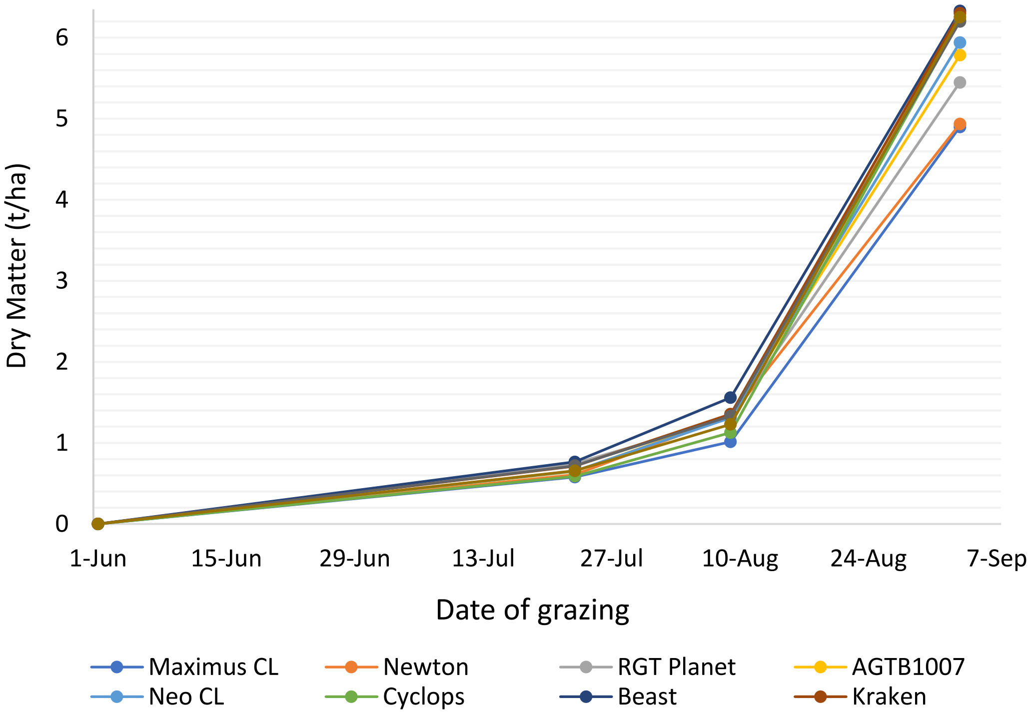

Figure 2: The total cumulative DM produced from the forage treatment, where the same plots were grazed three times during the season (July 23, August 9, September 3).

Conclusions

The impact of grazing on final grain yields at Giles Corner in 2024 was small, with majority of varieties having no significant reduction in grain yield compared to UTC. This is particularly significant during a growing season with Decile 1 rainfall and suggests some varieties tested could have provided a grazing source for livestock in the dry conditions and still recovered the same grain yield as if ungrazed. The grain and graze treatments were able to maintain high yields mainly due to an improved HI ratio across varieties. However, further data to come on grain quality will determine if there was any trade-off in reduced grain quality. The only significant reduction in grain yield following grazing was the two winter types, Newton and AGTB1007. However, these two varieties produced the most vegetative biomass prior to being locked up for grain. This highlights the use-case of the extended vegetative phase of winter phenology types compared to the quicker springs in mixed farming systems. For early season DM production, Beast was the strongest performer, being at the top after each grazing for DM removal.

Acknowledgements

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Achieving water limited yield frontiers more profitably

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Key findings

- A new GRDC project focuses on connecting crop agronomy practices to maximise grain number production and yield potential.
- Modern genetics and advanced crop management are delivering higher water use efficiencies, achieving transpiration efficiencies greater than 25 kg/ha/mm and evaporation losses below 60 mm.
- An extra 30 mm of water in the critical period increased wheat yield by 0.6–1 t/ha at Hart, a transpiration efficiency for grain yield of 20–33 kg/ha/mm.
- Barley suffered greater yield loss than wheat in 2024 at Hart and requires more analysis of water use patterns.

Introduction

A new GRDC project (CSP2404-020RTX - Profitable Yield Frontiers) is focused on supporting tactical agronomy decisions in low to medium rainfall zones to achieve water-limited yield potentials. In these rainfall zones, early season decisions often account for most of the crop expenditure. While higher inputs or adjusted timings can influence yield under different seasonal scenarios, knowing when and how to react, and the likely return, is challenging. Agronomic interventions must address the fundamentals of crop growth to deliver a yield response. Beyond sowing date, genetics, and nitrogen (N), opportunities to influence yield potential in season are limited. Our goal is to develop a responsive agronomic system that increases yields without significantly raising risk or costs.

We conducted a series of experiments across South-eastern Australia to:

1. Link tactical agronomy to physiological changes in the critical period and yield.
2. Identify key benchmarks (crop and soil traits) for actionable decisions during the season.
3. Lift water-limited yield potential in low to medium rainfall zones.

The 2024 season was defined by summer rainfall, a late break, low in-season rainfall, and September frost stress. Our work focused on understanding the crop canopy, how this influences grain yield formation (during the critical period) and refining agronomic benchmarks. This will help to better position crops for success and adapt to seasonal water supply fluctuations.

Methodology

A factorial plot experiment was carried out at Hart in 2024 (Table 1), utilising sowing date, genetics and nitrogen to create different canopy structures. Supplementary water (30 mm) was applied to a subset of treatments at the start of the critical period (flag leaf emergence) to determine the value of extra water and the response of different agronomy strategies.

Sowing date and emergence targets were April 25–May 10, and approximately three weeks later (or with the break). There were two times of sowing (TOS): May 24, emerging on June 11 and June 13 which emerged on June 25. Supplementary irrigation of 30 mm was applied at the onset of the critical period for Shotgun wheat on August 27 (TOS 1) and September 4 (TOS 2) via dripper irrigation.

Table 1. Trial details for Hart, SA.

Plot size	1.75 m x 10.0 m	**Fertiliser**	Seeding: MAP Zn 1% @ 120 kg/ha
Harvest plot width	0.92 m x 5.0 m		
Seeding date (TOS 1) **Seeding date (TOS 2)**	April 24, 2024 June 13, 2024		
Previous crop	Kingbale oaten hay		
Harvest date	December 4, 2024		

Growing season rainfall (GSR) received at Hart in 2024 was 176 mm (Figure 1) with 240 mm annual rainfall.

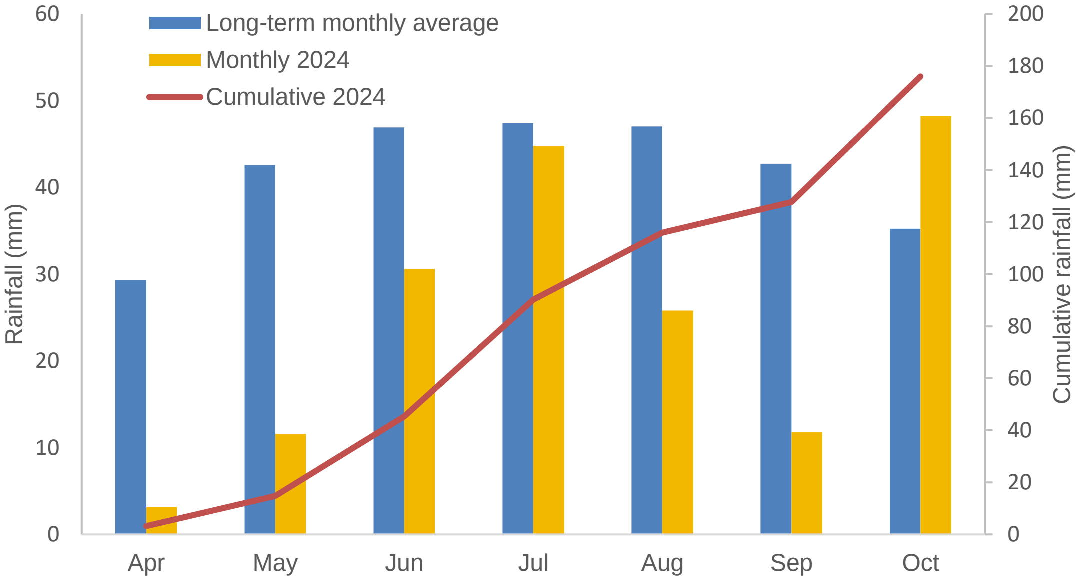

Figure 1. Long-term and 2024 monthly GSR rainfall for April–October.

The crop types and varieties included:

- Spring barley – Neo, Cyclops, Beast
- Winter barley – AGTB1007, AGTB1009
- Wheat – Shotgun, Rockstar
- Winter wheat – Mohawk

Nitrogen was seasonally adjusted to achieve two possible yield outcomes based on anticipated seasonal rainfall outlooks, a more conservative Decile 2-3, and a more aggressive Decile 7-8 yield. These were applied as split applications prior to stem elongation. A third treatment was applied to Neo barley and Shotgun wheat only where it low N levels were applied prior to stem elongation and then topped up to the higher N strategy (Table 2).

Table 2. Nitrogen rates (kg N/ha) and dates for treatments applied as urea.

N treatment	Timing 1 June 28	Timing 2 August 7	Timing 3 TOS 1: August 27 TOS 2: September 4	Total N applied
Low N (Decile 2)	20	30	-	50
High N (Decile 8)	60	90	-	150
Delayed N (Decile 8)	20	30	100	150

A linear mixed model was fit to the data using ASReml-R, and treatment predictions were extracted for subsets of treatments. Treatment yield predictions were grouped by Tukey's Honestly Significant Difference.

Results and discussion

Understanding grain yield

Grain yield is primarily determined by the number of grains produced, making processes that determine grain number worth focusing on (Fischer 2008). The most sensitive part of the critical period for wheat and barley occurs just prior to flowering, when grain number (and therefore, yield) is most sensitive to environmental factors like water, temperature, and nutrients. Water deficits during the critical period greatly influence grain number and yield. Aligning this phase with periods of minimal water stress or access to more water can enhance yield potential. Cossani and Sadras (2021) showed that reducing the duration of the critical period from 90 to 30 days can lead to a linear decline in yield from ~6 t/ha to <0.5 t/ha in low to medium rainfall zones (LRZ, MRZ), driven mainly by temperature. Porker et al. (2025) found that conditions during the critical period explained over 70% of yield variation in high rainfall zones (HRZ) due to sowing date, temperature and radiation, emphasising the importance of aligning agronomic practices with this critical phase.

Drivers of yield – Hart, 2024

The experiment at Hart in 2024 will add to a database of experiments that aim to maximise water use and grain number (yield potential) using tactical agronomy. Due to the late break, the time of emergence had little influence on grain yield in 2024 (Table 3). The biggest factor was crop type, with wheat performing up to 0.6 t/ha greater than barley. Nitrogen strategy had little impact on grain yield at this site in 2024 and there was little evidence of negative effects of high N despite the dry season, although there is some evidence of smaller grain size in barley from higher N strategies in Neo barley (Table 4). The reasons for the poor relative performance of barley require more investigation, however its likely related to timing of water use prior to anthesis.

The results also reaffirm the importance of understanding agronomic practices that influence grain number, while the differences in grain weight are not insignificant the key drivers of grain yield are grain number, for example an increase 30 mm of water in wheat almost increased grain number two-fold and had little to no impact on grain weight (Figure 2).

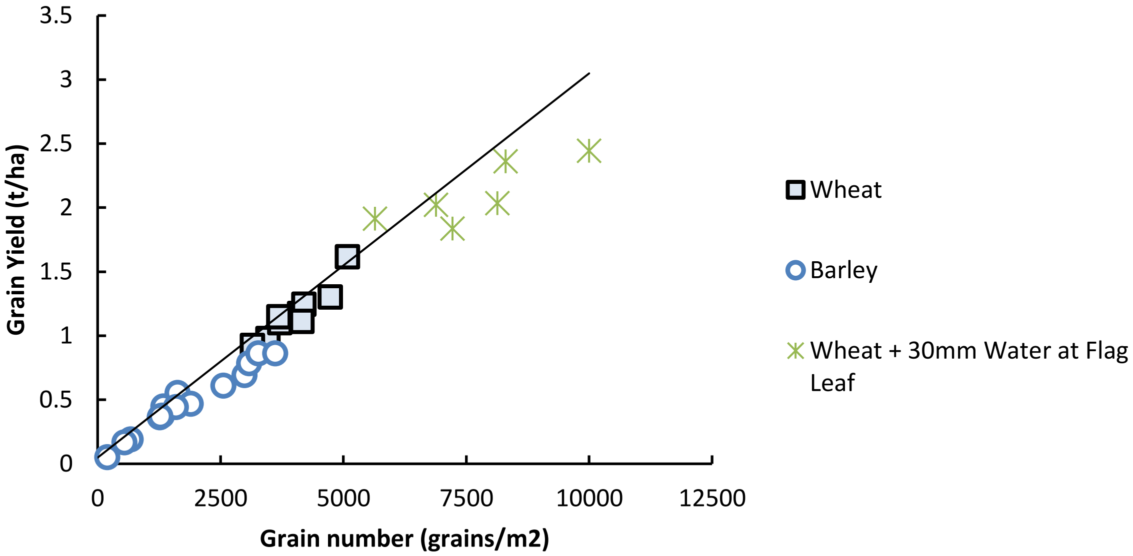

Figure 2. Relationship between grain number and yield across all treatments at Hart 2024.

The most interesting results occurred from the extra application of water. The critical developmental period for wheat and barley yield spans from late stem elongation to one week after flowering. Our main focus was that management of water use, and crop canopy needs to better consider this phase. For example, if we received more rain in the critical period, how could we use tactical agronomy to convert this into more yield. At Hart in 2024 an extra 30 mm of water in the critical period increased wheat yield by 0.6–1 t/ha, a transpiration efficiency for grain yield of 20–33 kg/ha/mm. (Table 3). This increased occurred irrespective of N strategy and sowing date.

Table 3. Grain yield (t/ha) and grain size of Neo, Shotgun and Shotgun with 30 mm irrigation at flag leaf emergence. Predicted values are across all N treatments (NS), letters are groups determined by Tukey's Honestly Significant Difference (HSD). Shaded values indicate best performing treatments.

Emerged	Variety	Grain yield (t/ha)	g/1000 grains
June 11	Shotgun + 30 mm	2.0^{a}	32.0^{c}
	Shotgun	1.4^{b}	31.8^{c}
	Neo	0.6^{cd}	38.5^{ab}
June 26	Shotgun + 30 mm	2.1^{a}	39.0^{a}
	Shotgun	1.0^{bc}	34.3^{bc}
	Neo	0.3^{d}	32.0^{c}

Table 4. Grain yield (t/ha) and grain size of spring barley varieties at two sowing dates and nitrogen rates. Shaded values indicate best performing treatments.

Emerged	Variety	Nitrogen	Grain Yield (t/ha)	g/1000 grains
June 11	Beast	N1	0.7	41.9^{ab}
	Beast	N2	0.8	39.0^{a-g}
	Cyclops	N1	0.7	32.7^{d-i}
	Cyclops	N2	0.4	31.8^{ehi}
	Neo	N1	0.7	41.4^{abc}
	Neo	N2	0.3	34.8^{d-i}

Summary

Results from 2024, a very dry season, emphasise the potential of new genetics. These results will be best interpreted when combined with more in depth understanding of soil water use across a wider range of season types. It’s clear from other experiments and this on it is possible to continue to increase grain yield through maximising resource efficiency by focusing on the critical period's sensitivity to environmental and management factors. We plan to develop new benchmarks that can assist in maintaining profitability in challenging low to medium rainfall zones.

Acknowledgements

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Photo: Taken at the Hart field site on September 4 of TOS 1 post-irrigation.

Legume and oilseed herbicide tolerance

Kaidy Morgan and Rebekah Allen

Hart Field-Site Group

Key findings

- Most IBS and PSPE treatments recorded no effect to slight crop safety effects (rated 1-2), likely resulting from dry conditions reducing herbicide activity. Some treatments caused severe effects in small seed crops including canola and medic, which supports the reason why they are not labelled for use in these crops.
- Pulse and oilseed control was reduced in 2024 compared to other years as a result of poor seasonal conditions limiting some herbicide uptake. Despite the dry season, the more robust herbicides provided high levels of control at Hart (rating 5-6) (Table 4).

Introduction

This demonstration has two primary objectives and is presented in two distinct protocols, the first is to compare the control of canola and legume varieties. The second is to compare the crop safety of canola and legume species to a range of herbicide products, timings and rates. As a result of dry conditions in the 2024 growing season, herbicide performance in both the control and crop safety plots was compromised. Reduced efficacy of herbicides was observed resulting from plant water stress following application, impacting herbicide uptake for the control of pulses and canola

Observations from 2024 may differ from expected results that would otherwise be seen in more favourable conditions.

Methodology

The 2024 legume and oilseed herbicide tolerance trial was set up as a demonstration and is a non-replicated matrix (Table 1). Sixteen varieties were sown in strips across seven different crop types including canola, faba bean, field pea, chickpea, lentil, vetch and barrel medic. Forty-six herbicide treatments were applied across all 16 crops at various timings. The trial was sown into a drying soil profile on July 3, with the site receiving 10.6 mm rainfall within seven days prior to sowing.

Table 1. Trial details for legume and oilseed herbicide tolerance at Hart, SA.

Plot size	2.2 m x 2.0 m	**Fertiliser**	MAP (10:22) + 1% Zn + Impact @ 80 kg/ha
Seeding date	July 3, 2024	**Soil type**	Clay loam
Location	Hart, SA (Quarter 2)		

Application timings:

1. Incorporated by sowing (IBS)	July 3
2. Post-seeding pre-emergent (PSPE)	July 3
3. Early post-emergent (3-4 node)	August 14
4. Post-emergent (5-6 node)	August 22
5. Post-emergent Group 14 spike (5-6 node)	August 22

Treatments were visually assessed and scored (Table 2) for herbicide effects approximately six weeks after each application from August to October (Tables 3 & 4).

Table 2. Crop damage ratings and descriptions used for visual assessment of legume and oilseed herbicide tolerance demonstration.

1	**No effect**	No herbicide effect evident.
2	**Slight effect**	Minor or temporary damage as reduced crop vigour and growth. Discoloration, distortion or stunting is negligible.
3	**Moderate effect**	Moderate damage with recovery likely expected in most, if not all cases. Moderate discolouration, distortion or stunting observed.
4	**Irreversible effect**	Majority of plants irreversibly damaged. Some discoloration, necrosis (death) of plant tissue and distortion.
5	**Severe effect**	Most plants dead with the remaining showing signs of severe distortion or necrosis across entire plant.
6	**Death**	Complete death of all plants although some crop residue may remain.

Some herbicides used in this demonstration are not registered for crops that have been sprayed. It is important to check herbicide labels before following these strategies used. In 2024, several herbicide treatments displayed varying crop tolerances that were not expected. Care should be taken when interpreting these results, as herbicide effects can vary between seasons and is also dependent upon conditions at application including soil type and weather conditions. This trial is un-replicated and observations are based on visual assessment at one point in time only.

Results and discussion

Crop safety

Most IBS and PSPE treatments caused minimal crop damage in 2024, likely due to dry conditions reducing herbicide activity (Table 3). Despite reduced damage across most crop types, Mateno® Complete, Terrain® Flow, Sentry® and Reflex® applied as IBS treatments, caused increased damage to canola this season, when compared to 2023 where conditions favoured herbicide activity.

For pulses, crop safety was improved in 2024 across IBS, PSPE and 3-4 node treatments, with Propyzamide®, Tenet®, Luximax® and Mateno Complete (not registered as safe for use in pulses) causing no effect to slight crop effects this season. This unexpected crop safety may not be experienced in seasons where herbicide activity is favoured in wetter conditions, and on-label registrations should therefore be followed.

Ultro® (registered for control or suppression of some grasses) applied at 1700 g/ha was safest across all applied IBS treatments for the crops it is registered in. In both 2023 and 2024 seasons, Ultro provided no effect to slight crop effect on canola and medic, however this use is off-label and is not recommended.

Despite registration for IBS application in canola, Overwatch® applied at 1.25 L/ha caused slight to moderate effects (rated 2-3) in all four canola varieties. Although recovery from these effects can be expected in favourable conditions, severe water stress in 2024 likely impacted recovery, even in cases where crop damage was low.

Balance® + simazine applied PSPE caused crop damage in canola, lentil, vetch and medic (rated 3-6) and had slight-moderate effect on faba bean, field pea and chickpea (rated 2-3). Of all IBS, PSPE and 3-4 node treatments Balance + simazine caused the highest level of visual crop damage. This effect was likely due to Balance having a registration in chickpea only for the control of some broadleaf and grass weeds and despite no registration for volunteer pulse control, some level of control may be achieved with this product. Terbuthylazine, Thistrol Gold® + CanDo® and Intercept® + Hasten® also caused irreversible damage across several crop types (Table 3).

Pulse and oilseed control

Pulse and oilseed control was reduced in 2024 as a result of poor seasonal conditions limiting herbicide uptake. Despite the dry season, several treatments provided high levels of control at Hart (rating 5-6) (Figure 1 and Table 4). Talinor® + Hasten when applied at 5-6 node controlled all crop types (rated 5- 6), including off label control of barrel medic. Velocity® + Hasten provided similar control to Talinor + Hasten for canola, beans and peas, however had reduced activity on chickpea (rating 3) and slightly reduced control on lentil, vetch and medic.

Carfentrazone 240 + MCPA Amine 750 was rated 5-6 (severe effect–death) for all four canola varieties, despite only MCPA Amine on label for control. As expected, this treatment performed poorly for other crop types, as this product targets marshmallow, lupin and selected broadleaf weeds only. Field pea control was low (rated 2-4) when treated with Lontrel® Advanced, Ally® + Wetter 1000 or Saracen® + CanDo, despite on-label control. Additionally, Saracen is registered to control volunteer faba bean and lentil in cereals or fallow, however, in 2024 when applied with CanDo (oil adjuvant), it did not provide adequate control (rating 3-4) and follow up herbicides would have been required.

Group 14 efficacy was reduced when compared to previous years. In 2023, high levels of control (rated 5-6) were achieved in most cases, however in 2024, dry conditions causing poor uptake resulted in several treatments recording no control to moderate effects (rated 1-3) across many plant types. Although plant recovery did not occur in 2024, favourable growing conditions are likely to result in re-growth of plants where only moderate damage occurred.

Crucial® (600 g/L glyphosate) applied at 800 mL and 1200 mL performed similarly, with a slight control advantage at the higher rate. Both rates provided good control (rated 5-6) for canola varieties HyTTec Trophy and new Pioneer variety PY421C, however all other crop types would require follow up application, or alternative herbicide options for TruFlex canola variety Nuseed Raptor (tolerant to glyphosate). Achieving control in two of the four canola varieties at 800 mL was surprising, with the lowest recommended on-label rate for canola 1100 mL/ha.

Although Sharpen® is not registered for field pea or lentil control, when applied with Crucial, this tank-mix treatment improved efficacy, with a crop damage rating of 5 (severe effect), outperforming Crucial alone (rated 3-4).

New generation Group 14 spike herbicides Terrad'or® and Voraxor® applied with Crucial performed similarly across all pulse and oilseeds, other than faba bean, where Voraxor did not offer adequate control (rating 3). Chickpea was not effectively controlled by Voraxor this season (rated 4) and would have required follow up herbicide application despite being registered for control. Sharpen + Crucial achieved similar control to the newer Group 14 herbicides across most crop types, with a slight reduction in efficacy recorded in vetch. In 2024, Voraxor and Terrad'or provided an additional level of control across all crop types when compared to Carfentrazone 400, Sledge® or oxyfluorfen 240, particularly for canola, medic and volunteer lentils.

In 2023 all Group 14 herbicides were rated 5-6 (severe effect-death) for chickpea control, however no Group 14 treatments provided effective in-season control for chickpea in 2024, with ratings ranging from 2-4 (slight–increasing effect).

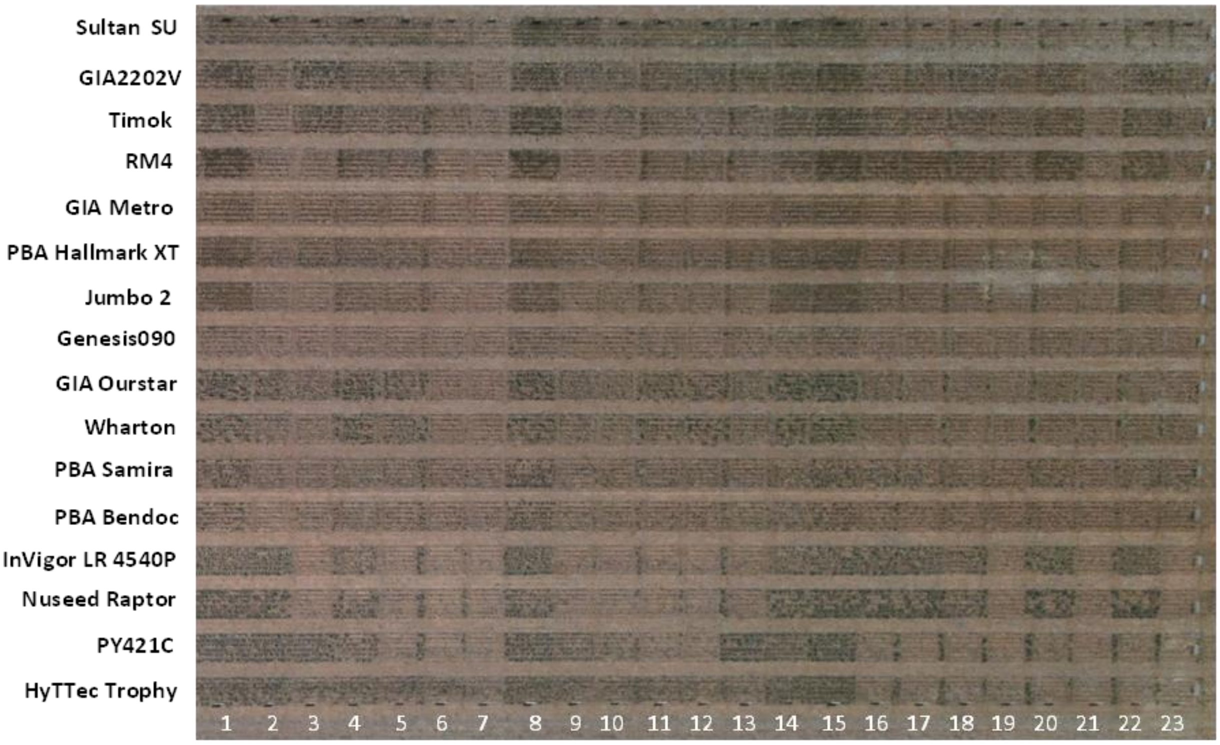


Figure 1. Pulse and oilseed control section at Hart in 2024. Photo taken on September 23, 2024 showing 16 varieties (top to bottom) and the 23 herbicide treatments in order from Nil (left) through to Voraxor + Crucial + MSO (right).

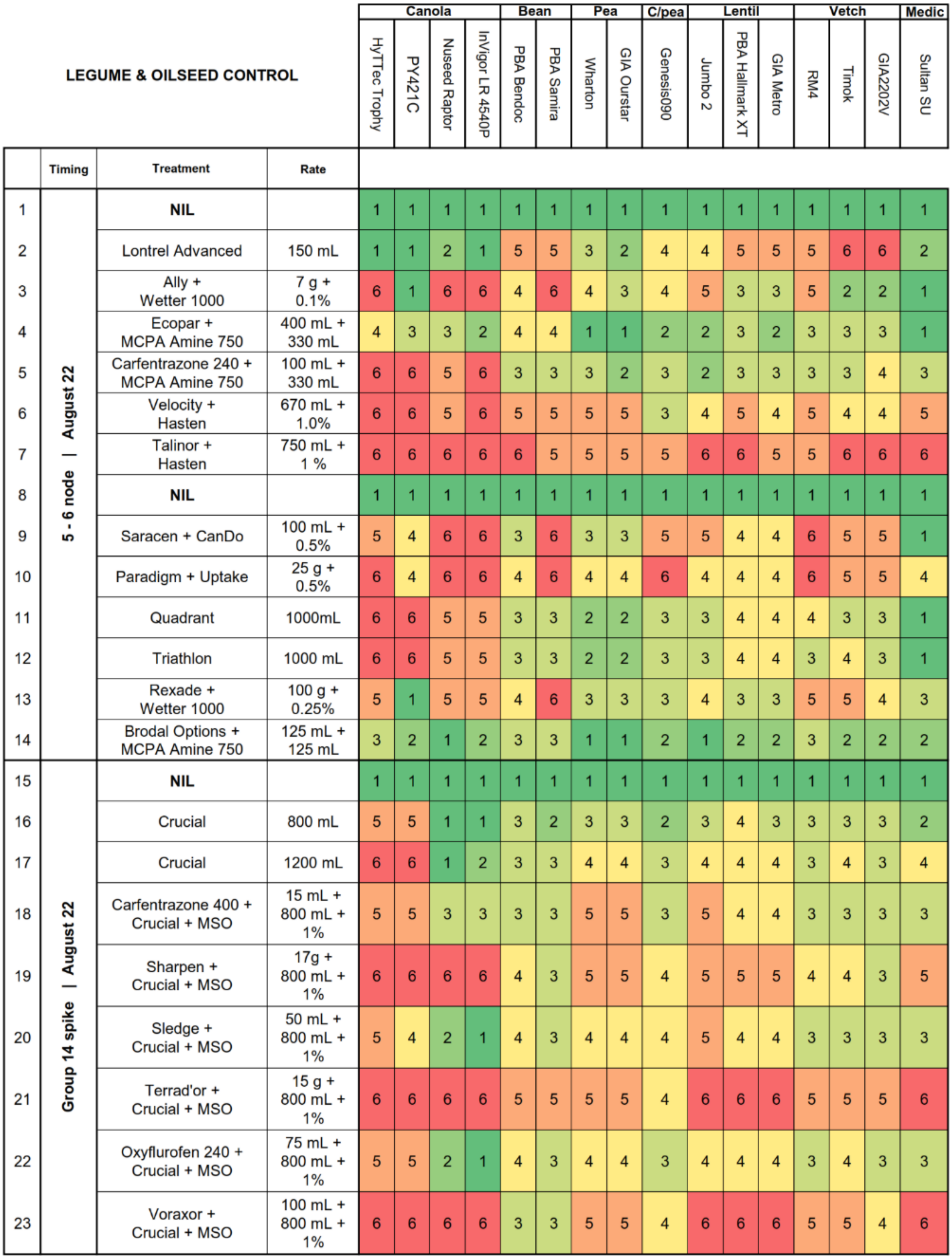
Table 3. Crop damage ratings for the legume and oilseed herbicide tolerance trial at Hart in 2024.

Trial layout – CROP SAFETY

CROP SAFETY				Canola				Bean		Pea		C/pea	Lentil			Vetch			Medic
	Timing	**Treatment**	**Rate**	HyTTec Trophy	PY421C	Nuseed Raptor	InVigor LR 4540P	PBA Bendoc	PBA Samira	Wharton	GIA Ourstar	Genesis090	Jumbo 2	PBA Hallmark XT	GIA Metro	RM4	Timok	GIA2202V	Sultan SU
1	**IBS | July 3**	**NIL**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2		Sakura	118 g	2	2	3	4	1	1	2	1	2	1	1	1	2	1	1	2
3		Boxer Gold	2500 mL	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	2
4		Propyzamide	1000 mL	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2
5		Tenet	1800 mL	2	1	1	1	1	1	1	1	1	1	1	1	2	3	2	3
6		Ultro	1700 g	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7		Reflex	1000 mL	5	6	6	4	1	2	1	1	2	1	1	1	2	1	1	2
8		Luximax	500 mL	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9		Overwatch	1250 mL	3	3	3	2	1	1	1	1	1	3	2	2	2	1	2	1
10		Sentry	50 g	6	1	5	5	1	1	2	1	2	3	1	1	2	2	2	2
11		Mateno Complete	1000 mL	4	4	4	4	1	1	1	1	1	1	1	1	1	1	2	3
12		Terrain Flow	190 mL	3	5	5	5	2	1	1	1	1	2	1	1	2	1	1	4
13		Voraxor	200 mL	6	3	5	2	1	2	1	1	1	1	2	1	1	1	1	2
14	**PSPE | July 3**	**NIL**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15		Diuron (900 g/kg)	825 g	3	3	4	4	1	1	1	1	1	1	1	1	1	1	1	2
16		Reflex	1250 mL	4	6	6	6	1	1	2	1	1	2	2	2	2	1	1	5
17		Simazine (900 g/kg)	825 g	3	5	5	4	1	1	2	1	1	2	1	1	1	1	1	5
18		Metribuzin (750 g/kg)	280 g	2	6	6	6	2	2	2	2	1	2	2	1	2	2	2	5
19		Terbuthylazine (875 g/kg)	1000 g	2	6	6	6	2	2	2	2	2	2	2	2	2	2	2	6
20		Balance + Simazine	100 g + 830 g	6	6	6	6	3	3	3	3	2	5	5	5	4	3	3	6
21	**3-4 node | August 14**	**NIL**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22		Metribuzin (750 g/kg)	280 g	1	6	5	6	2	1	2	2	1	2	2	1	4	4	1	3
23		Broadstrike + Wetter 1000	25 g + 0.2%	6	1	5	5	1	2	1	1	1	1	1	1	3	1	2	2
24		Thistrol Gold + CanDo	2000 mL + 0.5%	5	4	5	5	3	3	1	1	2	3	3	3	4	2	3	1
25		Brodal Options	150 mL	1	1	1	1	2	2	1	1	3	1	1	1	2	1	1	1
26		Spinnaker + Wetter 1000	70 g + 0.2%	6	2	6	4	2	2	1	1	2	2	1	1	2	2	1	1
27		Ecopar + Wetter 1000	800 mL + 0.2%	1	1	3	1	1	2	2	2	2	2	3	2	2	2	1	2
28		Intercept + Hasten	750 ml + 0.5%	6	1	5	5	1	3	3	1	4	4	2	1	4	4	2	2

Table 4. Crop damage ratings for the legume and oilseed herbicide tolerance trial at Hart in 2024.

Trial layout – PULSE & OILSEED CONTROL



LEGUME & OILSEED CONTROL

	Timing	Treatment	Rate	Canola				Bean		Pea		C/pea	Lentil			Vetch			Medic
				HyTTec Trophy	PY421C	Nuseed Raptor	InVigor LR 4540P	PBA Bendoc	PBA Samira	Wharton	GIA Ourstar	Genesis090	Jumbo 2	PBA Hallmark XT	GIA Metro	RM4	Timok	GIA2202V	Sultan SU
1	5 - 6 node | August 22	**NIL**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2		Lontrel Advanced	150 mL	1	1	2	1	5	5	3	2	4	4	5	5	5	6	6	2
3		Ally + Wetter 1000	7 g + 0.1%	6	1	6	6	4	6	4	3	4	5	3	3	5	2	2	1
4		Ecopar + MCPA Amine 750	400 mL + 330 mL	4	3	3	2	4	4	1	1	2	2	3	2	3	3	3	1
5		Carfentrazone 240 + MCPA Amine 750	100 mL + 330 mL	6	6	5	6	3	3	3	2	3	2	3	3	3	3	4	3
6		Velocity + Hasten	670 mL + 1.0%	6	6	5	6	5	5	5	5	3	4	5	4	5	4	4	5
7		Talinor + Hasten	750 mL + 1 %	6	6	6	6	6	5	5	5	5	6	6	5	5	6	6	6
8		**NIL**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9		Saracen + CanDo	100 mL + 0.5%	5	4	6	6	3	6	3	3	5	5	4	4	6	5	5	1
10		Paradigm + Uptake	25 g + 0.5%	6	4	6	6	4	6	4	4	6	4	4	4	6	5	5	4
11		Quadrant	1000mL	6	6	5	5	3	3	2	2	3	3	4	4	4	3	3	1
12		Triathlon	1000 mL	6	6	5	5	3	3	2	2	3	3	4	4	3	4	3	1
13		Rexade + Wetter 1000	100 g + 0.25%	5	1	5	5	4	6	3	3	3	4	3	3	5	5	4	3
14		Brodal Options + MCPA Amine 750	125 mL + 125 mL	3	2	1	2	3	3	1	1	2	1	2	2	3	2	2	2
15	Group 14 spike | August 22	**NIL**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16		Crucial	800 mL	5	5	1	1	3	2	3	3	2	3	4	3	3	3	3	2
17		Crucial	1200 mL	6	6	1	2	3	3	4	4	3	4	4	4	3	4	3	4
18		Carfentrazone 400 + Crucial + MSO	15 mL + 800 mL + 1%	5	5	3	3	3	3	5	5	3	5	4	4	3	3	3	3
19		Sharpen + Crucial + MSO	17g + 800 mL + 1%	6	6	6	6	4	3	5	5	4	5	5	5	4	4	3	5
20		Sledge + Crucial + MSO	50 mL + 800 mL + 1%	5	4	2	1	4	3	4	4	4	5	4	4	3	3	3	3
21		Terrad'or + Crucial + MSO	15 g + 800 mL + 1%	6	6	6	6	5	5	5	5	4	6	6	6	5	5	5	6
22		Oxyflurofen 240 + Crucial + MSO	75 mL + 800 mL + 1%	5	5	2	1	4	3	4	4	3	4	4	4	3	4	3	3
23		Voraxor + Crucial + MSO	100 mL + 800 mL + 1%	6	6	6	6	3	3	5	5	4	6	6	6	5	5	4	6

Strategies to mitigate and manage herbicide resistance and challenges when dry sowing

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[1]University of Adelaide; [2]SARDI; [3]Elders

Key findings

- Modern pre-emergent herbicides make dry sowing a practical option.
- More persistent and less-soluble pre-emergent herbicides are the best choices for dry sowing.
- Rotating pre-emergent herbicides is essential to manage resistance to these herbicides.

Dry sowing is a practical option with current pre-emergent herbicides

With autumn rainfall more uncertain in recent years and large crop programs to sow, many have been looking at dry sowing as a means of getting the crop in on time. With the very late start to the season in South Australia in 2024, a considerable proportion of the crop was sown dry. Perhaps the most important lesson learnt about dry sowing from 2024 is that it can be done with the pre-emergent herbicides we currently have. In some cases, herbicides had been applied six weeks prior to the first rainfall and were still present and able to control annual ryegrass when rain arrived.

There are several factors to consider when selecting the right pre-emergent herbicide for dry sowing. Firstly, is understanding where moisture is in the soil profile. If the soil is dry to sowing depth, different herbicide decisions should be made compared with if only the first centimetre of soil is dry. If the soil is dry to depth, the main considerations are to choose pre-emergent herbicides that are less mobile in the soil and which have longer persistence. In dry soil, the first rainfall will move herbicides further through the soil profile than if there is moisture in the soil. This can increase the amount of herbicide that reaches the crop seed resulting in crop damage. In addition, highly soluble herbicides can be moved below the root zone of the weeds, leading to poor control.

Achieving effective weed control

A second consideration when dry sowing is that the pre-emergent herbicide will be required to control the whole population of weeds, as there will be no knockdown herbicide used. This will put considerable pressure on the pre-emergent herbicide and it should be expected there will be a few escapes. If pre-emergent herbicides with lower solubility are selected, weeds may escape the herbicide on the shoulder of the furrow. There may be a need to follow up the pre-emergent herbicide with an early post-emergent herbicide to control ryegrass that escapes the pre-emergent herbicide.

In 2024, a pyroxasulfone based herbicide was applied pre-emergent followed by Boxer Gold® early post-emergent, due to low rainfall after sowing. This often provided better results than a prosulfocarb herbicide pre-emergent followed by Mateno® Complete early post-emergent. The low rainfall through July delayed activation of Mateno Complete and some ryegrass that emerged after sowing was not controlled. The relatively low rainfall for the rest of the growing season reduced late ryegrass emergence after the post emergent Boxer Gold had decayed.

As the season stayed dry, some growers who had used a less effective pre-emergent herbicide choice planning to use Mateno Complete early post, chose to not apply the Mateno Complete and had more ryegrass in crops as a consequence.

While pre-emergent herbicides generally lasted well in the soil, some herbicides, such as prosulfocarb and Boxer Gold that have less persistence did not control ryegrass as well as the more persistent herbicides. The small amount of loss of herbicide while sitting in the soil has a bigger effect on herbicides with less persistence than those with persistence. Therefore, in dry sowing situations, herbicides with longer persistence should be used prior to sowing.

Dry sowing practice

Attention to seeding depth and best practice was another lesson of dry sowing from 2024. With dry sowing, there will be an increased risk of crop damage, as there is no moisture in the soil to slow herbicide movement on the first rainfall events. This was particularly evident for Overwatch on wheat in 2024, where there was more damage than observed in previous years.

Damage was more likely to occur on lighter soil types where herbicides are more mobile. However, damage was also seen where the crop was sown too shallow, as well as in situations where herbicide treated soil was moved into the furrow. These problems highlight the need for additional attention to detail when sowing dry to ensure the crop is not excessively damaged by the herbicide.

Rainfall patterns can affect weed control following dry sowing

While most herbicides retained their efficacy with dry sowing in 2024, the amount and timing of rainfall influenced how effective each of the herbicides were for weed control. This is illustrated in a dry-sowing trial conducted at Redbanks in South Australia in 2024 (Table 1).

Table 1. Herbicide treatments used in the dry sowing trial at Redbanks, South Australia.

Treatment	Herbicides and rates
1	Nil
2	Sakura® Flow IBS 210 mL ha^{-1}
3	Mateno® Complete IBS 1 L ha^{-1}
4	Overwatch® IBS 1.25 L ha^{-1}
5	Luximax® IBS 0.5 L ha^{-1}
6	Boxer Gold® IBS 2.5 L ha^{-1} fb Mateno® Complete EPE 1 L ha^{-1}
7	TriflurX® IBS 2 L ha^{-1} fb Mateno® Complete EPE 1 L ha^{-1}
8	Nil fb Mateno® Complete EPE 1 L ha^{-1}
9	Overwatch® IBS 1.25 L ha^{-1} fb Mateno® Complete EPE 1 L ha^{-1}
10	TriflurX® IBS 2 L ha^{-1} fb Boxer Gold® 3 L ha^{-1}
11	Sakura® Flow 210 mL ha^{-1} + Voraxor® 200 mL ha^{-1} IBS
12	Overwatch® 1.25 L ha^{-1} + Voraxor® 200 mL ha^{-1} IBS

This trial was sown dry on May 27 and the first rainfall events were 6 mm from May 30 to June 1, followed by 11 mm from June 12 to 15 and 10 mm on June 20 and 21. These low sporadic rainfall events left the surface dry for long periods of time leading to less control of annual ryegrass than normal (Table 2). The addition of Voraxor® to the pre-emergent grass herbicides did not improve control of annual ryegrass in this trial. The addition of a broadleaf pre-emergent herbicide could be useful to control broadleaf weeds as well as grass weeds in dry sowing situations.

The early post-emergent herbicides were applied on June 16 and were followed by 10 mm rainfall on June 20 and 21, 8 mm on June 26 and 27 and 12 mm on June 29. This was sufficient to activate the early post-emergent herbicides in this trial. Overwatch followed by Mateno Complete provided the best annual ryegrass control.

The continuing dry conditions meant that annual ryegrass numbers declined as the season continued resulting in lower populations at 90 days after the early post-emergent application (Table 2). A similar level of control was provided by many of the herbicide choices at this time.

Table 2. Annual ryegrass control by pre-emergent and early post-emergent herbicides in a dry sown wheat crop at Redbanks in South Australia.

Herbicide treatment	**Annual ryegrass 28 DAT[a]**	**Annual ryegrass 90 DAT[a]**
1	493^{a}	327^{a}
2	274^{ab}	118^{b}
3	250^{ab}	119^{b}
4	153^{bc}	29^{b}
5	267^{ab}	178^{b}
6	136^{bc}	95^{b}
7	203^{ab}	76^{b}
8	206^{ab}	84^{b}
9	41^{c}	26^{b}
10	300^{ab}	109^{b}
11	395^{ab}	121^{b}
12	100^{bc}	112^{b}

Means in each column with different letters are significantly different.

[a] Days after application of the early post-emergent herbicides on June 16, 2024.

Managing resistance to pre-emergent herbicides

As pre-emergent herbicides are now the main tool for managing annual resistance in cropping systems, it is important that resistance to these herbicides is managed well. Trials were established to compare strategies for the management of resistance to pre-emergent herbicides. To ensure herbicide resistant annual ryegrass was present, Group 15 resistant seed was sown into the trials. A set of potential resistance management strategies involving Group 15 and other pre-emergent herbicides were employed over three years (Table 3).

Table 3. Herbicides used for each resistance management strategy over three successive crops in a trial of resistance management strategies conducted at Roseworthy from 2021 to 2023.

Crop strategy	**2021: Wheat**	**2022: Faba bean**	**2023: Wheat**
Nil	Untreated	Untreated	Untreated
Rotate Group 15	Sakura® (118 g ha^{-1})	Avadex Xtra® (3 L ha^{-1})	Sakura® (118 g ha^{-1})
Mix	Boxer Gold® (2.5 L ha^{-1})	Boxer Gold® (2.5 L ha^{-1})	Boxer Gold® (2.5 L ha^{-1})
Mix and rotate	Sakura® (118 g ha^{-1}) + Avadex Xtra® (2 L ha^{-1})	Boxer Gold® (2.5 L ha^{-1}) + Avadex Xtra® (2 L ha^{-1})	Sakura® (118 g ha^{-1}) + Avadex Xtra® (2 L ha^{-1})
Rotate other Groups	Luximax® (0.5 L ha^{-1})	Overwatch® (1.25 L ha^{-1})	Luximax® (0.5 L ha^{-1})

Some of the strategies were better at controlling annual ryegrass in this trial than other strategies. The mix and rotate and the rotate strategies resulted in lower annual ryegrass populations and less seed production (Table 4). This occurred despite resistance present to some of the herbicides used. This indicates that pre-emergent herbicides should be rotated across the cropping rotation. Better annual ryegrass control also resulted in significantly increased crop yields in the trial.

Table 4. Annual ryegrass populations and grain yield in year 3 of the trial testing resistance management strategies at Roseworthy. Columns with different letters are significantly different.

Strategy	**Ryegrass density 5 WAS (plants m^{-2})**	**Ryegrass seed heads (heads m^{-2})**	**Grain yield (t ha^{-1})**
Nil	688^{a}	2440^{a}	1.98^{c}
Rotate Group 15	56^{c}	96^{c}	3.34^{a}
Mix	155^{b}	190^{b}	2.93^{b}
Mix and rotate	11^{d}	16^{d}	3.63^{a}
Rotate other Groups	12^{d}	26^{d}	3.57^{a}

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Investigating glufosinate herbicide for annual ryegrass control

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Key findings

- Seasonal conditions at Hart and Hill River in 2023 were relatively dry from July through to Spring reducing emergence of annual ryegrass (ARG) populations. Trials conducted at these two sites targeted varying susceptibility: 100% susceptible to all chemistry (Hart) and moderate resistance to Group 1 – DIM herbicides and strong resistance to Group 2 – Imidazolinone herbicides (Hill River).
- Data from field trials undertaken at Hart and Hill River showed that Liberty® (200 g/L glufosinate) mixes applied as a two-spray approach, tank mixed with clethodim or registered glyphosate, applied with Liase® (ammonium sulphate) as the first application of the Liberty sequence, were the most effective options against ryegrass.
- At both sites, the low label rate of Liberty (2 L/ha + 2% Liase®) applied in sequence, ~14 days apart, was not adequate for the control of ARG.
- Liberty at higher label rates of 3 L/ha followed by a second 3 L/ha was effective in reducing ryegrass.

Introduction

A project supported by the South Australian Grains Industry Trust (SAGIT) was conducted in 2023 investigating best-use strategies for the control of annual ryegrass (ARG) with glufosinate herbicide. Active ingredient glufosinate-ammonium (200 g/L) registered as Liberty is a Group 10 (formerly N) herbicide which can now be applied in-crop to canola varieties with LibertyLink® technology (tolerance to Liberty herbicide). This registration provided a new herbicide mode of action (MOA) for use in broadacre cropping systems.

Glyphosate and glufosinate have two different MOA (Group 9 and 10, respectively), however structural elements are similar in that they are both charged herbicides (Preston, 2024). This means they are unable to pass through wax layers of plant cuticles and are alternatively required to enter via pectin strands (intercellular plant tissue) within cuticles. As pectin strands contain negative charges, these herbicides are slow moving into the leaf and the rate of this absorption is impacted by temperature and humidity (Preston, 2024). While the overall charge on glyphosate can be reduced by decreasing spray solution pH (5.73), the solution would need to be below pH 2.9 for this to be achieved (Preston, 2024).

Whilst glufosinate provides an alternative to glyphosate, its uptake, translocation and therefore activity can be strongly influenced by conditions upon application (e.g. temperature and humidity). Previous research suggests that temperature plays only a small part when it comes to glufosinate uptake, whereas humidity is the more important factor (Preston, 2024). Low humidity can reduce the ability of glufosinate to pass through the leaf via pectin strands within the cuticle, which need to remain hydrated for this to happen. It is suggested that humidity is not generally an issue in southern Australia during winter and that high humidity is only required for the first 24 hours after application for glufosinate uptake (Preston, 2024).

Atrazine, clethodim and glyphosate are the most common post-emergent herbicides used to control ryegrass in canola. Previous studies have shown that the combination of clethodim with glyphosate can improve control of ryegrass resistant to either, or in some cases both herbicides. This treatment is only relevant for glyphosate tolerant canola varieties. Although rare, ryegrass resistant to tank mix glyphosate + clethodim is being detected (Peter Boutsalis pers. comm.). To lower the risk of further increases in resistance to glyphosate and clethodim, the inclusion of another mode of action herbicide such as glufosinate (Liberty) would be useful.

A series of agronomic field and pot experiments exploring the effects of temperature and humidity on herbicide efficacy experiments with Liberty were implemented in 2023. In this article, data from field experiments at two locations across the Mid North region of SA is discussed.

Methodology

Site selection and rainfall

Two trials were implemented in the medium rainfall zone of the Mid North to evaluate the efficacy of glufosinate herbicide under field conditions (Table 1).

The core trial was located at Hill River with a known background population of ARG, susceptible to glyphosate and glufosinate herbicides. The site had moderate resistance to Group 1 – DIM herbicides (45% survival) and strong resistance to Group 2 – Imidazolinone herbicides (60% survival). Total annual rainfall received was 450 mm with 312 mm of growing season rainfall (GSR). Early rainfall from April–June promoted ARG germination, however seasonal conditions from July through to spring were below average (Figure 1), suppressing conditions for further ryegrass to emerge.

Similar conditions were observed at the Hart field site, SA, where a secondary trial was located, however both GSR and annual rainfall were lower, receiving 236 and 354 mm, respectively. This trial was sown to Liberty tolerant InVigor LR 4540P canola. Prior to seeding, ARG (wild type) with a known susceptibility to all herbicide groups was spread across the site ensuring adequate weed emergence (250 plants/m^2). Both Hart and Hill River trials were sown by a knife point press wheel trial plot seeder with 23 cm row spacings on April 2 and June 16, respectively.

Table 1. Site details for glufosinate trials at Hart and Hill River, SA in 2023.

Hart	**Plot size**	2.0 m x 10.0 m	**Water rate**	100 L/ha
	Seeding date	April 2, 2023	**Nozzle type**	Coarse
	Seed rate	45 plants/m^2		
	Previous crop	Kingbale oaten hay		
Hill River	**Plot size**	2.0 m x 10.0 m	**Water rate**	70–100 L/ha
	Seeding date	June 16, 2023	**Nozzle type**	Coarse
	Seed rate	45 plants/m^2		
	Previous crop	Kingbale oaten hay		
	Harvest date	November 22, 2023		

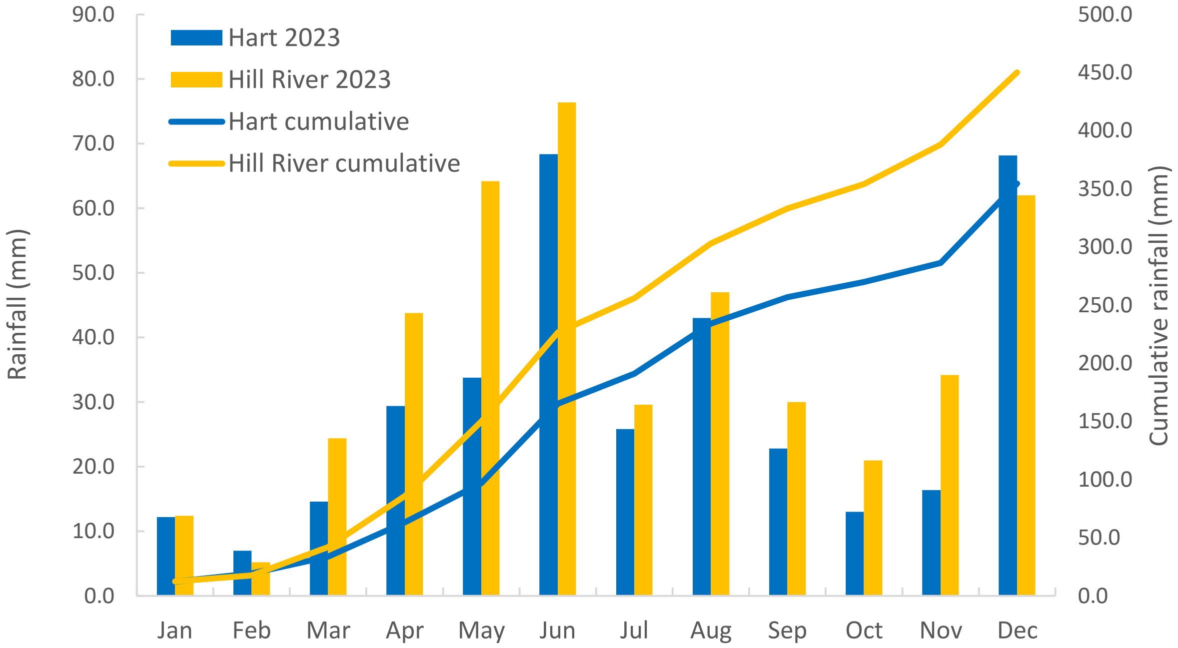

Figure 1. Monthly and cumulative rainfall for Hart and Clare (nearest Mesonet station to Hill River) in 2023 (Source: Mid North Mesonet).

Trial design and treatments

Hill River

The trial located at Hill River, SA, was established as a randomised complete block design with three replicates, each containing 16 treatments. The aim of this trial was to investigate and test best-use spray strategies required to optimise ARG control with the use of glufosinate herbicide (Table 2). The trial compared effects of:

- Liberty herbicide at two rates (2 and 3 L/ha)
- Rate of Liase (2% and 4%)
- Liberty herbicide +/- Liase
- Application timing (7, 14 and 21 days after initial application)
- Water rate (70 or 100 L/ha)
- Tank mixes as either glyphosate or clethodim (at various rates)
- Extended application window (first flower)
- Spray conditions (low temperature)

Three varieties with herbicide tolerances, including the LibertyLink trait were included:

- InVigor LT 4530P: LibertyLink + Triazine Tolerant + PodGuard® (TT) (early-mid maturity)
- InVigor LR 4540P: LibertyLink + TruFlex® + PodGuard (early-mid maturity)
- InVigor R 4520P: TruFlex + PodGuard (early-mid maturity)

The glufosinate herbicide product used was Liberty (200 g/L glufosinate) and Liase was selected as the ammonium sulphate (417 g/L) inclusion. Roundup Ready® PL herbicide with Plantshield® (Roundup Ready PL) was selected as the glyphosate option, however Crucial® is also registered for use on Roundup Ready, TruFlex or Optimum GLY® canola options. Herbicide applications were applied from August 11 to September 13, 2023 (Table 2 and Figure 2).

Hart field site

A secondary trial was undertaken at the Hart field site and was established as a split-plot design with five treatments and three application timings to target ryegrass at different growth stages. The trial investigated standalone Liberty herbicide at two rates (2 or 3 L/ha) with Liase (ammonium sulphate) and tank mixture of either glyphosate or clethodim (Table 3). Application dates and climate data can be found in Appendix 1.

Herbicide treatments were applied at three ARG growth stages from early emergence through to tillering (2-4 leaf, 1-2 tiller and 3-4 tiller) using a 100 L/ha water rate and coarse nozzles. No residual herbicides were applied pre-seeding.

Field assessments for both trials at Hart and Hill River included weed counts (plants/m^2) and ARG head counts (heads/m^2) as a measure of seed set. Data was analysed using a REML spatial model (Regular Grid) in Genstat 23rd edition. Ryegrass head counts for Hill River were analysed as log-transformed data for multiple comparisons using statistical program R.

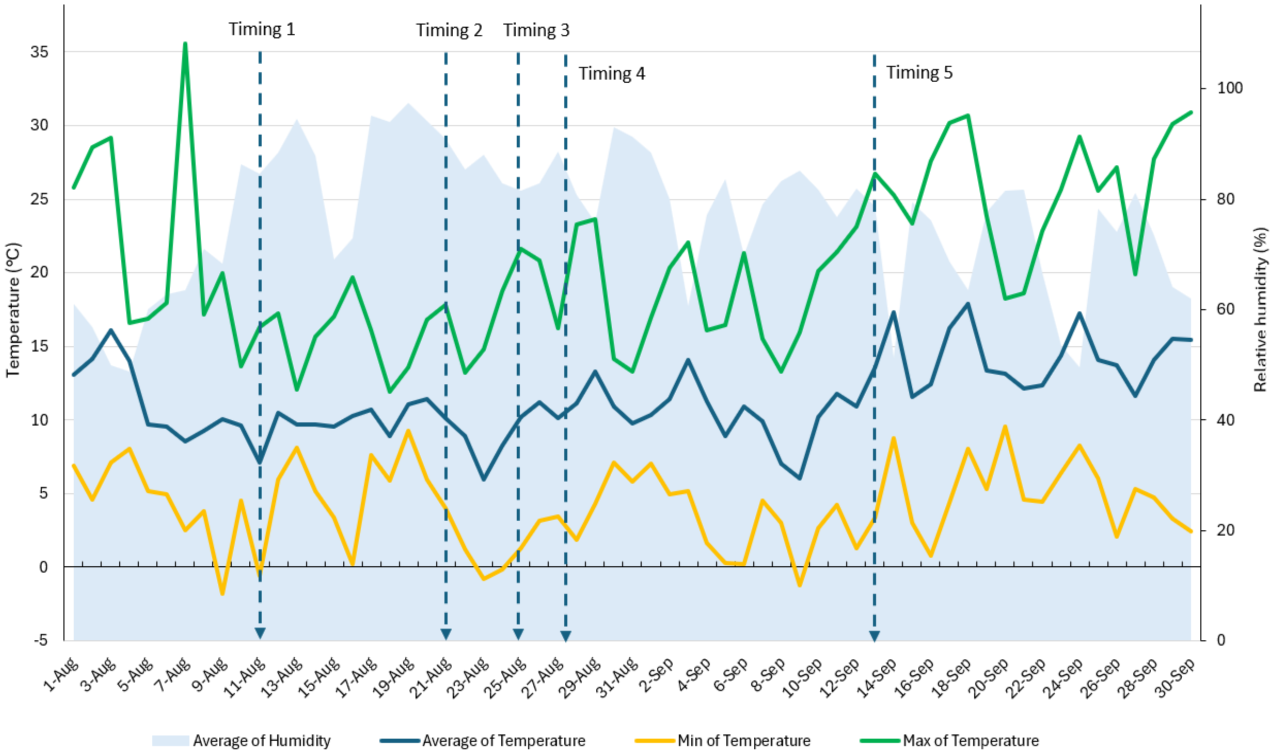

Figure 2. Average temperature (°C) and relative humidity (RH%) for Hill River, SA. Blue dotted lines indicate each application timing.

Table 2. Treatment list and application dates for glufosinate trial located at Hill River, SA in 2023.

Trt	PSPE		2-4 Leaf		6-8 Leaf (7 days later)		10-Leaf (14 days later)		Stem elongation (21- 28 days later)		First flower (≤10%)	
	June 16		August 11		August 21		August 25		August 28		September 13	
	Product	**Rate**	**Product**	**Rate**	**Product**	**Rate**	**Product**	**Rate**	**Product**	**Rate**	**Product**	**Rate**
1	Nil											
2	Atrazine	1 kg	Liberty + clethodim + Uptake + Liase	2 L + 330 mL + 0.5% + 2%			Liberty + Liase	2 L + 2%				
3			Liberty + Roundup PL + Liase	2 L + 1.67 L + 2%			Liberty + Liase	2 L + 2%				
4			Roundup PL + clethodim + Uptake + Liase	1.67 L + 330 mL + 0.5% + 2%			Roundup PL + Liase	1.67 L + 2%				
5			Liberty + Roundup PL	2 L + 1.67 L			Liberty	2 L				
6			Liberty + Roundup PL + Liase	2 L + 1.67 L + 4%			Liberty + Liase	2 L + 4%				
7			Clethodim + Liberty + Uptake + Liase	330 mL + 2 L + 0.5% +2%			Liberty + Liase	2 L + 2%				
8			Liberty + Roundup PL + Liase	2 L + 1.15 L + 0.5% + 2%			Liberty + Liase	2 L + 2%				
9			Liberty + Liase	2 L + 2%			Liberty + Liase	2 L + 2%				
10			Clethodim + Liberty + Uptake + Liase	330 mL + 2 L + 0.5% + 2%					Liberty + Liase	2 L + 2%		
11			Clethodim + Liberty + Uptake + Liase	330 mL + 2 L + 0.5% +2%	Liberty + Liase	2 L + 2%						
12			Liberty	2 L			Liberty	2 L				
13			Liberty + Liase	3 L + 2%			Liberty + Liase	3 L + 2%				
14			Clethodim + Liberty + Uptake + Liase	330 mL + 2 L + 0.5% + 2%			Liberty + Liase	2 L + 2%				
15			Liberty + Liase	2 L + 2%			Liberty + Liase	2 L + 2%			Roundup PL + Liase	1.67 L + 2%
16*			Clethodim + Liberty + Uptake + Liase	330 mL + 2 L + 0.5% +2%			Liberty + Liase	2 L + 2%				

**Second application applied early morning in cold temperatures of 9 degrees Celsius (°C).*

Table 3. Treatment list for glufosinate trial located at the Hart field site, SA in 2023. Treatments were applied targeting annual ryegrass at 3 different growth stages (2-4 leaf, 1-2 tiller and 3-4 tiller).

Trt	Timing 1		Timing 2 (10–14 days later)	
1	Nil			
2	Liberty + Liase	2 L + 2%	Liberty + Liase	2 L + 2%
3	Liberty + Liase	3 L + 2%	Liberty + Liase	3 L + 2%
4	Liberty + Roundup PL + Liase	2 L + 1.67 L + 2%	Liberty + Liase	2 L + 2%
5	Liberty + clethodim + Uptake + Liase	2 L + 330 mL + 0.5% + 2%	Liberty + Liase	2 L + 2%

Results and discussion

Hill River

Weed control

Low ARG numbers were initially observed across the site at Hill River in 2023 (61 plants/m^2), despite the paddock having a known high weed pressure. The low ARG numbers were likely due to an effective knockdown and pre-emergent herbicide treatment (Overwatch at 1.25 L/ha) coupled with below average winter rainfall from July onwards. Ryegrass numbers were highest in the untreated control (Nil treatment = 120 plants/m^2) where significant seed set resulted (160 heads/m^2; Figure 3 and Table 4).

Reduced weed control was observed for all standalone Liberty treatments at 2 L/ha +/- Liase (Treatments 9 and 12), applied as a two-spray approach.

Liberty herbicide applied at 3 L/ha + Liase at 2% as a two-spray approach (Treatment 13) could improve weed control and performed similarly to most Liberty treatments applied as a two-spray approach with either clethodim or glyphosate tank-mixed in initial applications. Similar trends were observed for ARG head counts (measured as seed set) for standalone Liberty treatments at 2 L/ha +/- Liase, with a greater number of heads measured (16–34 heads/m^2). When rates of Liberty were increased to 3 L/ha + Liase, the overall number of annual ryegrass heads was reduced, performing similarly most other treatments, with an average of 1 head/m^2 (Table 4).

There was no evidence to suggest that reducing the water application rate from 100 to 70 L/ha compromised the activity of Liberty mixtures with clethodim, uptake and Liase. In addition, similar control was observed irrespective of whether the follow-up application was undertaken at 7 or 21 days. However, it is important to note that the ARG weed pressure across the site was low. Cold conditions (<10 degrees Celsius) experienced when the second application of Liberty was undertaken (Treatment 16) also had no negative impact on weed control.

Despite the population being DIM resistant (Group 1), TruFlex spray regimes of Roundup Ready PL + clethodim (followed by (fb) Roundup Ready PL) provided similar control to Liberty + glyphosate and Liberty + clethodim as the first of two spray timings (fb Liberty approximately 14 days later: Figure 3).

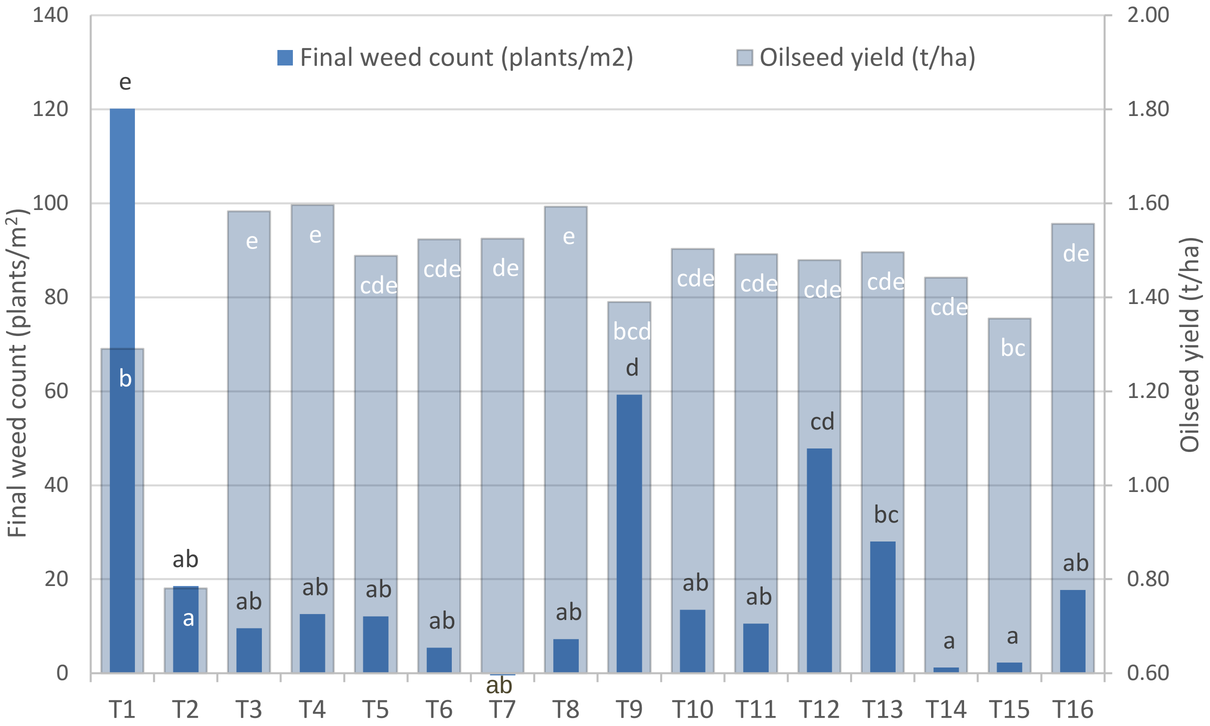

Figure 3. Final weed count (plants/m²) and oilseed yield (t/ha) for all treatments at Hill River, SA in 2023. Columns for final weed count (■) or oilseed yield (□) with the same letter are not significantly different.

Table 4. Annual ryegrass final weed counts (plants/m²) and head counts for all herbicide treatments at Hill River. Shaded values show best performing treatments

Treatment	**Annual ryegrass head count (heads/m²)**
1	160^{d}
2	2^{a}
3	0^{a}
4	0^{a}
5	1^{a}
6	0^{a}
7	0^{a}
8	2^{ab}
9	34^{cd}
10	2^{ab}
11	1^{a}
12	16^{bc}
13	1^{a}
14	0^{a}
15	0^{a}
16	1^{a}
P-value	**<0.001**

Oilseed yield

The lowest grain yield observed at Hill River was stacked tolerance variety InVigor LT 4530P (LibertyLink + Triazine Tolerant + PodGuard). This result was not entirely unexpected and may be associated with the TT tolerance trait which can influence yield. Yields were lowest for Liberty 2 L (+/- Liase) as a two-spray regime (1.3–1.39 t/ha) and the untreated control (1.29 t/ha). These results can be attributed to higher ARG numbers, competing with canola for soil moisture and nutrition (Figure 3).

A yield penalty was observed for Treatment 15 which had an extended application timing (glyphosate <10% flower). This is likely due to poor control with Liberty at 2 L/ha +/- Liase applied as a two-spray approach, with the third application of glyphosate too late to prevent ARG competition.

Hart

Weed control

Results at the Hart field site in 2023, on a susceptible ARG population show that herbicide regime was most significant in determining weed control (plants/m^2). It is important to note that while applications were made to ARG at varying growth stages from 2-4 leaf to 2-4 tiller, tillering ARG plants were small and sprayed early (not at stem elongation). Similar humidity (RH%) and temperature (°C) conditions were observed at each application (see Appendix 1).

Similarly to Hill River results, applications of Liberty standalone, sprayed as a sequential two-spray regime had reduced ARG control (62 plants/m^2), when compared to Liberty tank mixed with clethodim or Roundup Ready PL (23 plants/m^2) in initial spray timings. Liberty at 3 L/ha performed similarly, reducing overall weed number. Liberty at 2 L/ha + Liase at Hart also significantly reduced overall ARG head number (Table 5), similar to all other treatments, this result was not observed at Hill River. The untreated control had the highest level of ARG present, with an average of 219 plants/m^2 (Figure 4).

Figure 4. Photos showing post-emergent activity for treatments applied at 2-4 leaf stage: 2 L/ha Liberty + 330 mL clethodim + 2% Liase (left), untreated control (middle) and 2 L/ha Liberty + 2% Liase (right). All treatments received 2 L/ha Liberty + 2% Liase 12 days later.

Table 5. Average annual ryegrass weed count and head density following final herbicide treatment at Hart in 2023. There was no significant effect of growth stage on ryegrass weed count (p-value=0.735) or head density (p-value=0.964). Shaded values show best performing treatments.

Treatment	**Annual ryegrass weed count (plants/m^2)**	**Annual ryegrass head count (heads/m2)**
1	219^{c}	240^{b}
2	62^{b}	19^{a}
3	28^{ab}	5^{a}
4	20^{a}	8^{a}
5	19^{a}	4^{a}
P-value	**<0.001**	**<0.001**

Summary

Data from field trials undertaken at Hill River and Hart in the Mid North of SA showed that Liberty at low label rate of 2 L/ha + ammonium sulphate was not adequate for the control of ARG.

The higher rate of 3 L/ha + 3 L/ha Liberty provided more consistent results reducing both weed numbers and ARG head numbers. Liberty herbicide tank mixed with clethodim or registered glyphosate options in early spray applications with ammonium sulphate, were generally the most effective treatments indicating that these mixes are more likely to provide better ryegrass control than Liberty only treatments, particularly at lower label rates of Liberty. The use of the 3 L/ha Liberty followed by a further 3 L/ha should be considered in a rotation to slow down resistance developing to clethodim and glyphosate. Liase or similar products should be included to improve activity.

Acknowledgements

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References

Preston C., (2024). Strategies for optimising glufosinate and tackling efficacy challenges. Available online : https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2024/02/strategies-for-optimising-glufosinate-and-tackling-efficacy-challenges

Appendix 1. Application timing details for glufosinate trial at Hart, 2023.

ARG Growth stage timing at application 1: 2-leaf	**Application 1**	
	Canola growth stage:	2-4 leaf
	Date:	June 29
	Time:	12:30pm
	Cloud cover:	10%
	RH%	66%
	Temperature:	12°C
	Application 2	
	Canola growth stage:	2-4 leaf
	Days since application:	**12**
	Date:	July 11
	Time:	12:30pm
	Cloud cover:	10%
	RH%	59%
	Temperature:	17°C
ARG Growth stage timing at application 1: 1-2 tiller	**Application 1**	
	Canola growth stage:	6 Leaf
	Date:	July 21
	Time:	1:00pm
	Cloud cover:	15%
	RH%	69%
	Temperature:	13°C
	Application 2	
	Canola growth stage:	10 leaf
	Days since application:	**17**
	Date:	August 7
	Time:	12:00pm
	Cloud cover:	90% but conditions still bright
	RH%	62%
	Temperature:	17°C
ARG Growth stage timing at application 1: 2-4 tiller	**Application 1**	
	Canola growth stage:	10 leaf
	Date:	August 7
	Time:	12:00pm
	Cloud cover:	90% but conditions still bright
	RH%	62%
	Temperature:	17°C
	Application 2	
	Canola growth stage:	Stem elongation-budding
	Days since application:	**14**
	Date:	August 21
	Time:	1:00pm
	Cloud cover:	10% - cloud cover from 3pm + small amount of rain
	RH%	67%
	Temperature:	18°C

Investigating effects of temperature, humidity and photoperiod for efficacy of glufosinate on resistant and susceptible annual ryegrass

Peter Boutsalis[1], Sam Kleemann[1] and Rebekah Allen[2]
Plant Science Consulting[1] Hart Field-Site Group[2]

Key findings

- Results from pot experiments suggest that humidity within 24-hours of application of Liberty® was very important to glufosinate activity on annual ryegrass.
- It was also identified that under lower humidity, increasing the photoperiod from 1 to 8 hours was found to improve control with Liberty and suggests that applying in the morning may be better than late afternoon. This was observed in field trials where morning applications of sequential Liberty at 3 L/ha, or Liberty tank mixes at 2 L/ha with glyphosate or clethodim as the first application in the sequence still provided good control despite lower humidity conditions (60-80%).

Introduction

Active ingredient glufosinate-ammonium (200 g/L) registered as Liberty is a Group 10 herbicide which can now be applied in-crop to canola varieties with LibertyLink® technology (tolerance to Liberty herbicide). This registration provides a new herbicide mode of action (MOA) for use in broadacre cropping systems.

Glyphosate and glufosinate belong to two different MOA (Group 9 and 10, respectively), however their structural elements are similar in that they are both charged herbicides (Preston, 2024). This means they are unable to pass through wax layers of plant cuticles and are alternatively required to enter via pectin strands (intercellular plant tissue) within cuticles. As pectin strands contain negative charges, these herbicides are slow moving into the leaf and the rate of absorption is impacted by temperature and humidity (Preston, 2024). Previous research suggests that temperature plays only a small part when it comes to glufosinate uptake, whereas humidity is the more important factor (Preston, 2024). Low humidity can reduce the ability of glufosinate to move through the pectin strands, which need to remain hydrated for this to happen. However, it is suggested that humidity is not generally an issue in southern Australia during winter and that high humidity is only required for the first 24-hours after application for glufosinate uptake (Preston, 2024).

In addition to two field trials, a series of pot experiments exploring the effects of temperature and humidity on herbicide efficacy were implemented in 2023. In this article, data from two pot experiments conducted at Waite, SA are discussed.

Methodology

Two pot experiments were implemented at Waite, SA in 2023 (Table 1) to evaluate the influence of temperature and photoperiod on sequential applications of Liberty on three biotypes of annual ryegrass; Susceptible, DIM (Group A – Cyclohexanediones) resistant and DIM + glyphosate resistant (experiment 1). It also investigated the efficacy of Liberty on DIM-resistant ryegrass at two growth stages (2-3 leaf and 3-4 tiller) and three temperature regimes (warm, cold and outdoor temperatures) for 24-hours after spraying (experiment 2).

Table 1. Trial details for experiments at Waite, SA in 2023.

Experiment 1	**Plant density:**	5 plants/plot	**Pressure:**	2 bar
	Spray date:	Timing 1: August 10 Timing 2: August 24	**Nozzle:**	Teejet 110-01
	Growth stage:	2-tiller		
	Application:	Spray chamber		
	Spray volume:	100 L/ha		
	ARG biotypes:	1. Susceptible: Jeparit 2. DIM-resistant: 700.3-20 3. DIM + Glyphosate resistant: 896-20		
Experiment 2	**Plant density:**	5 plants/plot	**Pressure:**	2 bar
	Spray date:	Timing 1: November 14	**Nozzle:**	Teejet 110-01
	Growth stage:	2-3 leaf, 3-4 tiller		
	Application:	Spray chamber		
	Spray volume:	100 L/ha		
	ARG biotype:	DIM-resistant: 700.3-20		

Experiment 1

An initial pot study was undertaken in August to evaluate influence of temperature and photoperiod on sequential applications of Liberty on three biotypes of annual ryegrass: susceptible, DIM and DIM + glyphosate resistant (Table 2).

Plants were grown outdoors and at 2-tiller stage (GS 22) sprayed with 2 L/ha Liberty in a spray chamber at either 9am or 4pm on August 10. After spraying, pots were transferred to one of two different locations, (1) a cold room or (2) shed (outdoor temperatures of 15-6°C). At each location plants were exposed to the same light source (Arlec 20W) for either eight hours (9am-5pm) or one hour (4pm-5pm) after spraying. At 5pm lights were turned off exposing the plants to complete darkness until the next morning after which pots were returned outdoors to a common location (natural light plus fluctuating ambient temperature). This process was repeated on August 24, 14-days after the first application to mimic the sequential spray as per label directions.

An untreated control of each biotype was included for comparative purposes with assessments undertaken 25-days after the second application on September 18. Herbicide activity was measured using biomass reduction and control (mortality assessed as percent of the untreated). Data was analysed using Graph Pad Prism 6.0. Vertical bars represent the standard error of means for percentage biomass reduction and control.

Table 2. Treatment list for experiment 1 at Waite, SA. Outside refers to plants kept in a shed exposed to outside temperatures and 'Cold room' refers to a refrigerated cold room operating at 10°C constant temperature. Light source: Arlec 20W light (1600 lumen, 5000K) producing light intensity of 30 $\mu mol\ m^{-2}\ s^{-1}$.

Trt	Timing 1 = 2-tiller	Timing 2 = 14 days after timing 1 on August 24, 2023	Spray time	Location
1	Untreated	Nil	9am	Outside
2	Liberty 2 L/ha	Liberty 2 L/ha	9am	Outside
3	Untreated	Nil	9am	Cold room
4	Liberty 2 L/ha	Liberty 2 L/ha	9am	Cold room
5	Untreated	Nil	4pm	Outside
6	Liberty 2 L/ha	Liberty 2 L/ha	4pm	Outside
7	Untreated	Nil	4pm	Cold room
8	Liberty 2 L/ha	Liberty 2 L/ha	4pm	Cold room

Table 3. Temperature and relative humidity at the two locations (cold room and shed) after spraying. Data collected from Tinytag Plus 2 data loggers.

Application	**August 10**				**August 24**			
	Cold room		**Shed**		**Cold room**		**Shed**	
	Temp (°C)	Humidity (%)	Temp (°C)	Humidity (%)	Temp (°C)	Humidity (%)	Temp (°C)	Humidity (%)
9am (8-hour light exposure)	10.5	90	15.6	64	10.3	86	12.9	67
4pm (1-hour light exposure)	10	95	15.2	67	9.8	94	15	88

Experiment 2

A secondary pot experiment was conducted in November of 2023 to investigate the efficacy of Liberty on DIM-resistant ryegrass at two growth stages (2-3 leaf and 3-4 tiller) and three temperature regimes (warm, cold and outdoor temperatures) for 24-hours after spraying.

Plants were grown outdoors during spring at the Waite Campus. At the 2-3 leaf (GS 12-13) and 3-4 tiller stage (GS 23-24) pots were sprayed with 2 L/ha Liberty in a spray chamber. After spraying, pots were transferred outdoors, or to growth rooms programmed to provide warm or cold temperatures (Table 4). After 24-hours, pots from both growth rooms (cold and warm) were relocated outdoors (i.e. outdoor location). The conditions for the 24-hour period were:

1. Cold growth room = 15°C day/10°C night, light intensity 250 µmol m-2 s-1, 14-hour night/ 10-hour day photoperiod; average relative humidity of 98% and an average temperature of 13.5°C over the 24-hour period after spraying.
2. Warm growth room = 25°C day/15°C night, light intensity 250 µmol m-2 s-1, 14-hour night/ 10-hour day photoperiod; average relative humidity of 91% and an average temperature of 19.7°C over the 24-hour period after spraying.
3. Outside outdoors in direct light = Overcast cloudy day with average light intensity of 400 µmol-2 s-1; average relative humidity of 76% and an average temperature of 16.1°C over the 24-hour period after spraying.

Three days later all pots were transferred from direct sunlight to a shade house with 50% light reduction (white shade cloth). This resulted in three distinct groups where only conditions for the first 24-hours after spraying (i.e. most significant period of uptake and translocation) varied.

Table 4. Treatment list for experiment 2 at Waite, SA.

Trt	**Treatment**	**Location**	**Light**	**Time at this location**	**Time outdoors**
1	Untreated	Outside	400 µmol m-2 s-1	-	-
2	Liberty 2 L/ha	Outside	400 µmol m-2 s-1	-	-
3	Untreated	Cold room	250 µmol m-2 s-1	24 hours	3 weeks
4	Liberty 2 L/ha	Cold room	250 µmol m-2 s-1	24 hours	3 weeks
5	Untreated	Warm room	250 µmol m-2 s-1	24 hours	3 weeks
6	Liberty 2 L/ha	Warm room	250 µmol m-2 s-1	24 hours	3 weeks

Annual ryegrass was assessed for herbicide damage (%) and survival (%). Data was analysed using Graph Pad Prism 10.0. Vertical bars represent the standard error of means for herbicide damage and control (%). Means were analysed using ANOVA and separated with use Tukey's multiple comparisons test at $p \leq 0.05$. Data logger measurements of temperature (°C) and relative humidity (%) were taken at each of the three locations for the 24-hour period directly after spraying (Appendix 1). These measurements were also taken for the 7-day period from the common location (e.g. 'outside') for which pots from both growth chambers (cold and warm) were relocated (Appendix 2).

Results

Experiment 1

Irrespective of biotype (resistance status), significantly greater control resulted when plants were exposed to colder temperatures (Figure 1) in the cold room (10°C) relative to those housed in the shed under warmer outdoor temperatures (+5°C). This result is contrary to some reports in literature indicating that control with glufosinate is greater at warmer temperatures (Kumaratilake and Preston 2005).

Apart from temperature, another key factor that has been identified as important in glufosinate activity is humidity. At both locations (cold room vs shed) humidity varied but was significantly higher in the cold room than shed location (91% vs 72%). Humidity is a key driver of glufosinate activity with higher humidity levels enhancing control, and most likely contributed to the stronger activity observed following exposure to the cold room despite the lower temperatures. High humidity within 24-hours of application can assist glufosinate passage through the leaf and therefore the overall amount absorbed (Preston 2024).

Timing of application and consequently the photoperiod (light exposure) can also influence glufosinate performance (Takano and Dayan 2021). Like humidity, light has been shown to increase absorption of glufosinate (Preston 2024). In this study where humidity was highest (cold room), photoperiod after spraying (1 vs 8 hours) appeared to be less influential on glufosinate.

The effect of photoperiod was much more pronounced when humidity was low after spraying (shed), with Liberty providing significantly greater control and biomass reduction of all three biotypes exposed to the 8-hour photoperiod compared to 1-hour. This finding tends to indicate that application timing and therefore photoperiod is perhaps more important when humidity is suboptimal.

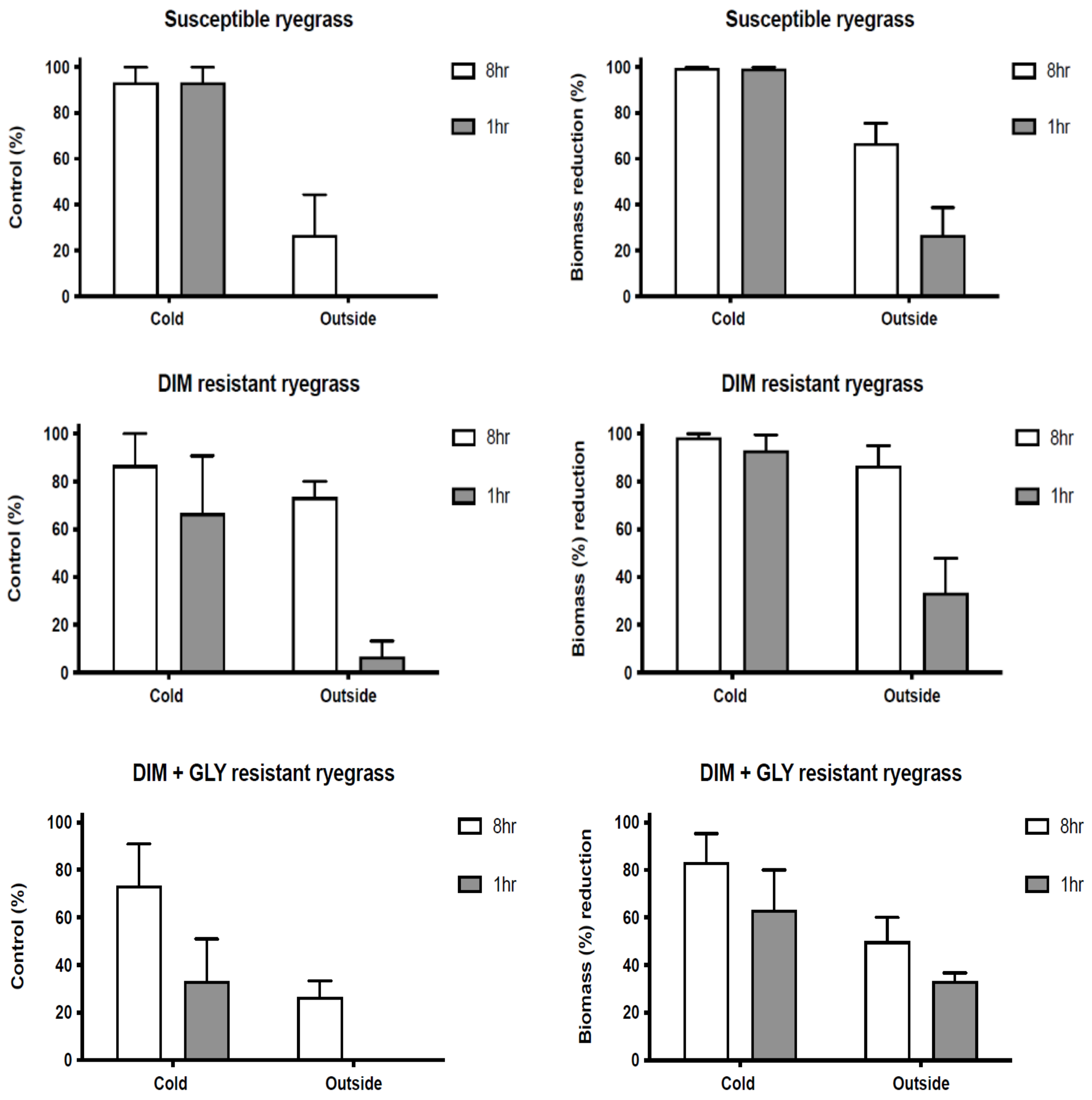

Figure 1. Percent control and biomass reduction (%) of three annual ryegrass biotypes treated to sequential applications of 2 L/ha Liberty 14 days apart.

Experiment 2

On 2-3 leaf and tillering ryegrass there was improved efficacy following treatment to ‘warm’ and ‘cold’ conditions compared to ‘outside’ (27ºC day maximum/15ºC minimum) (Figures 2 and 3). The temperature range between both growth rooms and the outside was relatively similar, however humidity was the key difference, with humidity levels higher for both growth rooms (cold = average 98%, range 82.1–100%; warm = average 91%, range 72.5–100%) relative to outside (average 76%, range 43–100%; Figure 4).

Of other potential influences of activity, light intensity was found to be within similar range between both growth rooms (average = 250 µmol m^{-2} s^{-1}) and outdoors (average = 400 µmol m^{-2} s^{-1}).

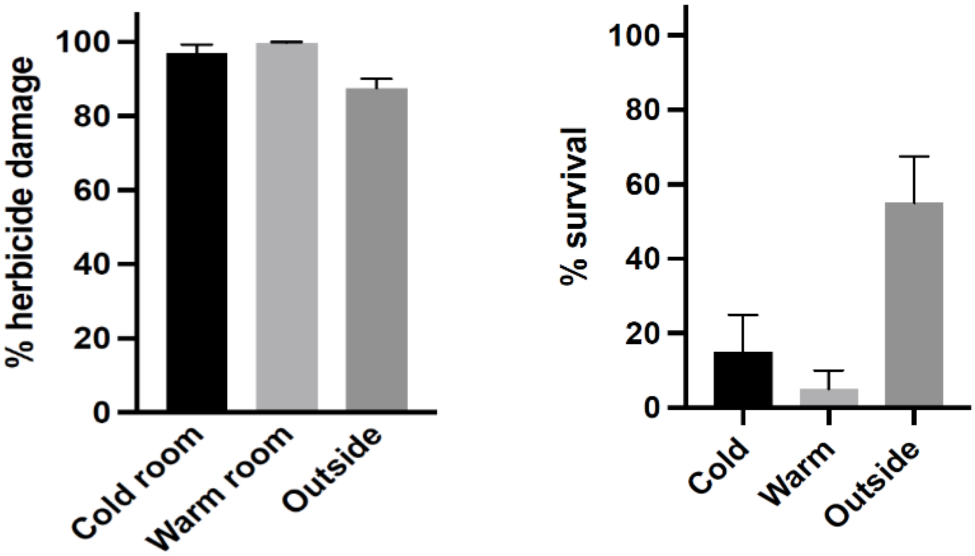

Figure 2. Herbicide damage and survival (%) of a susceptible ryegrass biotype three weeks after treatment at the 2-3 leaf stage with 2 L/ha Liberty. Vertical bars represent the standard error of means.

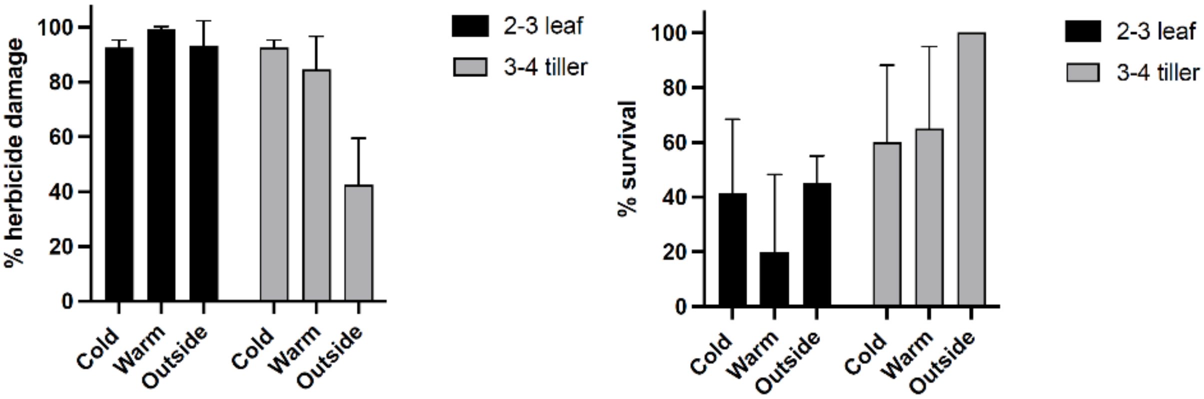

Figure 3. Herbicide damage and survival (%) of a Group 1 DIM resistant ryegrass biotype (‘96-22’) 3 weeks after treatment at the 2-3 leaf and 3-4 tiller stage with 2 L/ha Liberty. Vertical bars represent the standard error of means.

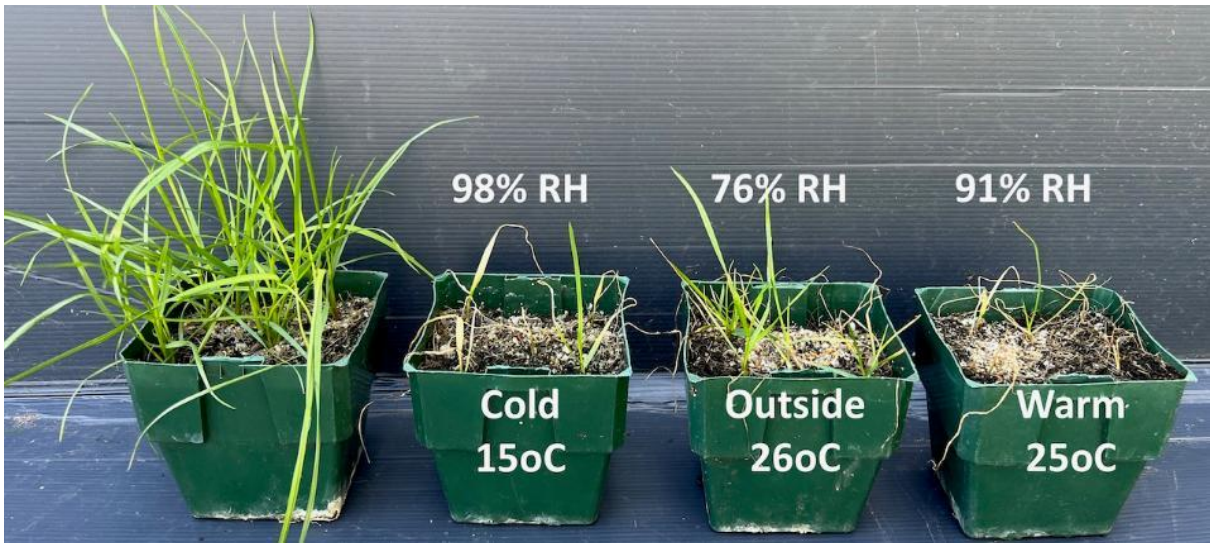

Figure 4. Visual symptoms in response to relative humidity (%) conditions after applying Liberty at 2 L/ha to susceptible ryegrass (2-3 leaf).

There was no significant difference between biotype, location or their interaction in regard to damage, however, survival was significantly affected by location (P<0.05) (Figure 5).

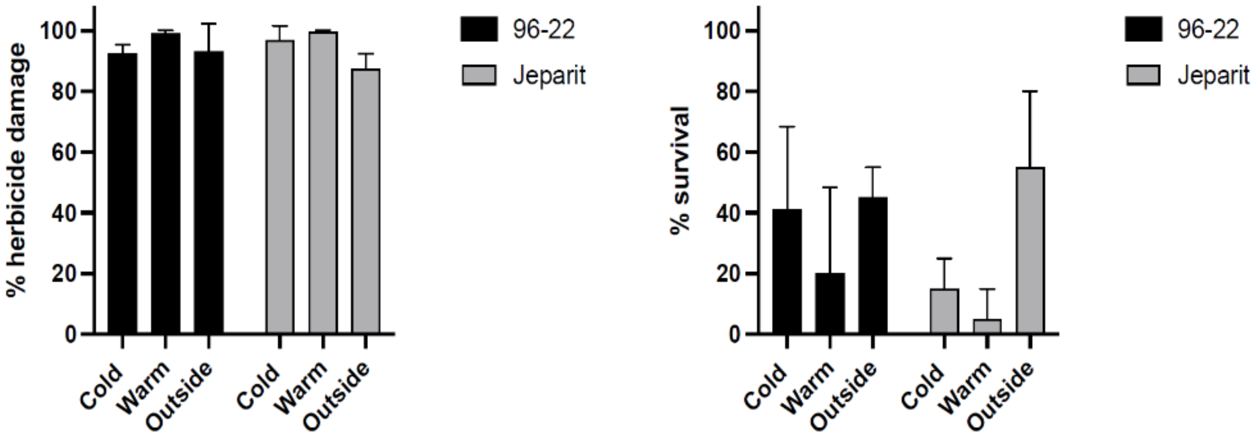

Figure 5. Herbicide damage and survival (%) of a Group 1 DIM resistant ('96-22') and susceptible ryegrass biotype ('Jeparit') 3 weeks after treatment at the 2-3 leaf stage with 2 L/ha Liberty. Vertical bars represent the standard error of means.

Control irrespective of growth stage (2-3 leaf and 3-4 tiller) was similar between both growth rooms despite the difference in temperature ('Cold' = 15ºC day/10ºC night; 'Warm' = 25ºC day/15ºC night) and appeared to be more strongly correlated to exposure to higher humidity levels at both locations (91% and 98%). This indicates that temperature is perhaps not as important as humidity for activity of Liberty on ryegrass.

Although temperature has been found to be important for glufosinate activity (Kumaratilake and Preston 2005) the current study suggests that humidity is the key factor in determining glufosinate activity with higher humidity enhancing control, irrespective of the temperature. Coetzer et. al. 2001 concluded that humidity was more important than temperature for increasing glufosinate control of *Amaranthus* spp.

There was no significant influence of biotype on herbicide damage (biomass reduction) with activity similar on both DIM-resistant and susceptible ryegrass (2-3 leaf) from the same location. However, survival of the susceptible was more strongly influenced by location, with significantly ($p \leq 0.05$) better control from both growth rooms (cold and warm) relative to outside.

Conclusion

Results from these trials suggest that humidity following application of Liberty is very important to glufosinate activity on ryegrass. In addition, it also identified that under lower humidity, increasing the photoperiod from 1 to 8 hours was more conducive to ryegrass control with Liberty. The experiments have shown that Liberty can be effective across a range of temperatures (cold and warm) provided relative humidity is high soon after application (>90%) and ryegrass is targeted at younger growth stages. Control (herbicide damage and survival) was clearly correlated to growth stage with 2-3 leaf ryegrass more effectively controlled than later growth stages. Growth stage is therefore an important factor to consider with Liberty application. The current Liberty label recommends applications be made to ryegrass between 2-4 leaf to start of tillering.

Data from the two Mid North field trials showed that sequential applications of 3 L/ha Liberty, or Liberty tank mixes at 2 L/ha with glyphosate or clethodim as the first application in the sequence can still provide good control despite lower humidity conditions (60-80%). Often the best results with Liberty are observed when using higher rates, applying to small weeds, and when conditions of high humidity, modest temperature and adequate light intensity prevail.

Acknowledgements

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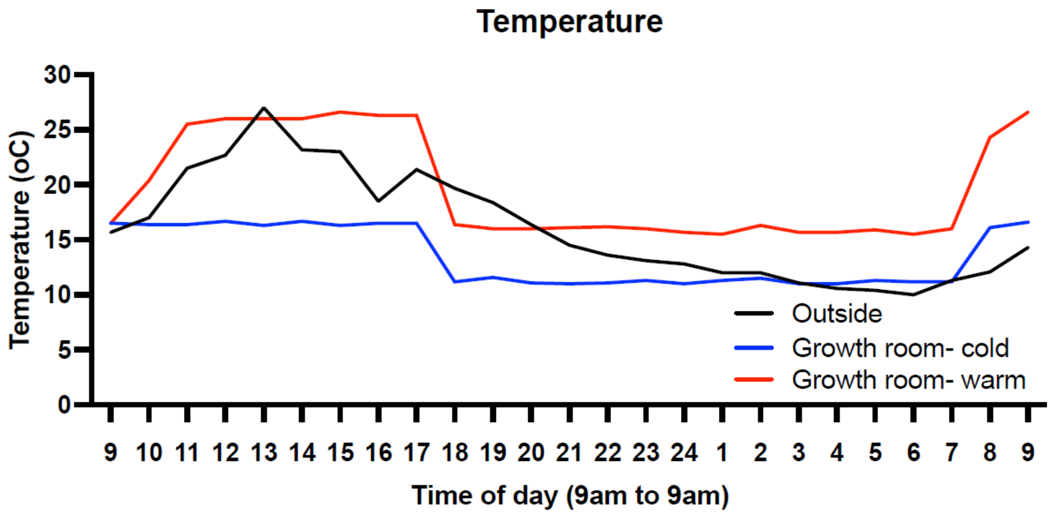
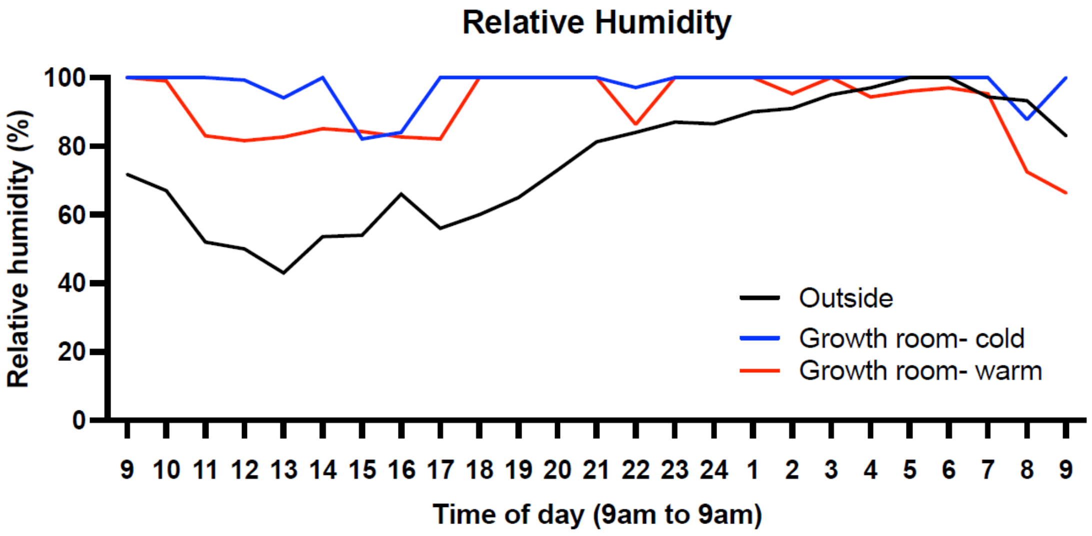
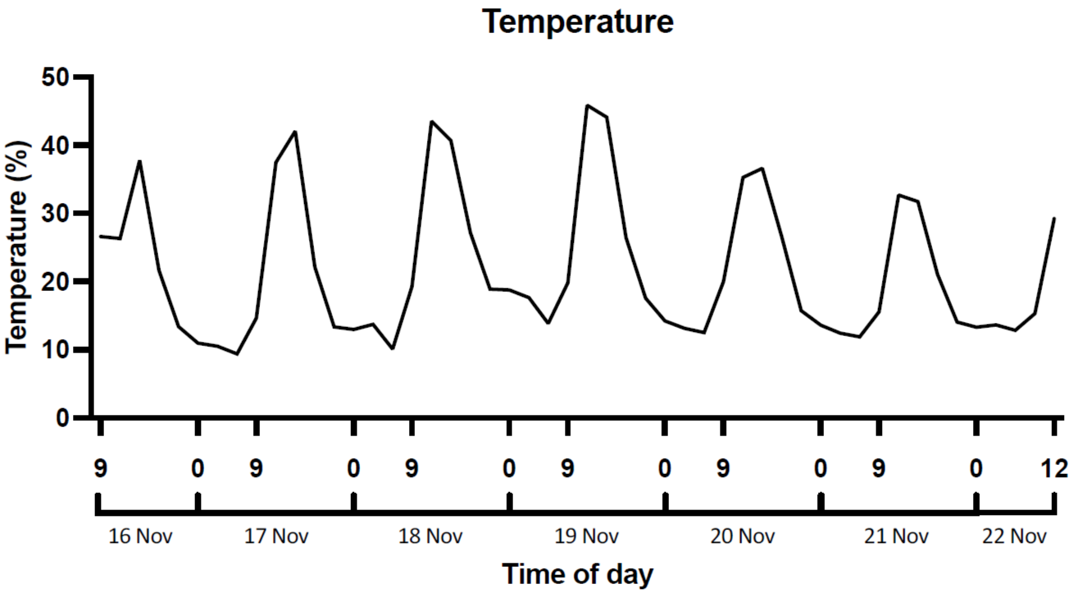
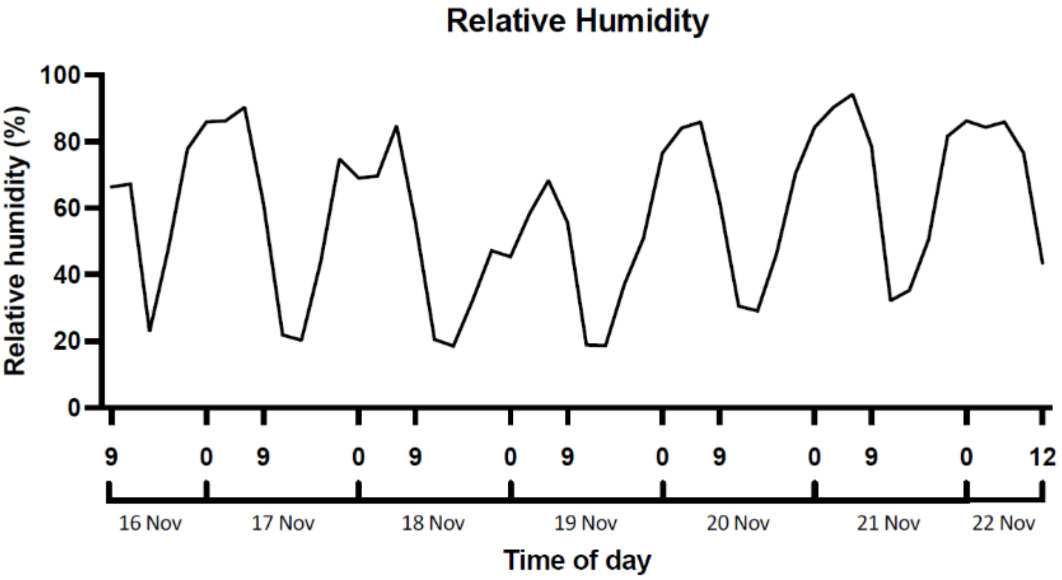
Appendix 1. *Temperature (ºC) and relative humidity (%) at each of the three locations for the 24-hour period directly after spraying.*





Appendix 2. *Temperature (ºC) and relative humidity (%) for the 7-day period from the common location (i.e. 'outside') for which pots from both growth chambers (cold and warm) were relocated.*





Investigation of combinations of cropping sequence and herbicides for the management of brome grass

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Key findings

- Management systems based on integration of crop type (wheat, barley, canola and lentil) with herbicide options are being investigated for brome grass management at a trial site near Snowtown in the Mid North of SA.
- The soil cores taken from trial site showed presence of a large and uniform brome grass seedbank (5849 ± 631 seeds/m^2).
- Systems where pre-emergent herbicides were followed by post-emergent Group 1 herbicides in break crops (lentils and canola) virtually eliminated brome grass plants.
- Brome grass panicle density provided the clearest separation between management systems. Wheat treated with Sakura + Avadex was the worst performer with >500 panicles/m^2. In contrast, the lowest density of brome panicles was found in canola and lentil-based systems where post-emergent herbicides were used.
- Barley systems based on Clearfield (Intercept post-emergent) or CoAXium system provided 78- 93% reduction in brome grass panicle density. In contrast, Barley CL based on pre-sowing Sentry herbicide had a significantly higher number of brome grass panicles than the same barley variety treated with Intercept post-emergent.
- There were large differences in brome grass seed set on an area basis with Calibre wheat sprayed with Sakura + Avadex producing more than 8000 seed/m^2. The lowest weed seed production was observed in lentils and canola, which ranged from 41 to 118 seeds/m^2.
- Lentil based management systems provided excellent brome grass control and produced good grain yields (>2 t/ha). The canola system with Group 1 post-emergent herbicide also gave effective control of brome grass. Among cereals, Clearfield barley and CoAXium barley (T4, 5 and 7) produced similar grain yield (3.11-3.39 t/ha).

Introduction

Brome grass is currently ranked the fourth worst weed in Australia in terms of the area infested, as well as yield and revenue loss in grain crops (Llewellyn et al. 2016). Brome grass tends to be difficult to effectively control with pre-emergent herbicides that are registered for use in cereal crops. However, development of herbicide tolerant cereal varieties has opened options for growers to manage brome grass effectively in the cereal phase of the rotations.

Integration of herbicide tolerant cereals with break crops such as pulses and canola offer opportunities to effectively deplete brome grass seedbank and minimise the risk of buildup in its populations. Fortunately, the frequency of resistance to Group 1 and 2 herbicides in brome grass is still low (<2%).

It is important to demonstrate the potential effectiveness of combinations of cropping sequences with herbicides, for the management of brome grass in different agroecological environments. To achieve this objective, a three-year field trial was implemented during the 2024 growing season near Snowtown in the Mid North region of South Australia. This trial is a collaborative effort between the University of Adelaide, the Hart Field-Site Group and Trengove Consulting.

Methods

Site selection and rainfall

A field trial was established in a randomised complete block design with seven treatments (Table 1) on a commercial farm near Snowtown in the Mid North region of South Australia. This farm has a loamy textured soil which is suitable for brome grass. Visual inspection of the site in autumn showed presence of brome grass residue and confirmed suitability of this site for this investigation.

Prior to seeding, soil cores were taken to determine seedbank of brome grass at the trial site. Twenty cores of 10 cm diameter were taken from each replicate block and bulked and taken to Roseworthy. Soil samples were placed in seedling trays (pots) in May and watered as required to maintain ideal moisture conditions for seed germination and seedling emergence. Established brome grass seedlings were counted and removed each week until seedling emergence ceased. This data was used to determine brome grass seedbank and its seedling establishment pattern, which is an indicator of seed dormancy.

The trial was sown on May 22 with a double shoot knife point press wheel system on 25 cm spacings after the application of IBS (incorporated by sowing) treatments. Plots were 15 m long and there was one buffer plot of Spartacus CL barley between each experimental plot to minimise the risk of spread of weed seeds to neighbouring plots during crop harvest or by wind dispersal and minimise the risk of herbicide drift from an adjacent plot to a sensitive crop. Information on crop varieties and other management practices used in this trial can be found in Table 1.

Table 1. Details of the experimental site including location and seeding details.

Operation	**Details**
Location	Snowtown, SA (-33.74190, 138.18355)
Seedbank soil cores	May 10, 2024
Plot size	1.5 m x 15 m
Seeding date	May 22, 2024
Seeder information	No-till 6-row experimental seeder
Fertiliser application	At seeding 80kg MAP + Zn1% on all plots plus 100 kg urea to wheat, barley and canola plots. All fertiliser was applied 30 mm below the seed. In-crop application of urea to wheat and canola on August 14
Crop varieties	Wheat - Scepter Canola - HyTTec Trophy Lentil XT - GIA Thunder Barley CL - Maximus CL Lentil XT - GIA Thunder Barley AX - Titan AX
Crop establishment	July 2, 2024
Weed assessments	Brome plant density – July 2 and October 1 Brome panicle density – November 1
Crop grain yield harvest	November 4 (desiccation of canola and lentil on November 1)

The summer months of 2024 were extremely dry with no follow up rainfall from March to April (Table 2). Conditions following seeding were dry with below average rainfall received for May (15 mm), with
10 mm follow-up rainfall eight days later.

Above average rainfall in June and average rainfall in July were important for stimulating crop growth. The site also received above-average rainfall in the month of October, which played an important role in grain filling of crops. The site also received 139.5 mm out of season rainfall, most of which occurred in December 2023 (96.5 mm). Based on 25% conservation of summer rainfall with good management practices, it is estimated there was 38 mm additional stored soil water at this site.

Table 2. Manual rainfall records for 2024 season at the Snowtown trial site.

Month	Rainfall in 2024 (mm)
Jan	22.0
Feb	0.0
Mar	0.0
Apr	0.0
May	15.0
Jun	71.8
Jul	40.5
Aug	21.0
Sep	10.0
Oct	53.5
Nov	0.0
Dec	0.0
Annual total	**233.8**
Growing season rainfall	**211.8**

Rationale for management systems selected

Crops grown widely in the Mid North region were selected and trialed with various herbicide regimes (Table 3 and 4). System 1 represents the best option currently available for use in non-herbicide tolerant varieties. This system typically provides 60-70% control and brome grass plants often recover late in the season to set seed. Therefore, brome grass population in this system is likely to remain stable or increase steadily.

The duration of break years represents the period of effective control during the three-year sequence. Two Clearfield® barley systems were selected; post-emergent imidazolinone (IMI) herbicide treatment, which is likely to be highly effective and PRE IMI system, which is likely to have a lower efficacy. In addition to pre-emergent and post-emergent herbicides, crop-topping will be used in lentils to prevent seed set by brome grass.

Table 3. Management systems to be investigated for brome grass control at Snowtown, SA.

Trt #	System	2024	2025	2026
1	Weaker control	**Wheat**	**Wheat**	**Barley**
		Sakura + Avadex (IBS)	Overwatch + Avadex (IBS) Fb Crusader (POST)	Treflan + Avadex + Met (IBS)
2	1 year break	**Canola**	**Wheat**	**Barley**
		Propyzamide + simazine (IBS) Clethodim + atrazine (POST)	Sakura + Avadex (IBS)	Treflan + Avadex + Met (IBS)
3	1-year break	**Lentil XT**	**Wheat**	**Barley**
		Propyzamide (IBS) Fb Factor + clethodim + Intercept (POST) Fb crop topping	Overwatch (IBS)	BoxerGold (IBS)
4	2-year break (POST IMI)	**Maximus CL**	**Lentil XT (soaker)**	**Wheat**
		BoxerGold + Treflan (IBS) Fb Intercept (POST)	Propyzamide (IBS) Fb Group 1/A (2x POST timings) Fb crop topping	Sakura + Avadex (IBS)
5	2-year break (PRE IMI)	**Maximus CL**	**Lentil XT (soaker)**	**Wheat**
		BoxerGold + Treflan + Sentry (IBS)	Propyzamide (IBS) Fb Group 1/A (1x POST timings) Fb crop topping	Sakura + Avadex (IBS)
6	3-year break	**Lentil XT**	**Canola XC**	**Wheat Cl+**
		Propyzamide (IBS) Fb Group 1/A + Group 2/B (POST) Fb crop topping	Propyzamide or Overwatch (IBS) Fb Crucial + Group 1/A (POST) Fb Crucial TBC (POST)	Sakura + Avadex (IBS) Fb Intercept (POST)
7	3-year break (no IMI)	**Barley AX**	**Metro Lentil**	**Canola TF**
		Treflan + Avadex + Metribuzin (IBS) Fb Aggressor (POST)	Ultro + Metribuzin (IBS) Fb group 1/A herbicide (POST)	Propyzamide (IBS) Fb Crucial + Group 1/A herbicide (POST) Fb Crucial (POST)

Table 4. Information about the herbicides to be used for brome grass control in the trial at Snowtown in 2024.

Product name	Active ingredient	Label rate
Sakura®	Pyroxasulfone 850 g/kg	118 g/ha
Boxer Gold®	Prosulfocarb 800 g/L and S-metolachlor 120 g/L	2.5 L/ha
Avadex®	Triallate 500 g/L	3.2 L/ha when used as incorporated by sowing in no-till
Treflan®	Trifluralin 480 g/L	1.5-3.0 L/ha when used in min or no-till knifepoint press wheel system and incorporated by sowing
Intercept®	33 g/L imazamox and 15 g/L imazapyr	375-750 mL/ha for brome grass
Sentry®	525 g/kg imazapic and 175 g/kg imazapyr	40-50 g/ha
Propyzamide	Propyzamide 500 g/L	1 L/ha
Simazine	Simazine 900 g/kg	1 kg/ha in triazine tolerant canola
Clethodim	Clethodim 240 g/L	175-500 mL/ha
Factor®	250 g/kg butroxydim	80-180 g/ha
Metribuzin 750 WG	750 g/kg metribuzin	
Crucial®	Glyphosate 600 g/L	1-1.5 L/ha (in Truflex canola)
Aggressor® AX	Quizalofop 185 g/L	200 mL/ha

Results and Discussion

Crop establishment

Seedling establishment for all crops was lower than the target density (Table 5). For example, wheat target density was 150 plants/m^2 but the actual density was only 81 plants/m^2. The exact reason for lower-than-expected crop plant density are unclear. However, distribution of crop plants within plots was uniform and representative of grower establishment and allowed crops to produce good grain yields.

Table 5. Crop density established in different management systems. Information on herbicides used for brome grass control are shown in Table 2.

Treatment	Crop grown in 2024	System	Crop establishment (plants/m^2)[1]
1	Wheat	Weaker control	81^b
2	Canola TT	1-year break	18^a
3	Lentil XT	1-year break	73^b
4	Barley CL	2-year break (POST IMI)	77^b
5	Barley CL	2-year break (PRE-IMI)	95^b
6	Lentil XT	3-year break	67^b
7	Barley AX	3-year break (no IMI)	93^b

[1] Means within a column followed by a different letter indicate significant differences at $p \leq 0.05$. PRE and POST refer to pre-emergent and post-emergent herbicide application.

Brome grass seedbank and plant density

Data from seedling emergence census in pots at Roseworthy during autumn and winter months was used to determine brome grass seedbank at the trial site. The analysis of this data showed the site had a large and uniform brome grass seedbank ((5849 ± 631) seeds/m^2), thus making it ideal for this three-year investigation. Data from seedling establishment pattern was used to determine time taken to 50% emergence (t_{50}), which is an indicator of seed dormancy status of a weed population. Seedling emergence data fitted well (R^2=0.99) to a logistic function and showed t_{50} of Snowtown population to be 14-days, which indicates a moderate level of seed dormancy (Figure 1).

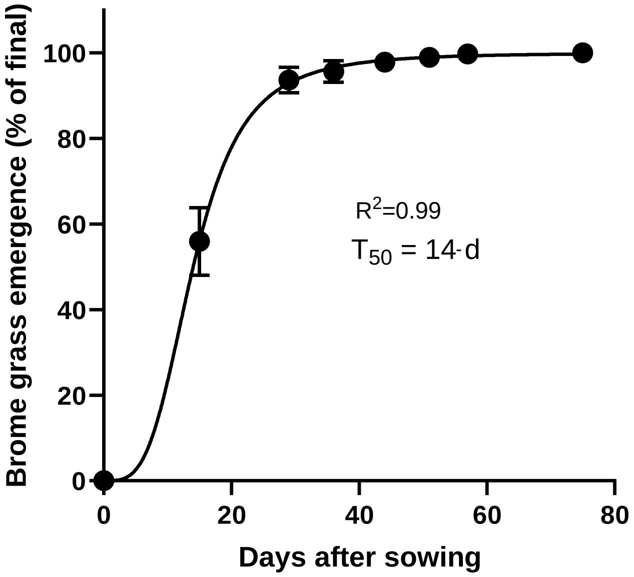

Figure 1. Emergence pattern of brome grass population sampled from the trial site at Snowtown.

Brome grass plant density

There were no differences between the management systems in initial brome grass plant density (July 2) most likely due to this assessment occurring before the pre- and post-emergent herbicides had exerted their full effect (Table 6). There was only 16.2 mm rainfall in four weeks after seeding, which created dry soil conditions after crop sowing that were not conducive for the activity of pre-emergent herbicides, particularly Sakura. The final brome density count (October 1) provided clear separation between the treatments.

Systems where pre-emergent herbicides were followed by post-emergent Group 1 herbicides in break crops (lentils and canola) achieved significant control of brome grass plants. Barley CL (T5 – 410 plants/m^2), which relied on pre-emergent IMI herbicide Sentry had similar efficacy as Sakura + Avadex only in Calibre wheat (T1 – 316 plants/m^2). Brome grass plant density in Barley AX treated with Aggressor® herbicide (Treatment 7) was also very high (298 plants/m^2).

Clearly brome grass plants were still dying at the time of final assessment of brome grass density on October 1. This argument is strongly supported by the sharp reduction in brome panicle density (November 1) compared to brome plant density (Figure 2).

Table 6. The effect of different management systems on brome grass density. Shaded values in each column indicate best performing treatments.

Treatment	**Crop grown in 2024**	**System**	**Brome density[1] (Ju 2l) (plants/m^2)**	**Brome density[1] (Oct 1) (plants/m^2)**	**Reduction (%)**
1	Wheat	Weaker control	1777	316^{cd}	82
2	Canola TT	1-year break	1284	0^{a}	100
3	Lentil XT	1-year break	1348	4^{a}	100
4	Barley CL	2-year break (POST IMI)	2389	89^{b}	96
5	Barley CL	2-year break (PRE IMI)	1200	410^{d}	66
6	Lentil XT	3-year break	1337	8^{a}	99
7	Barley AX	3-year break (no IMI)	1712	298^{c}	83
P-value			**0.055 (NS)**	**<0.001**	

[1] Initial and final brome grass density data was square root transformed before undertaking ANOVA. Means within a column followed by a different letter indicate significant differences at p≤0.05. PRE and POST refer to pre-emergent and post-emergent herbicide application.

Brome grass panicle density

Brome grass panicle density provided the clearest separation between the management systems (Table 7). Wheat (T1) treated with Sakura + Avadex was the worst performer with > 500 panicles/m^2. It should also be noted that brome grass panicle density was greater than plant density only in this treatment, indicating an average of 1.7 panicles per plant. This result is somewhat expected as no post-emergent herbicides were applied to supress growth of escaped weeds.

In contrast, the best control of brome panicles occurred in TT canola and lentil-based systems. Clearfield or CoAXium barley systems provided 78-93% reduction in brome grass panicle density (Table 7). Clearfield barley with Sentry herbicide applied IBS (T5) had significantly higher brome grass panicles than the same variety treated with Intercept post-emergent (T4).

Table 7. The effect of different management systems on brome grass panicle density. Shaded values in each column indicate best performing treatments.

Treatment	**Crop grown in 2024**	**System**	**Brome panicle density[1] (panicles/m^2)**	**Reduction (%) relative to wheat (control)**
1	Wheat	Weaker control	526^{d}	0
2	Canola TT	1- year break	1^{a}	99.7
3	Lentil XT	1-year break	4^{a}	99.3
4	Barley CL	2-year break (POST IMI)	35^{ab}	93.4
5	Barley CL	2-year break (PRE IMI)	115^{c}	78.1
6	Lentil XT	3-year break	1^{a}	99.7
7	Barley AX	3-year break (no IMI)	70^{bc}	86.7
P-value			**<0.001**	

[1] Final brome grass density data was square root transformed before undertaking ANOVA. Means within a column followed by a different letter indicate significant differences at p≤0.05. PRE and POST refer to pre-emergent and post-emergent herbicide application.

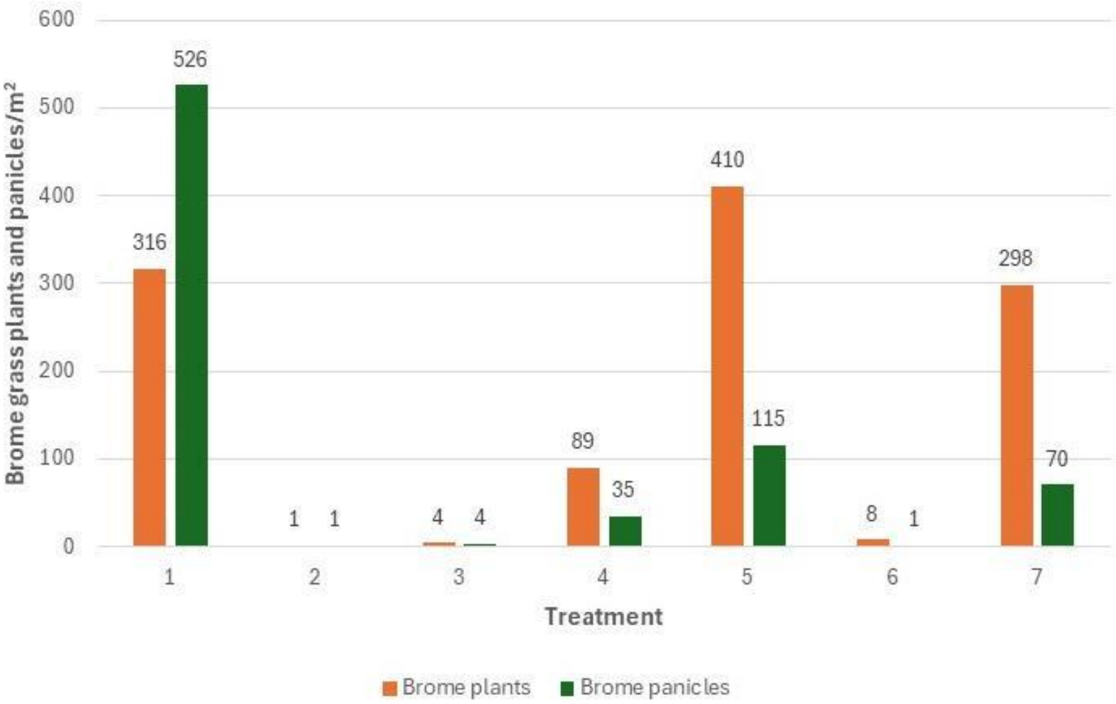

Figure 2. The response of brome grass plant density (October 1) and panicle density (November 1) to different management systems. Note panicle density was greater than plant density only in treatment 1. These results suggest significant mortality in brome grass plants after the assessment of final plant density as indicated by <1 panicle/plant for most treatments.

Brome grass seed production

Even though brome grass panicle production in lentils and canola was extremely low, panicles produced were large and produced >28 seeds/panicle. Calibre wheat treated with Sakura + Avadex (T1) not only produced the highest panicle density, but it also set 16 seeds/panicle (Table 8). Herbicide tolerant barley varieties (T4, 5 and 7) had the lowest seed set per panicle (5-7 seeds/panicle). The lowest seed set in barley may be associated with the herbicide tolerance trait and its highly competitive ability with weeds.

There were large differences in brome grass seed set on an area basis with Calibre wheat sprayed with Sakura + Avadex producing more than 8000 seed/m^2 (Table 8). The lowest weed seed production was observed in lentils and canola, which ranged from 41-118 seeds/m^2. There was a significant difference in seed set between the two Barley CL treatments (T4 and 5) with Intercept applied post-emergent allowing lower weed seed production than the system reliant on pre-emergent Sentry. Barley AX system with Aggressor herbicide had an intermediate performance of the two barley systems.

Table 8. The effect of different management systems on brome grass seed production. Shaded values in each column indicate best performing treatments.

Treatment	Crop grown in 2024	System	Brome seeds[1] per panicle	Brome seed set[1] (seeds/m^2)
1	Wheat	Weaker control	16.4 ^{ab}	8004^{c}
2	Canola TT	1-year break	38.7 ^{b}	71^{a}
3	Lentil XT	1-year break	30.4 ^{b}	118^{a}
4	Barley CL	2-year break (POST IMI)	5.2 ^{a}	184^{a}
5	Barley CL	2-year break (PRE IMI)	6.4 ^{a}	763^{b}
6	Lentil XT	3-year break	28.6 ^{b}	41^{a}
7	Barley AX	3-year break (no IMI)	7.2 ^{a}	345^{ab}
P-value			**0.007**	**<0.001**

[1] Brome grass seeds per panicle and seed set data were square root transformed before undertaking ANOVA. Means within a column followed by a different letter indicate significant differences at P=0.05. PRE and POST refer to pre-emergent and post-emergent herbicide application.

Crop grain yield

Lentil based management systems provided excellent brome grass control and produced good yields (>2 t/ha, see Table 9). Canola system also gave effective brome grass control, but its suboptimal crop density (18 plants/m^2) may have reduced yield. Among cereals, Clearfield and CoAXium barley (T4, 5 and 7) produced similar grain yield (3.11-3.39 t/ha). These herbicide tolerant barley varieties provide excellent options for integration with oilseed and pulse crops to develop multi-year crop sequences for effective brome grass management. In contrast, Calibre wheat with the best currently available pre-emergent herbicide options had 526 brome panicles/m^2 and produced significantly lower grain yield than herbicide tolerant barley (1.77 vs >3 t/ha).

Contrasting levels of weed control and brome grass seed production in different management systems in this field trial has nicely set the scene for an informative three-year investigation on brome grass management in locally adapted cropping systems.

Table 9. The effect of different management systems on crop grain yield.

Treatment	Crops grown in 2024	System	Grain yield (t/ha)[1]
1	Wheat	Weaker control	1.77 ^{b}
2	Canola TT	1-year break	1.01 ^{a}
3	Lentil XT	1-year break	2.08 ^{c}
4	Barley CL	2-year break (POST IMI)	3.11 ^{d}
5	Barley CL	2-year break (PRE IMI)	3.39 ^{d}
6	Lentil XT	3-year break	2.21 ^{c}
7	Barley AX	3-year break (no IMI)	3.21 ^{d}
P-value			**<0.001**

[1] Means within a column followed by a different letter indicate significant differences at P=0.05. PRE and POST refer to pre-emergent and post-emergent herbicide application.

Acknowledgements

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Photo: Brome grass management trial site at Snowtown pre-seeing in 2024.

Novel management strategies for the control of fusarium root rot in lentil

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Key findings

- An experimental seed treatment was observed to control some negative effects, including seedling survival (%), caused by *Fusarium avenaceum* (fusarium root rot) in lentil.
- Rhizobia growth in lentil was not affected by the presence of an experimental seed treatment.
- Further research on lentil is required to understand the interaction between the experimental seed treatment, fusarium root rot and rhizobia strain.
- The seed treatment used in this experiment is not registered for use in lentils or for the control of fusarium root rot and was used for experimental purposes only.

Introduction

Lentils are a common break crop across the Mid North of South Australia (SA). Over the past two seasons (2023 and 2024) the Upper North, Mid North and Lower North of SA combined, grew approximately 39,000 hectares of lentils per year, equating to an estimated 57,060 metric tons. This makes lentils an important commodity to SA's agricultural industry (Department of Primary Industries and Regions, 2023).

Soil borne diseases affect a range of cereal and pulse crops, significantly impacting the Australian grains industry. In wheat alone, diseases such as root lesion nematode (*Pratylenchus* spp.), and crown rot (*Fusarium* spp.) are estimated to cause losses of $134-$404 million each year (Murray & Brennan, 2009). As pulses are relatively new to Australian farming systems, first planted in the 1990's, (Pulse Australia, 2015) soilborne diseases affecting these crops are poorly understood. Their impacts often go unnoticed, as they are less visual compared to foliar diseases (Gontar et.al. 2024).

Surveys across Australia demonstrated that root diseases are common in pulses, and further work has led to the identification of key soilborne pathogens likely reducing pulse yields (Gontar et.al. 2024). Pathogens such as *Fusarium avenaceum*, *Rhizoctonia solani AG8* (rhizoctonia root rot), and *Didymella pinodella* (the major pathogen of the ascochyta blight foliar disease complex of field pea) are commonly found in soil and root DNA tests through the Mid North of South Australia, and across other Australian growing regions. The effect these pathogens have on lentil yield is not well known, however approximately 20% of poor performing pulse roots were found to have *Fusarium avenaceum* present (Gontar et.al. 2024).

A field trial was established at the Hart field site to quantify yield loss from fusarium root rot in lentil, and an experimental seed treatment was identified that can potentially reduce yield loss. A controlled environment experiment was established at SARDI at the South Australian Waite Research Institute to validate field observations and effects of the seed treatment control of *F. avenaceum*. The aim of this controlled environment experiment was to investigate the benefit lentil producers might observe from the use of a suitable seed treatment where *F. avenaceum* is known to be present.

Methodology

Trial design and treatments

In 2024, a lentil pot experiment was implemented at SARDI at the South Australian Waite Research Institute. This experiment was conducted on PBA Hallmark lentils and was designed as a two-way randomised complete block design with six replicates, using RStudio statistical software. The experiment had two main treatments: no seed treatment (nil), and an experimental seed treatment applied at 80 mL/100 kg seed. Three concentrations of F. avenaceum pathogen were applied as colonised millet grain inoculum, alongside a control treatment (sterile millet – no inoculum) (Table 1). The seed treatment used in this experiment is not registered for the control of fusarium root rot in lentil and was used for experimental purposes only.

Table 1. Treatment combinations used in the 2024 pot experiment at SARDI Waite Research Institute to assess the effects of an experimental seed treatment on fusarium root rot in lentils. The concentration rates of the pathogen are in relation to the total soil weight (% w/w).

Seed Treatment	Pathogen
Nil	Sterile millet (nil)
Seed treatment	Sterile millet (nil)
Nil	0.25% w/w *F. avenaceum*
Seed treatment	0.25% w/w *F. avenaceum*
Nil	0.5% w/w *F. avenaceum*
Seed treatment	0.5% w/w *F. avenaceum*

Methods and assessment

The pot experiment was established on August 21, 2024, using a fine sand and peat (UC) potting mix blend. Prior to sowing, the potting mix was autoclaved, a process involving steam treatment to remove bacteria and other organisms which may impact experiment results.

The pathogen inoculum, applied at seeding, was produced by adding 7-day old cultures of *F. avenaceum* growing on a petri dish made from Potato Dextrose Agar (PDA) to a sterile plastic bag containing 1.5 kg of sterile millet grain. The bags were gently mixed every two days to encourage full colonisation on millet grain. This pathogen inoculum was left to develop until all grains were colonised, before being dried at 40°C for seven days, and then passed through a 2 mm sieve to produce a homogeneous, flowable inoculum. To get two rates of the fusarium pathogen (0.25% and 0.5%), two separate bags of sterile millet were coated with each fusarium pathogen rate. The millet was left for the *Fusarium avenaceum* to adequately grow.

Colonised millet grain was added to soil at a rate of either 0.25% w/w (weight to weight ratio) or 0.5% w/w of UC soil mix. The inoculum was thoroughly mixed through the soil before being added to pots. Control treatments (nil inoculum) were prepared using non-colonised sterile millet grain applied at 0.5% w/w UC soil mix.

Lentil pots that received the seed treatment were coated on the day of sowing. Lentils in treatment pots which did not contain a seed treatment (nil) were not coated but all other methods remained the same. Following application, all seeds including nil treatments were sown dry at a rate of five seeds per pot.

Pots were placed in a glasshouse and maintained at a constant temperature of 20°C. The moisture level in each pot was maintained at 80% of field capacity. Field capacity was calculated by preparing a pot with soil for sowing as above (with no seeds) and watering the pot until the water drained heavily through the bottom of the pot. After leaving the pot to drain upright on a wire rack for 24-hours, it was watered to saturation using the same method. The soil, now at maximum saturation, and the pot the soil is contained in was weighed, and that weight was recorded. Next, the soil only was transferred into a silver aluminium foil tray, which was placed in a specialised drying oven at 100°C for twenty-four hours. After drying, the soil was weighed again, and 80% of field capacity was calculated. From the calculation results, 80% field capacity was achieved by watering every pot up to a weight of 448 g every two days.

To promote normal nodulation, rhizobia was added to every pot after seedling emergence as 1 mL of liquid rhizobia suspension containing 10 ^9 cfu/mL per seedling (cfu = colony-forming unit). The suspension was pipetted directly onto the seedling base.

Measurements conducted during this experiment included plant establishment as the number of germinated plants and number of surviving seedlings three weeks later, shoot weight (g), root weight (g) and root health scores (scale 0–10, where 0 = no disease and 10 = total root infection and lesioning).

Plant establishment counts were first conducted on September 2, and again three weeks later on September 19, with the aim to determine how the presence or absence of the seed treatment and varying pathogen rates (nil 0%, 0.25% and 0.5%) impacted seedling survival. On September 19, plants were removed from pots to conduct lentil shoot and root measurements. Using scissors, the root and shoot system were separated and placed into a drying oven at 60^{o}C for 48 hours. Once removed from the oven, root and shoot weights were recorded. Root weight and root health data could not be analysed due to unforeseen contamination factors negatively influencing results.

A second experiment was established on September 20 at SARDI, Waite Research Institute, to test the effect of experimental seed treatment on rhizobia growth. This was conducted on a petri dish made from Potato Dextrose Agar (PDA) under controlled temperature conditions to investigate impacts of rhizobia growth resulting from the presence of the seed treatment.

Distances were measured from the centre of the rhizobia growth to the edge of the colony, and from the centre of the rhizobia growth to the centre of the cardboard disk onto which the seed treatment was pipetted.

Results and discussion

Plant establishment

Treatments with the fusarium pathogen present at both concentrations of 0.25% and 0.5% w/w, without a seed treatment, showed reduced plant numbers with only 33% survival rate (0–2 plants per plot surviving out of 5), compared to 87%, with the inclusion of the experimental seed treatment (Figure 1). Similar results were observed between treatments with no pathogen (nil treatment) and those where seed treatment + pathogen was present. This result shows the inclusion of the experimental seed treatment provided effective control of Fusarium root rot for seedling survival.

Shoot weight

Significant differences were observed for shoot weight, with the lowest weights recorded in treatments where *Fusarium avenaceum* was applied at 0.25 and 0.5% with no applied experimental seed treatment.

Reduced shoot weight was observed for seed treatment + 0.5% *Fusarium avenaceum* when compared to nil treatments (no pathogen as sterile millet +/- seed treatment). The findings indicate that although seed treatment had a positive influence on plant survival rate, a reduction in individual plant biomass was observed where higher levels of fusarium were present (Figure 2).

When compared to various treatments, the absence of the pathogen allows for optimal growth, indicating that the presence of fusarium root rot is a limiting factor to plant performance and seed treatment alone may not completely reduce the pathogen's effects (Figure 1).

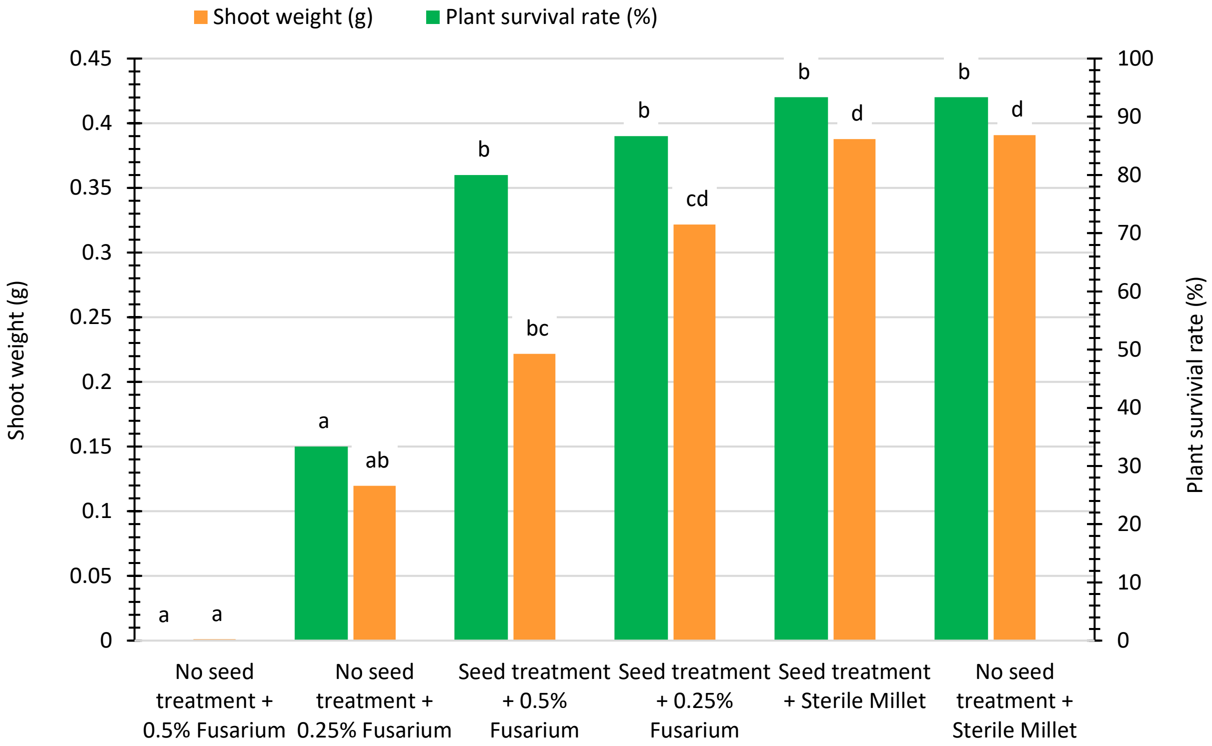

Figure 1. Comparison of the effect of a seed treatment and Fusarium avenaceum concentrations on plant counts and shoot weight in lentils. Bars for each measurement with the same letters are not significantly different.

Figure 2. Visual comparison of treatments in replication 1 of the pot trial, showing biomass differences across pathogen concentration +/- seed treatment. Top (L-R): No seed treatment + no fusarium, no seed treatment + 0.25% fusarium, no seed treatment + 0.5% fusarium. Bottom (L-R): Seed treatment + no fusarium, seed treatment + 0.25% fusarium, seed treatment + 0.5% fusarium.

Potato Dextrose Agar (PDA) results

Results from the Potato Dextrose Agar (PDA*)* plate experiment showed that the presence of experimental seed treatment did not affect rhizobia growth (Figure 3). Rhizobia was spread across the agar plate and small carboard disks containing seed treatment concentrations of 0%, 0.3%, 1% and 3% were delicately placed on top. The result, as shown in Figure 3, demonstrates that in a controlled environment, the rhizobia growth is not affected by the presence of the experimental seed treatment. Results suggest that the addition of this seed treatment is beneficial, and rhizobia growth is not affected. Further research across various environmental conditions and soil types should be considered to validate 2024 results.

Figure 3. Rhizobia and seed treatment interaction on agar plates. Photos show replication 1-3 (L-R).

Summary

This report investigates novel management strategies for controlling fusarium root rot in lentils, focusing on an experimental seed treatment not registered for use on lentils. While lentils have been part of the Australian agricultural industry since the early 1990s, their role has evolved from a break crop to a significant export product. Soilborne diseases, particularly fusarium root rot, pose challenges for lentil growers, with no sufficient fungicide treatments available.

Results suggest that the experimental seed treatment used in this study, particularly where lower concentrations of fusarium root rot were present, show good control. Results from the Potato Dextrose Agar (PDA) plate experiments show no negative effects on rhizobia growth from the experimental seed treatment. Future research opportunities would be beneficial to explore the interactions between this seed treatment and rhizobia, as well as the control of fusarium root rot in additional field studies.

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Evaluating impacts of applied nitrogen on grain yield and quality in wheat and barley

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Key findings

- Seasonal conditions at Hart in 2024 were dry, reducing water availability and nitrogen (N) uptake of crops.
- There is a strong correlation showing that increased biomass contributed to reduced grain yield (t/ha) for Compass barley (up to 61%). This result indicates a haying-off effect in dry seasonal conditions for this variety. No yield penalty was observed for Maximus CL, although biomass increased with application of N.
- Maximus CL had a slight reduction in retention when N was applied, however rates from 30-180 kg N/ha still exceeded minimum receival standards (70%). Screenings slightly increased as nitrogen rates increased, however differences were small, and all treatments achieved <7% screenings.
- No differences were observed for screenings and retention across N rate for Compass barley.
- There was no yield differences observed for any wheat variety or nitrogen rate.
- A minimum application of 30 kg N/ha was required for wheat varieties to meet a minimum protein threshold of 13%. All wheat varieties and N rates met minimum receival standards for H1 (76 kg/hL), however higher N did contribute to lower test weights. No differences were observed for wheat screenings.

Introduction

Nitrogen (N) is an essential nutrient required in broadacre cropping systems and is a primary contributor to match crop demands for grain yield (Baldock et.al, 2018). Systems without an adequate nitrogen balance will not match water-limited yield in most years, leading to reduced productivity and profitability on-farm, in addition to declining soil organic N balances (Baldock et.al, 2018).

Matching crop N demand to seasonal forecasts is challenging and over-application of N has been shown to cause negative crop effects including haying off in dry conditions, as well as lodging in favourable seasons. Haying off causes the grain filling process to end too early in the season after utilising water and nutrient resources for crop biomass production. As the season progresses and grain filling begins, the plant does not have access to required soil moisture due to this premature uptake (Herwaarden et al., 1998).

There is a consensus that the concentration of grain yield and grain protein is negatively correlated. As grain yield increases, protein concentration can decrease. This relationship suggests that higher yields may incur lower protein levels in the grain (Bogard et al., 2010). The range of the negative correlation is under researched and not well understood.

A trial established in the Mid North at Kybunga, SA in 2022 has shown negative haying-off effects resulting from high nitrogen application in barley (2023 Kybunga results). This trial is a series of long-term experiments across the Southern region, aiming to evaluate the productivity (yield and protein), profitability (gross margin) and sustainability (soil organic matter, carbon and N losses) of long-term N management systems. This is done by matching nitrogen rates to seasonal yield potential, targeting nitrogen rates to maintain baseline fertility (nitrogen banking), and comparing both to the national average of 45 kg N/ha.

To better understand relationships between grain yield, grain quality and nitrogen, a field trial was established at Hart, SA in 2024 to investigate wheat and barley variety response to increasing rates of nitrogen.

Methodology

Trial design and treatments

Two adjacent wheat and barley trials were established at the Hart field site in 2024 to investigate the effect of increasing rates of nitrogen on lodging and haying off (Table 1). Each trial had two varieties of wheat (Scepter and Calibre) or barley (Compass and Maximus CL) (Table 2). Both trials were designed in Genstat 24th Edition, as a two-way factorial with two varieties, seven nitrogen rates and three replicates.

Compass barley and Scepter wheat were selected as current benchmark varieties for the Mid North region. Compass (erect plant type) was selected due to observations of a higher lodging frequency and was compared to Maximus CL. Maximus CL was selected as it is well-suited to the environment at Hart and surrounding regions. It was assumed that Maximus CL would behave differently to Compass as it's not as free tillering and has a reduced plant height, providing a good comparison. Scepter wheat was selected as it's both widely grown and has been observed to stand upright well. Comparison variety Calibre, may lean with high yields but is not commonly seen to lodge. Both varieties have similar maturities.

Table 1. Trial details for 2024 wheat and barley nitrogen trials located at Hart, SA.

Harvested plot size	0.92 m x 10 m	**Starting soil N**	36.4 kg N/ha (0-70 cm)
Seeding date	May 14, 2024	**Fertiliser**	Seeding: MAP at 100 kg/ha July 19: Nitrogen treatments applied
Location	Hart, SA		
Harvest date	Barley: October 30, 2024 Wheat: November 14, 2024		
Previous crop	Kingbale oaten hay		
Growing season rainfall	Decile 2 (176 mm)		

Seven rates of nitrogen were applied on July 19 to both trials. Rates applied were 30, 60, 90, 120, 180 and 240 kg N/ha, including a nil treatment (0 kg N/ha). Low N rates were applied to intentionally limit N availability to crops and exaggerate the effects of nitrogen deficiency. In contrast, high rates of N were applied to demonstrate the effect of haying off in dry conditions or lodging in wet conditions. Nitrogen treatments were applied as granular urea at tillering. Nitrogen was spread uniformly across each plot and was absorbed into the soil, following 9.2 mm rainfall shortly after application, with another 8.0 mm received four-days later.

Table 2. Crop type, variety and sowing rates for 2024 nitrogen trials at Hart, SA.

Trial	Varieties	Sowing rate
Wheat	Calibre Scepter	180 plants/m^2
Barley	Maximus CL Compass	150 plants/m^2

Site selection and rainfall

Soil mineral N levels were low in 2024, following the previous year's oaten hay crop with a total of 36.4 kg N/ha (0-70 cm). To measure baseline soil N, twelve soil cores were taken on April 9 across each trial prior to seeding. Cores were sampled to a depth of 70 cm and sectioned by depths of 0-10 cm, 10-40 cm and 40-70 cm for analysis.

The Hart field site received below average annual rainfall of 240.2 mm in 2024, compared to the long-term average of 400 mm. Growing season rainfall received was also low with 176 mm of April to October rain (average of 300 mm) (Figure 1). This contributed to poor nitrogen availability and uptake by plants.

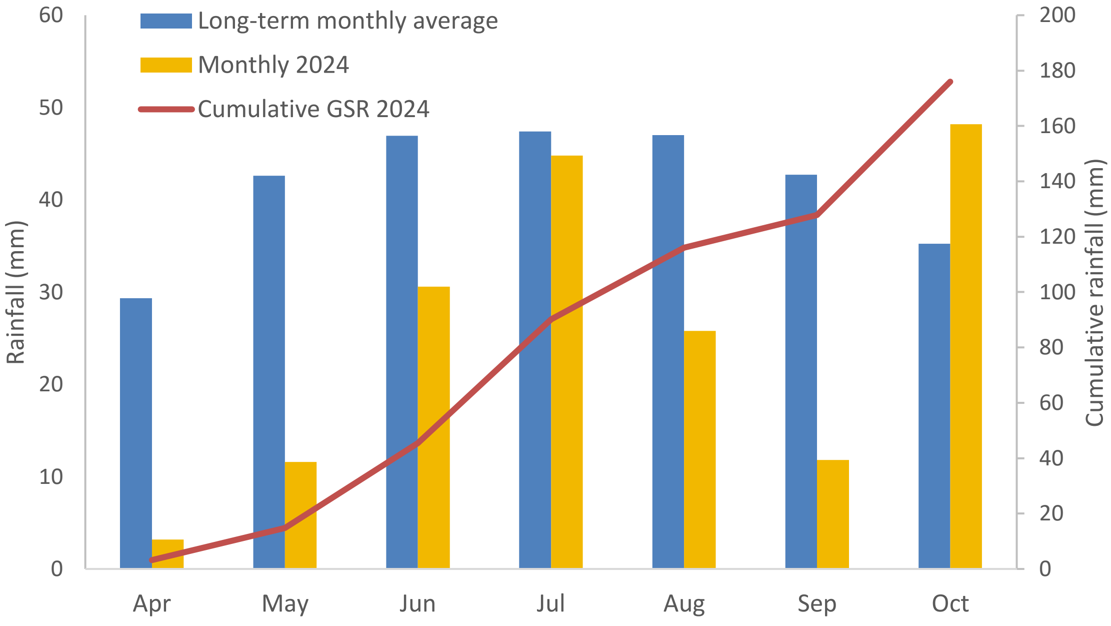

Figure 1. Growing season rainfall at Hart, SA in 2024.

Measurements

In addition to starting soil N, trial measurements conducted include Normalised Difference Vegetation Index (NDVI), grain yield (t/ha), protein (%), screenings (%), test weight (kg/hL), retention (%) (barley only), 1000 grain weight (g) and post-harvest soil N. Severe water stress in 2024 resulted in a strong edge row effect. Edge rows were therefore removed prior to harvest, to accurately determine grain yield results from the middle four crop rows (0.92 m x 10 m).

Normalised difference vegetation index (NDVI) data was collected as a measure of plant growth (higher NDVI values indicate less exposed soil and greener vegetation). Three NDVI measurements were conducted in each plot on July 19 at early-tiller (prior to N application), August 20 (first node) and September 11 (50% flower). This data was recorded using a handheld Green seeker, measured at a constant height. All assessment data was analysed as a REML spatial model (Regular Grid) with Bonferroni test and post-harvest soil N was analysed using a REML spatial model (Irregular Grid) with Bonferroni test using Genstat 24th Edition.

Results and discussion

Crop biomass (NDVI)

Throughout the growing season, Compass barley showed greater vigour, indicated by higher NDVI values compared to Maximus CL (Table 3). There is a strong correlation showing that this increased biomass contributed to reduced grain yield (Figure 2), as biomass production contributed to reduced availability of resources during grain fill. The higher NDVI values observed for Compass are supported by varietal traits which are characterised by rapid and vigorous early growth (Matthews et al., 2023). While biomass for Maximus CL slightly increased as nitrogen increased (NDVI 1 & 2 in Table 3), a yield penalty was not observed.

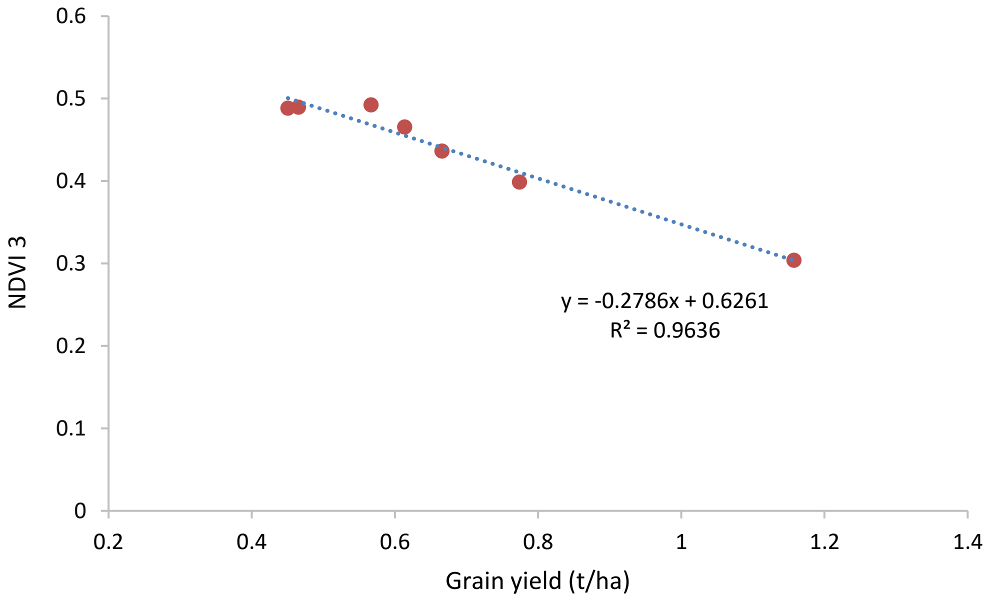

Figure 2. Correlation between Compass grain yield (t/ha) and biomass at Hart in 2024.

Table 3. NDVI values for barley and wheat from 2024 nitrogen trials at Hart, SA. Shaded values in each column indicate higher biomass.

Variety	N rate kg N/ha	NDVI 1	NDVI 2	NDVI 3	Variety	N rate kg N/ha	NDVI 1	NDVI 2	NDVI 3
Compass	240	0.28^{d}	0.61^{d}	0.49^{f}	Scepter	240	0.24^{b}	0.37^{a}	0.29^{a}
	180	0.28^{d}	0.62^{d}	0.49^{f}		180	0.23^{ab}	0.33^{a}	0.29^{a}
	120	0.28^{cd}	0.61^{d}	0.49^{f}		120	0.23^{ab}	0.39^{a}	0.32^{a}
	90	0.27^{d}	0.59^{d}	0.47^{ef}		90	0.22^{ab}	0.36^{a}	0.30^{a}
	60	0.26^{bcd}	0.57^{d}	0.44^{def}		60	0.22^{ab}	0.38^{a}	0.29^{a}
	30	0.28^{d}	0.54^{cd}	0.40^{cde}		30	0.23^{ab}	0.34^{a}	0.28^{a}
	0	0.29^{d}	0.47^{bc}	0.30^{ab}		0	0.22^{ab}	0.31^{a}	0.25^{a}
Maximus CL	240	0.21^{ab}	0.46^{bc}	0.37^{bcd}	Calibre	240	0.19^{a}	0.40^{a}	0.33^{a}
	180	0.21^{ab}	0.49^{bc}	0.37^{bcd}		180	0.21^{ab}	0.41^{a}	0.30^{a}
	120	0.19^{a}	0.45^{b}	0.34^{abc}		120	0.22^{ab}	0.40^{a}	0.34^{a}
	90	0.21^{ab}	0.44^{b}	0.36^{bc}		90	0.21^{ab}	0.38^{a}	0.33^{a}
	60	0.20^{ab}	0.43^{ab}	0.33^{abc}		60	0.22^{ab}	0.38^{a}	0.27^{a}
	30	0.21^{abc}	0.41^{ab}	0.27^{a}		30	0.24^{ab}	0.39^{a}	0.30^{a}
	0	0.20^{ab}	0.35^{a}	0.26^{a}		0	0.20^{ab}	0.33^{a}	0.26^{a}
P Value (≤0.05)		**<0.001**	**<0.001**	**<0.001**	**P Value (≤0.05)**		**0.01**	**0.005**	**0.025**

Grain yield (t/ha)

Compass barley resulted in a significant yield penalty with in-season applications of nitrogen from 30-240 kg N/ha, reducing grain yield by up to 0.71 t/ha (61%) (Table 4). These results indicate a haying-off effect in dry seasonal conditions, associated with increased biomass production as shown above (Figure 2). No yield penalty was observed for Maximus CL, despite biomass increasing with high applications of N. There was no difference observed for any wheat variety and nitrogen rate.

Grain quality

Irrespective of barley variety, protein (%) increased as nitrogen rate increased (Table 4). Due to dry conditions, even treatments with no in-crop N applied (starting soil N 36.4 kg/ha) exceeded the maximum threshold of 12% protein for Malt 1 receival standards due to low crop yields.

For Maximus CL there was a slight reduction in retention when nitrogen was applied, however rates from 30-180 kg N/ha still exceeded minimum receival standards (70%). Screenings also slightly increased as nitrogen rates increased, however differences were small, and all treatments achieved <7% screenings. No differences were observed for screenings and retention across N rate for Compass barley. This contrasts with results from a nitrogen banking trial conducted in 2023 at Kybunga, SA, (Compass barley phase), showing that the highest nitrogen rate applied (144 kg N/ha) led to the highest screenings (22.6%) (Allen et.al 2024). Similarly to the 2024 trial at Hart, the highest nitrogen rate did not result in the highest yield (on 275 mm GSR), supporting the concept of haying off in this variety.

Test weight was high for all treatments (>65 kg/hL) and was not influenced by increasing N rate.

A minimum application of 30 kg N/ha was required for wheat varieties to meet a minimum protein threshold of 13% for H1 receival standards. Similar trends to barley were observed for test weight of wheat, with all varieties and N rates meeting minimum receival standard for H1 (76 kg/hL), however higher N did contribute to lower test weights. No differences were observed for wheat screenings.

Similar wheat and barley trials were conducted at Hart over three years, from 2017 to 2019. The growing season rainfall for these years was comparable to 2024 (176 mm), with recorded GSR of 191, 160 and 162 mm, respectively. The three-year trial tested Spartacus CL and La Trobe barley and Scepter and Mace wheat. While the three-year trial had similar growing season rainfall each year, grain yield in 2017 (Spartacus CL) and 2018 (La Trobe) increased, but plateaued with applications of 40 kg N/ha applied, when compared to the nil treatment (Rose and Noack, 2019). This is in contrast to the 2024 barley trial where any application of nitrogen at 30 kg N/ha or above saw either a decline (Compass), or no response (Maximus CL) in grain yield (t/ha) (Table 4). Only slight decreases in screenings were observed in high N treatments, however these were negligible. Differences in results may be attributed to environmental conditions and timing of rainfall experienced across seasons.

In 2018 and 2019, where Scepter was trialed, trends showed that grain yield increased with increased rates of N. No response was observed in 2024 due to dry winter conditions. Further investigation into timing of N and rainfall would need to be considered to make further comparisons between trials.

Table 4. Barley grain yield and quality results from Hart in 2024.

Variety	**Nitrogen rate kg N/ha**	**Grain yield t/ha**	**Protein %**	**Test weight kg/hL**	**Screenings %**	**Retention %**
Compass	240	0.45^{a}	19.4^{def}	73.7^{abcd}	3.0^{abc}	85.9^{bc}
	180	0.47^{ab}	20.6^{f}	73.7^{ab}	3.1^{abc}	85.6^{bc}
	120	0.57^{abc}	19.6^{ef}	74.3^{a-i}	2.9^{abc}	85.9^{bc}
	90	0.61^{abc}	18.3^{cde}	74.0^{a-i}	2.8^{abc}	87.6^{bc}
	60	0.67^{a-d}	18.3^{cde}	74.9^{bgi}	2.4^{abc}	89.0^{bc}
	30	0.77^{a-d}	16.7^{bc}	74.9^{b-i}	1.9^{abc}	89.9^{bc}
	0	1.16^{f}	12.8^{a}	74.8^{b-i}	1.2^{a}	93.5^{c}
Maximus CL	240	0.82^{b-f}	18.4^{cde}	73.6^{a}	4.1^{c}	68.0^{a}
	180	0.79^{a-e}	18.1^{cde}	73.9^{a-h}	3.5^{bc}	73.2^{a}
	120	0.89^{c-f}	17.9^{cde}	73.8^{a-f}	4.0^{bc}	71.3^{a}
	90	0.85^{c-f}	17.6^{bcd}	73.7^{abc}	3.7^{bc}	73.2^{a}
	60	0.92^{c-f}	17.1^{bc}	73.7^{abc}	3.4^{bc}	75.1^{a}
	30	1.01^{def}	15.8^{b}	73.8^{a-e}	3.3^{abc}	74.0^{a}
	0	1.11^{ef}	12.9^{a}	73.9^{a-g}	1.8^{ab}	83.8^{b}
Malt 1 Receival standards			9-2%	>65	<7.0	>70
P Value (≤0.05)		**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**

Table 5. Wheat grain yield and quality results from Hart in 2024.

Variety	Nitrogen rate kg N/ha	Grain yield t/ha	Protein %	Test weight kg/hL	Screenings %
Scepter	240	0.67	15.1^{cde}	81.4^{de}	2.9^{ab}
	180	0.66	15.1^{de}	81.5^{cde}	2.7^{ab}
	120	0.67	15.0^{b-e}	81.4^{cde}	2.1^{ab}
	90	0.63	14.8^{b-e}	81.5^{cde}	2.2^{ab}
	60	0.69	14.2^{bcd}	81.9^{e}	2.4^{ab}
	30	0.68	13.3^{b}	82.3^{ef}	2.0^{a}
	0	0.67	11.1^{a}	83.4^{f}	2.6^{ab}
Calibre	240	0.64	15.9^{e}	78.6^{a}	3.9^{b}
	180	0.69	15.6^{de}	79.4^{ab}	3.2^{ab}
	120	0.68	15.4^{de}	79.4^{ab}	3.1^{ab}
	90	0.68	15.1^{de}	79.6^{ab}	2.6^{ab}
	60	0.70	14.7^{b-e}	80.0^{abc}	2.3^{ab}
	30	0.69	13.6^{bc}	80.2^{bcd}	2.5^{ab}
	0	0.62	11.5^{a}	81.1^{cde}	3.1^{ab}
H1 receival standards			>13	>76	<5
P Value (≤0.05)		**NS (0.135)**	**<0.001**	**<0.001**	**<0.001**

Post-harvest N

Post-harvest soil samples were conducted on December 4 to measure carry-over nitrogen from various treatments. Samples were taken from one variety of each crop type at three rates: 0 (nil), 90 and 240 kg of applied N/ha. Available nitrogen measured post-harvest was greater than initial soil N of 36.4 kg N/ha due to dry conditions experienced at Hart in 2024. Available nitrogen increased by 14.2 (N rate 0)–138.7 (N rate 240) kg N/ha in wheat and 4.2 (N rate 0) –151.8 (N rate 240) kg N/ha in barley.

Table 6. Soil nitrogen available post-harvest. Samples were conducted on December 4 at 0-0 cm, 10-40 cm and 40-70 cm.

Calibre		Maximus CL	
N rate	**Post-harvest N (kg/ha)**	**N rate**	**Post-harvest N (kg/ha)**
0 (nil)	50.6^{a}	0 (nil)	40.6^{a}
90	110.1^{ab}	90	114.1^{ab}
240	175.1^{b}	240	188.2^{b}
P Value (≤0.05)	**0.042**	**P Value (≤0.05)**	**0.033**

Summary

In 2024, the Hart site experienced below average annual rainfall with 240.2 mm, almost half of the long-term average (400 mm). Only 176 mm was received during the growing season (April-October), contributing to poor water availability and uptake of nitrogen by crops. In very dry conditions, the application of nitrogen, especially at higher rates, may cause haying-off effects leading to a reduction in grain yield and quality, particularly in barley as observed in 2024. Increasing nitrogen rates in dry conditions is likely to also increase the concentration of protein. These trials will be continued at Hart across several seasons, to develop a better understanding of the grain yield and quality response associated with applied N in field conditions. This will provide further information to support nitrogen decisions.

Acknowledgements

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Integrating spatial data and long-term strategies for improved phosphorus fertiliser management

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Key findings

- A methodology called the phosphorus (P) sufficiency index (pHnNDVI) has been developed for combining soil pH and NDVI data layers and generating P fertiliser prescription maps for use in variable rate seeders and spreaders.
- Across 57 P fertiliser response trials conducted from 2019-2024 the optimal P rate to maximise partial gross margin ranged from 0 up to 50 kg P/ha.
- Among different long-term P management strategies trialed, increases in DGT-P levels pre-seeding in 2024 generally only occurred where high rates of P fertiliser (50 or 90 kg P/ha) had been applied repeatedly or the year prior to soil sampling.
- Residual P available in the year following fertiliser application continued to increase grain yields in four out of six trial years, however generally only at rates greater than 50 kg P/ha. This is highlighted in highly P responsive soils, where current district practice application rates of 10-20 kg P/ha are unlikely to provide any useful residual P from the season prior.

Background

Fertiliser inputs are the single largest variable cost for grain growers producing a crop. The variability in rainfall experienced by growers coupled with high fertiliser prices has resulted in conservative fertiliser management. As a consequence, phosphorus (P) deficiency still causes yield losses in many environments and soil types across SA. In contrast there are many areas where P response is minimal and optimum gross margin can be achieved with little or no application of P fertiliser.

The use of pH mapping has become common practice to identify areas within a paddock of low pH to improve lime application efficiency. While generating pH maps and comparing them with satellite NDVI imagery, it has been observed that high pH areas on the map correlate with low crop vigour and P deficiency in many instances (Trengove et al. 2019; Mason et al. 2022) (Figure 1). This finding resulted in the development of the P sufficiency index.

The P sufficiency index has been given the acronym pHnNDVI as it is the soil pH value divided by NDVI normalised to the paddock average using the formula below.

pHnNDVI = soil pH / (NDVI/paddock NDVI average).

Areas of a paddock with high soil pH (>7.5) and low relative normalised NDVI (<0.9) result in a high pHnNDVI value and are likely to be highly responsive to applied P (for example, site 23 and 25 in Figure 1). Areas with lower pH (<6.5) and high relative NDVI (>1.1) result in a low pHnNDVI value and are likely to be unresponsive to applied P (for example site 22 in Figure 1). This data layer can then be used to generate P application maps for variable rate seeding operations.

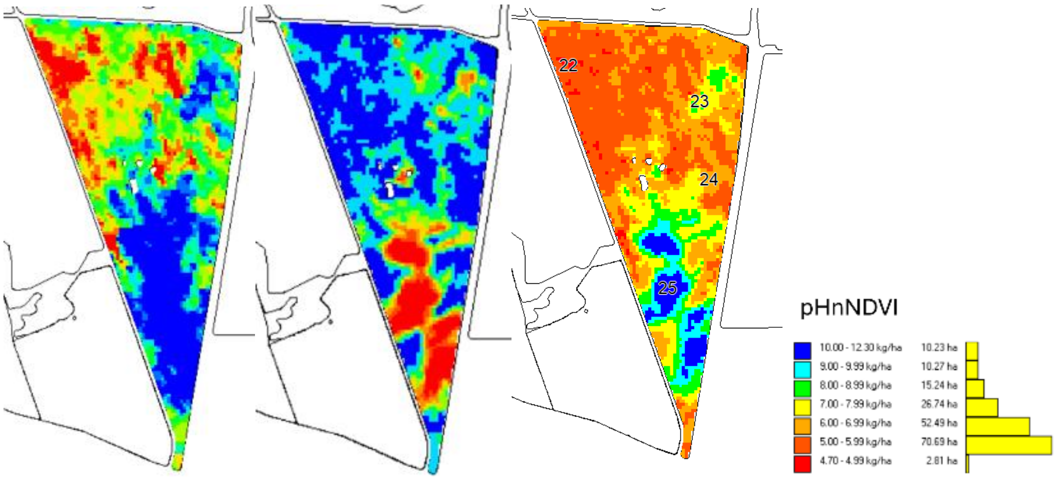

Figure 1. Soil pH (left), satellite NDVI (middle) and pHnNDVI (right) for a paddock at Crystal Brook

Methodology

From 2019 to 2024, 57 P fertiliser rate response trials have been established across 14 paddocks in the Mid North, Yorke Peninsula, Eyre Peninsula and Mallee. Within each paddock the pHnNDVI maps were used to locate four small plot trials with seven P rates ranging from 0-90 kg P/ha. The P fertiliser was applied as MAP and urea was used to match the nitrogen to the highest P rate at each trial. All fertiliser was applied below the seed using a knife point and press wheel system. The plots were monitored for Normalised Difference Vegetation Index (NDVI), leaf tissue P concentration, grain yield and quality. NDVI and grain yield will be discussed in this paper.

Three of the 57 trial sites (Hart, Spalding and Crystal Brook) had long-term trial sites established in 2021 where the range of P rates were applied. The P fertiliser management strategies evaluated single applications of high P rates (0-90 kg P/ha) followed by 15 kg P/ha in subsequent seasons or repeated applications of 0-90 kg P/ha applied each season. Alternative P management strategies were also included such as broadcasting MAP prior to seeding and the use of chicken litter. Full trial details and soil characterisations can be found in previous reports (Trengove et al. 2023). Soil samples were collected from these plots prior to sowing in the fourth season (2024) to assess changes in soil P levels, Colwell P, and DGT-P.

Results and discussion

Field evaluation of the P sufficiency index

In paddocks with significant spatial variation the P sufficiency index has shown it can accurately predict areas of low, medium and high P response in the Mid North and Yorke Peninsula. More recently, this method has also been tested in areas of the Mallee and the Eyre Peninsula. This trial series has provided a robust database to assess the capabilities of the pHnNDVI methodology (Figure 2).

Across six years of investigation there was a strong in-season biomass response (measured by Greenseeker NDVI) to higher rates of P with increasing pHnNDVI (Figure 2). This strong relationship for crop biomass can be used by growers for hay crops and biomass production for grazing.

The P rate to achieve maximum biomass and pHnNDVI relationships have been stronger than the yield response. This can be attributed to the fact that biomass (NDVI) is assessed earlier in the season and is less likely to be influenced by as many factors as grain yield such as seasonal conditions, crop disease, herbicide residues, frost and weed competition.

For paddocks that contain soil types such as calcarosols, dermosols, chromosols and sodosols the model has been most accurate. For paddocks that contain vertosols (deep black cracking clays) the model has been less accurate. It is unclear why the vertosols do not produce similar grain yield responses when predicted to be highly P responsive. Both soil test values (DGT-P range 14-97 µg/L) and the pHnNDVI suggest they should be P responsive, and while they produce a biomass response this has not translated into grain yield. This lack of grain yield response on vertosols has been observed in other trials in the Southern region. For this reason, the vertosol sites have been removed from the dataset presented here (Figure 2).

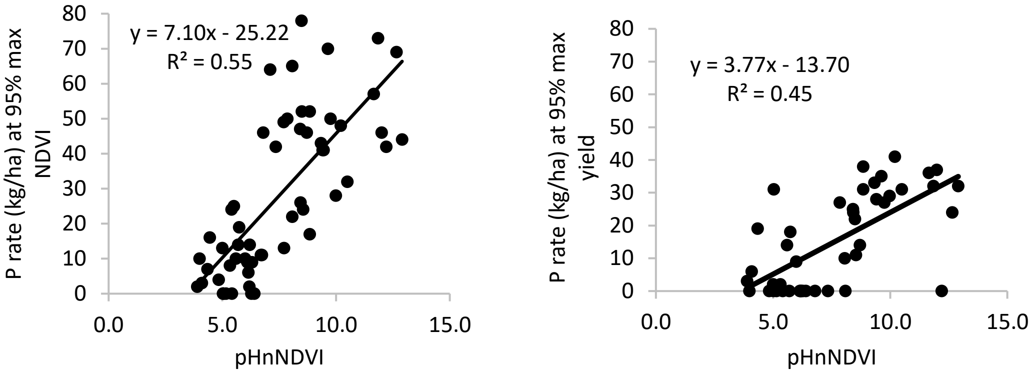

Figure 2. Relationship between pHnNDVI and P fertiliser rate (kg/ha) at 95% maximum NDVI for 57 sites (left) and 95% maximum grain yield for 45 sites across the Mid North, Yorke Peninsula and Eyre Peninsula (right).

The pHnNDVI has been able to predict where there will be a low P requirement to maximise partial gross margin (PGM), however, there has been some variability around the higher end of the pHnNDVI scale. Where grain yields were low, the grain yield response to P has been reduced, resulting in a lower P rate to maximise PGM than predicted by pHnNDVI alone. Where a grain yield potential (maximum yield) for the site is included in the prediction model, the accuracy is improved (Table 1).

The information presented in Table 1 can be used by growers and advisers to determine the optimum P rate for given paddock zones. The response modelling shows at low pHnNDVI (<5) there is a low predicted P rate requirement (0-5 kg P/ha). As pHnNDVI increases the P fertiliser rate required to maximise PGM also increases and it increases at a faster rate at higher yields. For example, at pHnNDVI 11 a crop with 3.0 t/ha yield potential is predicted to require 18 kg P/ha. However, as the yield potential for the same pHnNDVI increases to 6.0 t/ha, the P fertiliser required is now 40 kg P/ha.

Grain yield data from a reliable historical yield map could be included in the model with pHnNDVI to produce a P rate prescription, or a yield target could be chosen for a given paddock to calculate the optimum P rate to produce the prescription.

Table 1. Predicted P rate (kg P/ha) at maximum partial gross margin for pHnNDVI and site max yield.
*P rate at max PGM = -4.72-3.66*site max yield + 1.01*(site max yield * pHnNDVI), R2 = 0.56*
Assumptions for gross margins – MAP = $1100/t, lentil = $800/t, wheat = $330/t, barley = $275/t.

Site max yield	1	2	3	4	5	6	7
pHnNDVI	Predicted P rate at Max PGM						
4	0	0	0	0	0	0	0
5	0	0	0	1	2	4	5
6	0	0	2	5	7	10	12
7	0	2	5	9	12	16	19
8	0	4	8	13	17	22	26
9	1	6	12	17	22	28	33
10	2	8	15	21	27	34	40
11	3	10	18	25	32	40	47
12	4	12	21	29	37	46	54
13	5	14	24	33	43	52	61

Long-term P management trials

Residual soil available P from repeated and once off applications of P fertiliser rates

The P use efficiency (PUE) of fertilisers is generally low in the year of application, ranging from 2-26% in this trial series, however, it continues to provide P to crops for several years. Pre-seeding 2024, the three long-term trials were soil sampled (following three trial seasons) to understand if the various P management strategies have built up or mined soil available P compared to year one.

At Hart all DGT-P values remained below the critical limit (60 µg/L). There was a greater range and higher number of treatments above the critical DGT-P at both Crystal Brook and Spalding (Figures 3 and 4). Among the three trial sites, Hart has the highest PBI (111) compared to Spalding (77) and Crystal Brook (88) which indicates a stronger ability to bind added fertiliser P. This has likely contributed to the lower P availability and lower variation in DGT-P values at this site.

Among all the strategies trialed, the only P rates to have an impact on starting DGT-P were generally where high rates of P fertiliser had been applied repeatedly each year (Figure 3) or in year three only, prior to testing in year 4 (Figure 4). This shows a portion of the fertiliser P applied in these high rates last season or cumulatively has carried over in the plant available form and will be available to the subsequent crop. However, it also highlights P fertiliser rates of <50 kg P/ha applied repeatedly or in a single season, are not sufficient to increase DGT-P to an impactful level the following season on P fixing soils.

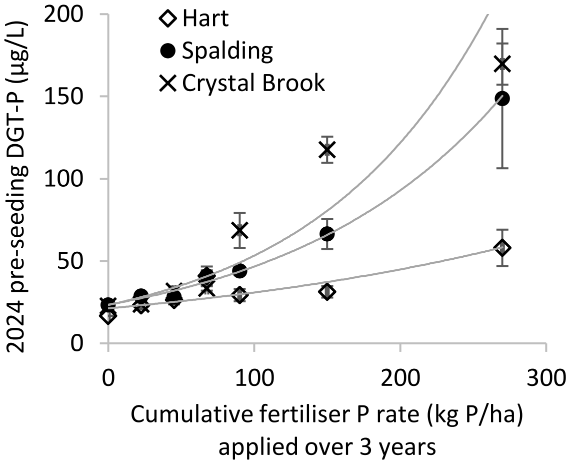

Figure 3. Pre-seeding 2024 DGT-P following three seasons (2021-2023) of repeated applications of P fertiliser rates ranging from 0-90 kg P/ha for Hart (R2 = 0.79), Spalding (R2 = 0.997) and Crystal Brook (R2 = 0.87).

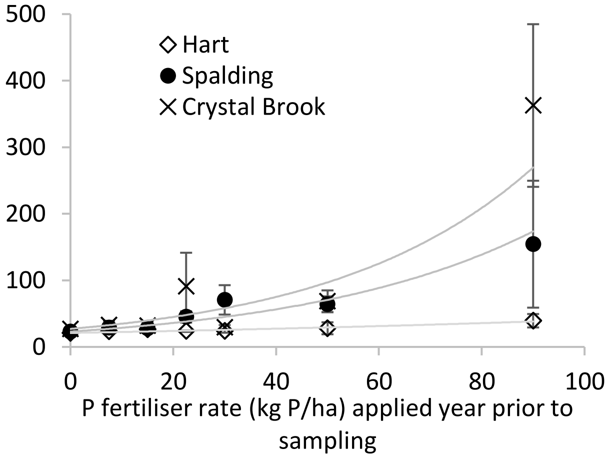

Figure 4. Pre-seeding DGT-P following once off applications of P fertiliser rates ranging from 0-90 kg P/ha the year prior (2023) to sampling at Hart (R2 = 0.92), Spalding (R2 = 0.94) and Crystal Brook (R2 = 0.94).

In addition to soil testing, yield responses assessing the value of residual P were also measured (Figure 5). In general, yield responses were measured in year 2 in response to P application the year prior in four out of six site years, as demonstrated at Hart (Figure 5). Responses were also observed in year 3 in two out of three site years, though the level of response declines from year 2 to 3 (Figure 5). However, while there are meaningful responses to residual applied P, the Hart results also demonstrate that higher yields are attainable in subsequent years, by repeatedly applying higher rates, rather than relying on the residual benefit of the year prior.

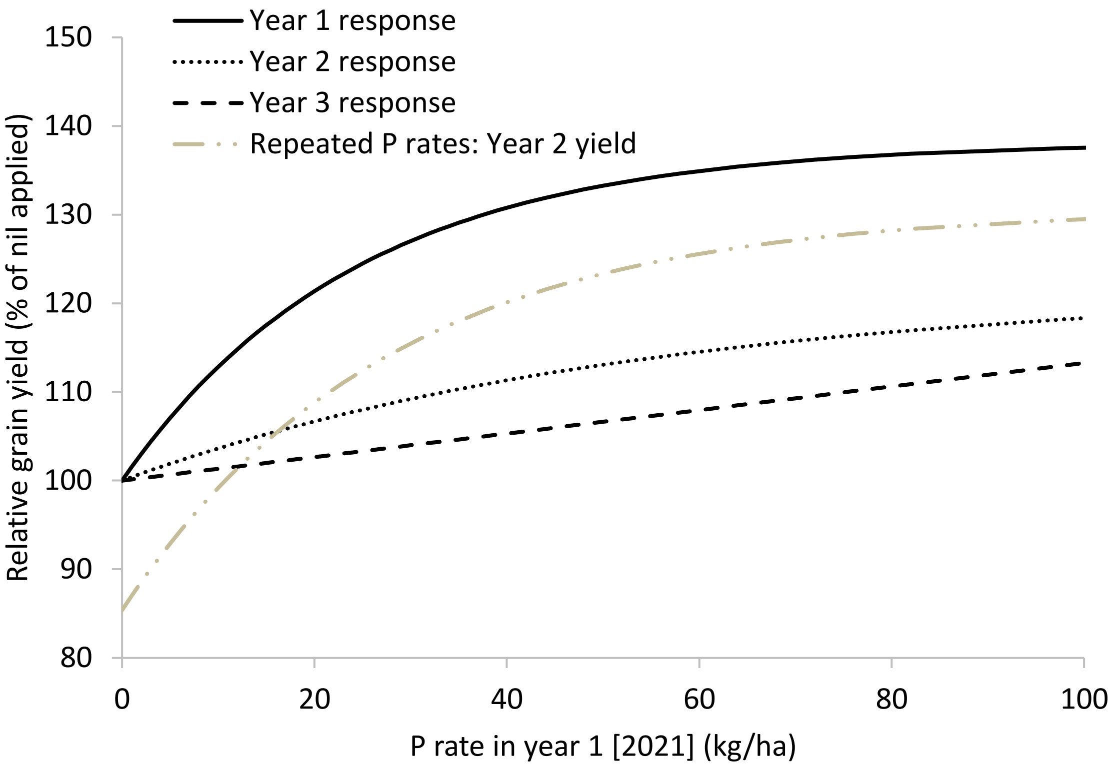

Figure 5. Grain yield response at Hart to P rate range applied in year 1 (2021) and residual response to year 1 application in year 2 (2022) and year 3 (2023) when 15 kg P/ha was applied in those years. This is compared with the response in year 2, when the P rate range are repeated in both years.

Crop response to P fertiliser strategies in a dry 2024

Wheat (Hart)

Grain yields at the Hart site in 2024 were low, averaging 0.83 t/ha (Figure 6). High rates of P fertiliser (50 kg P/ha and 90 kg P/ha) applied in 2024 led to increased grain yields. On average these two application rates increased grain yield by 40% (0.3 t/ha) compared to the district practice treatment (15 kg/ha/year). The slightly lower P rate of 30 kg P/ha also increased grain yield this season. This demonstrates that even in a low yielding year such as 2024, grain yield increases are still likely on these responsive soil types, although the rate that optimises gross margin will be lower, as per Table 1.

The alternative P management strategies had mixed outcomes on wheat grain yield this season. Broadcasting MAP did not improve grain yields compared to the district practice treatment. However, the application of chicken litter (2021 and 2024) increased grain yield by 23%. As previously reported the chicken litter treatment has generally performed as well as higher P rates and provided one of the highest PGM at both Hart and Crystal Brook (Trengove et al. 2023).

Repeated applications of different P fertiliser rates (0-90 kg P/ha) did not result in a consistent increase in grain yield (Figure 6). Two out of the five P fertiliser rates resulted in improved grain yield (22.5 kg P/ha and 50 kg P/ha) while the remaining were no different to the district practice. It is likely crop water use in previous seasons (e.g. high yielding treatments = less carried over soil water) may have influenced the results in these treatments this season. This lack of response in the year following high applications of P fertiliser demonstrates that on these soil types relying on the previous year’s fertiliser is likely to result in reduced grain yields.

As a result of the dry season and low grain yields it is not surprising that grain protein across the trial was high, averaging 13.6% (data not shown). In general, there was little variation among the P management strategies. The most consistent outcome was higher grain protein where 90 kg P/ha had been applied in 2024 (one off or repeated application strategies).

Lentils (Crystal Brook and Spalding)

Grain yields across both sites were low averaging 0.46 t/ha at Crystal Brook (Figure 6) and 0.86 t/ha at Spalding. At Crystal Brook there were minor differences in lentil grain yield among the P management strategies. Generally, the highest grain yield came from the application of 90 kg P/ha applied this season as either MAP spread prior to sowing or the repeated application.

At Spalding, there were even fewer differences in grain yield compared to the Crystal Brook site. All P management strategies had grain yield similar to the district practice. The only exception was the repeated 0 kg P/ha which reduced grain yield.

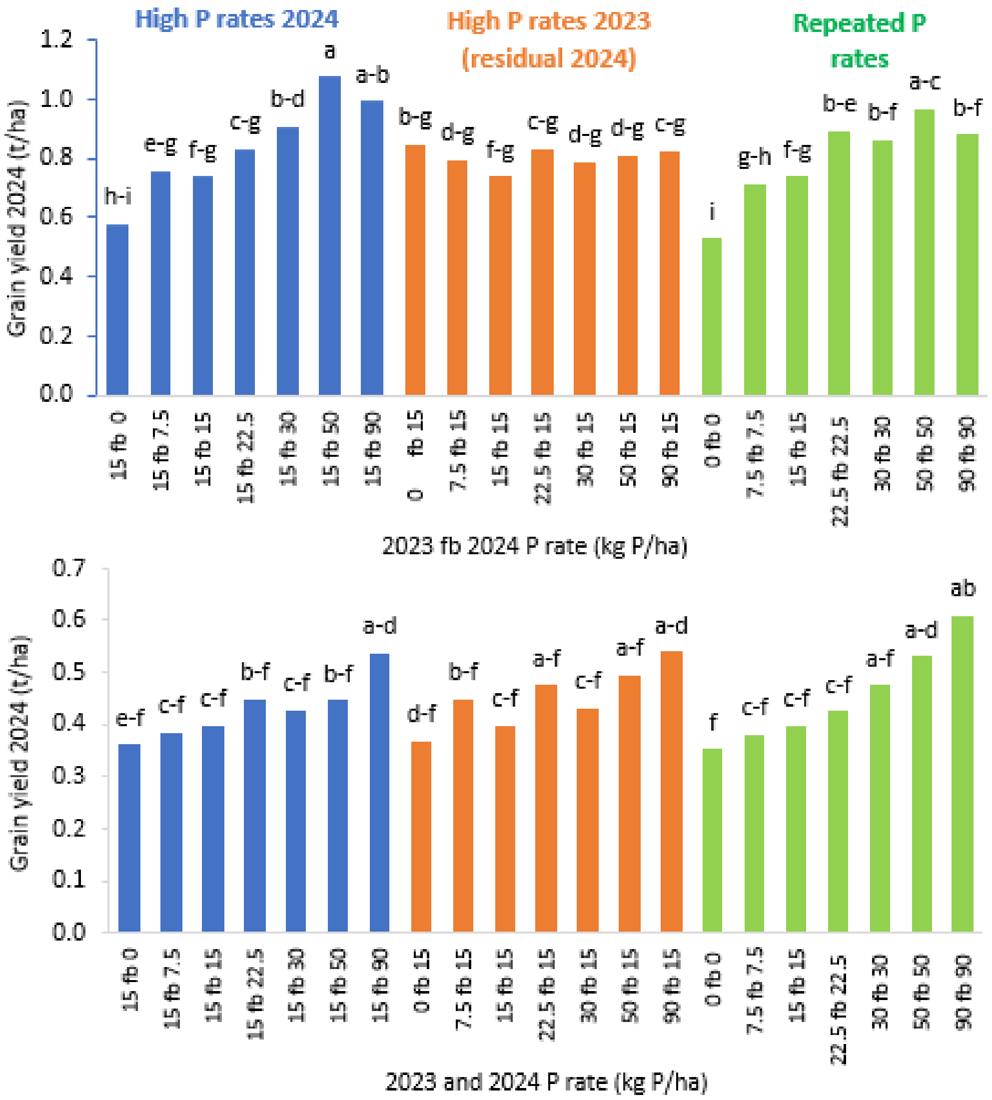

Figure 6. Grain yield (t/ha) for the Hart (top) and Crystal Brook (bottom) long-term P management site 2024.

Implications for P fertiliser management in 2025

It is common for growers in the southern region to use a P replacement strategy based on the amount of P removed in the grain (i.e. 3 kg P/t cereal grain) to determine fertiliser P application rates. Using this strategy, 'district practice' P fertiliser rates are generally in the range of 10-20 kg P/ha/annum. Given the below average grain yields last season, it would be fair to assume <5 kg P/ha has been exported in the grain in many areas. The P replacement strategy would therefore assume a reduction in P fertiliser rates going into this season. Using the field trials above we explore the question – can we cut back to 5 kg P/ha as replacement this season?

This research has shown at district practice P fertiliser application rates (<20 kg P/ha) a grower cannot rely on residual P from the season prior if the zone or paddock is P responsive with moderate PBI (range 77-110 at these sites). Repeated applications of >20 kg P/ha or more were required to shift pre-seeding DGT-P soil levels enough to have any implications on crop growth and grain yield.

The yield responses from Hart (Figure 5) have shown the response to residual P, when returning to district practice in year 2 and year 3. However, this graph also shows how much economic benefit is lost by not applying the optimum P rate or continuing with repeated fertiliser rates. It is in fact, a demonstration of what not to do on P responsive soils, unless the expectation is for low cereal yield potential of less than 2 t/ha. Reducing P fertiliser rates coming into 2025 will limit the yield potential of this season's crop (year 1 response), and the yield potential of the subsequent crop may also be limited (year 2 response), even when 'district practice' rates are reapplied in future years.

Conversely, P fertiliser management for non-responsive zones/paddocks requires a different approach. For these areas there is significant value in residual fertiliser P from previous applications. In some cases, they are not responsive to P at all, and it is rare that they respond to greater than replacement levels. The pHnNDVI methodology can help to identify where these areas are, and it can be used to make considerable savings on P fertiliser application on these soil types.

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Management options for dry saline soils on Upper Yorke Peninsula: results from three seasons

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Trengove Consulting

Key findings

- In season one, lentil grain yields were generally low (0.16-0.62 t/ha) across the trial. The high sand application rate (1300 t/ha) was the only treatment to improve lentil grain yield compared to the control.
- In seasons two and three, larger increases in crop emergence, NDVI and grain yield emerged among the sand and straw rates. Specifically, sand rates above 650 t/ha and straw rates above 6.6 t/ha resulted in the highest wheat and barley grain yields.
- Two years after the trial was implemented, all sand and straw application rates reduced the salinity level (ECe and TDS) in both the 0-10 cm and 10-20 cm depths.
- In general, the results show three years after application, the straw and sand rates are having a positive impact on both cumulative grain yield and partial gross margin (despite the high initial amelioration costs).

Background

Dry saline soils are a type of land salinity that occurs in soils with high levels of naturally occurring salt (but is not associated with a shallow water table). In mild situations, dry saline land can also be referred to as transient salinity, where salts are trapped within the soil profile (e.g. due to low permeability clay subsoil) and salts move up and down depending on seasonal conditions. Situations which lead to higher evaporation of moisture e.g. long hot summers, periods of drought and the loss of surface plant or stubble cover increase the presence and severity of saline soil patches. Poor plant growth and yields are commonly observed on impacted areas due to the difficulties for crops to take up water in saline soils and the toxic effects of high salt in the plant.

This research aims to trial and demonstrate different management practices which could be used by growers to ameliorate saline soil patches. The application of amendments (e.g. straw and sand) to the soil surface were trialed to improve crop emergence by reducing evaporation leading to reduced accumulation of salt in the topsoil, more soil moisture, or by reducing the moisture required to germinate a seed by increasing the sand content of the soil surface. Gypsum was also included to increase the amount of calcium relative to the level of sodium (salt) and address sodicity in the longer term.

Methodology

Site selection and rainfall

An amelioration trial for the management of saline soils was established at Tickera, SA (-33.8466, 137.6844) in 2022. The saline area was selected based on historical crop performance and soil test results (Table 1). The trial was a randomised complete block design with four replicates and eight treatments that are described below (Table 3). All plots were scored prior to seeding in 2022 for stubble cover (barley) to assess the variation in salinity level across the site. Stubble cover was measured visually by scoring each plot from 1 (low stubble cover = more saline) to 5 (high stubble cover = less saline).

Soil properties

Soil samples were collected on April 29, 2022 by sampling the surface 0-10 cm in all five stubble cover scores (Table 1). These scores were used as a covariate in the statistical analysis of the experiment. Deeper cores were sampled in areas with scores 1 and 4 and segmented as follows, 0-10 cm, 10-20 cm, 20-40 cm and 40-60 cm, these were not replicated.

The Tickera site is a moderate to strongly alkaline (pH >8.0) clay loam with salinity issues (Table 1). Salinity was measured using chloride and an electrical conductivity estimated (ECe) which uses a texture conversion factor (9.5 for sandy loam) from the EC1:5. Chloride levels in the surface and subsurface ranged from 520-4800 mg/kg. The critical level for chloride in clay soils is 300 mg/kg (Hughes 2020). Above this critical value salinity damage is likely to occur depending on crop tolerance. The ECe across the site was 5.9-37. In general, it is expected at ECe 4-8 yields of many crops will be affected and 8-16 only crops with tolerance will yield well (Hughes 2020). Beyond 32 is generally considered too salty for most broadacre crops to grow.

Boron levels across the site and soil depths ranged from 8-38 mg/kg. Boron toxicity for sensitive crops generally occurs at levels >5 mg/kg and at levels >15 mg/kg it is considered toxic for dryland cereals (Hughes 2020).

Table 1. Soil properties for samples collected at salinity management trial Tickera, SA 2022.

Stubble cover score	**Sample depth**	**pH 1:5 water**	**Chloride**	**Salinity $EC_{1:5}$ (soil:water)**	**EC_e (estimated)**	**Boron**
	cm		**mg/kg**	**dS/m**	**dS/m**	**mg/kg**
1 (Low stubble / more saline)	0-10	8.1	4800	3.9	37	-
	10-20	8.6	1500	1.5	14	18
	20-40	8.9	1400	1.4	13	29
	40-60	9.1	1400	1.5	14	32
2	0-10	8.2	1800	1.6	15	-
3	0-10	8.2	1300	1.2	11	-
4 (High stubble / less saline)	0-10	8.0	1600	1.4	13	-
	10-20	8.8	520	0.62	5.9	8
	20-40	9.1	770	0.97	9.2	25
	40-60	9.1	1400	1.5	14	38
5	0-10	8.2	720	0.71	6.7	-

Trial details

Sand and gypsum treatments were spread on the soil surface May 3, 2022. Straw treatments (from baled wheat) were applied post seeding on May 27, 2022. Treatments included; control, gypsum 10 t/ha, straw 3.3 t/ha, straw 6.6 t/ha, straw 10 t/ha, sand 130 t/ha, sand 650 t/ha and sand 1300 t/ha. Sand rates were calculated on applying a sand layer of 1 cm (130 t/ha), 5 cm (650 t/ha) and 10 cm (1300 t/ha) covering the surface. The sand was sourced from a sand pit 15 km northeast of the trial site at Alford and applied using a front-end loader and shovel. The gypsum used in the trial had a purity of 69% making it a grade three product.

Table 2. Summary of rainfall and seeding details from 2022-2024.
** Long-term average growing season rainfall for Tickera is 252 mm.*

Year	Growing season rainfall*	Seeding date	Crop and seeding rate	Fertiliser at seeding
2022	250 mm	May 26	Hurricane XT lentils @ 50 kg/ha	MAP 1%Zn 60 kg/ha
2023	219 mm	May 11	Chief CL Plus wheat @ 80 kg/ha	MAP 65 kg/ha + urea 42 kg/ha
2024	146 mm	May 10	Commodus CL barley @ 80 kg/ha	MAP 1%Zn 60 kg/ha + urea 100 kg/ha

Soil and crop assessments 2024

Pre-seeding all plots were soil cored 0-10 cm, 10-20 cm and 20-40 cm from the original soil surface. Soil samples were analysed for total dissolved solids (TDS) and ECe (as per method above). The high application rates of sand (650 t/ha and 1300 t/ha) created a new soil layer and an additional soil sampling increment was added 'sand' which represents the layer above the original soil surface. The control and gypsum treatment soil samples were also analysed for exchangeable sodium percentage (ESP).

Plant establishment was scored on May 31 and July 9, Greenseeker NDVI on July 12 and September 11. All plots were harvested for grain yield and quality on November 8.

Statistical analysis

Analysis of this experiment was conducted using linear mixed models with restricted maximum likelihood using ASReml-R (Butler, 2022) and the R Core Team (2022) package biometryassist (Nielsen et al. 2022). Where there is significant evidence from the model that the explanatory variable means differ, Tukey's multiple comparison test was used to determine which of the means are different at a significance level of 5%.

Year one and two results

In season one lentil grain yields were generally low (0.16-0.62 t/ha) across the trial. The high sand application rate (1300 t/ha) was the only treatment to improve lentil grain yield compared to the control (Table 3). In the second season larger differences among the sand and straw rates were emerging. Sand rates above 650 t/ha and straw rates above 6.6 t/ha resulted in wheat grain yields of 1.95-2.42 t/ha compared to the control 0.67 t/ha.

Year three results

Changes in soil properties

Soil salinity can be measured using both ECe and TDS. The average ECe across the site 0-10 cm was 16.5 prior to trial establishment. Without any amelioration, the current control ECe was 18.1 (Table 3) and it is expected only salt tolerant crop types will yield well in these areas. The salinity level (ECe) in all the sand and straw application rates has been reduced, on average by 58% and 33% in the 0-10 cm and 10-20 cm depths, respectively. Overall, it has lowered ECe to an average of 7.6 in both of these layers. This reduction in salinity has also lowered the effect on plant growth to the category ‘yield of many crops effected’ from ‘only tolerant crops yield well’ prior to treatment (Hughes 2020).

Total dissolved solids (TDS) is a measure of the total salt content in a given soil or water sample. Similar to the ECe results, any application rate of sand or straw has reduced TDS compared to the control in both the 0-10 cm and 10-20 cm layer (Table 3).

In the 20-40cm layer the analysis using the linear mixed model identified the overall treatment as a significant effect for both ECe and TDS with all sand and straw treatments trending down for ECe and some variation in TDS. However, as Tukey’s multiple comparison test is conservative it was unable to identify the pairwise differences between individual treatments.

The ESP identifies the degree to which the soil exchange complex is saturated with sodium and is used to characterise sodicity. ESP was measured in the control and gypsum treatment. It showed a reduction in sodicity in 0-10 cm layer from 17.3 (control) to 12.5 (gypsum) where gypsum was applied (data not shown). This reduction in ESP reduced the soil from >15% ‘strongly sodic’ down to a ‘sodic’ classification (Huges 2020). No changes in the ESP for the 10-20 cm and 20-40 cm layer were observed. However, the results also show the application of gypsum has had no effect on salinity (Table 3). This treatment was imposed to address sodicity at this site in the longer term.

Table 3. Pre-seeding EC$_e$ and TDS for treatments in the salinity management trial Tickera, SA 2024.

Treatment	**ECe**			**TDS (mg/L)**		
	0-10 cm	10-20 cm	20-40 cm	0-10 cm	10-20 cm	20-40 cm
Control	18.1^a	11.4^a	15.2^a	1235^a	807^a	993^a
Sand @ 130 t/ha	8.6^b	8.6^b	12.4^a	598^b	592^b	820^a
Sand @ 650 t/ha	6.7^b	8.6^b	14.3^a	450^b	581^b	948^a
Sand @ 1300 t/ha	5.7^b	7.6^b	13.3^a	355^b	511^b	898^a
Straw @ 3.3 t/ha	8.6^b	6.7^b	10.5^a	575^b	474^b	720^a
Straw @ 6.6 t/ha	9.5^b	7.6^b	10.5^a	615^b	498^b	695^a
Straw @ 10 t/ha	6.7^b	6.7^b	10.5^a	450^b	473^b	708^a
Gypsum @ 10 t/ha	15.2^a	12.4^a	15.2^a	1035^a	836^a	1005^a
P-value	**<0.001**	**<0.001**	**0.001**	**<0.001**	**<0.001**	**0.003**

Crop establishment and biomass

Despite dry conditions pre and post seeding, there were differences observed in crop establishment at the end of May (three weeks after seeding). Both the higher rates of sand (650 t/ha and 1300 t/ha) and the high rate of straw (10 t/ha) had more plants emerged compared to the control (Table 4). The higher plant establishment can be attributed to the retention of more soil moisture under the sand and straw treatments due to reduced evaporation and lower matric potential (pressure by which water is held in the soil pores) in the sand, meaning the sandier soils can germinate seeds with less moisture. However, early establishment in sand at 1300 t/ha is less than for sand at 650 t/ha. This is due to deeper sowing in the high sand rate (despite best efforts to adjust seeder setup) reducing early emergence. The remaining treatments were no different to the control at this timing.

Following 40 mm of rain during June, crop establishment was improved by all sand and straw rates when assessed in early July (Table 4). In general, the establishment was similar across the three rates of straw trialed, averaging 88%. However, for the sand, application rates >650 t/ha resulted in the highest crop establishment (>91% of the plot emerged).

In general, NDVI assessments in late winter-early spring show that crop biomass was improved by the two higher application rates of both sand and straw. Similar to crop establishment the lower rates of both products also increased NDVI compared to the control. These results show three years after application, the straw and sand rates are having a positive impact on crop establishment and biomass on a saline soil.

Table 4. Crop establishment and GreenSeeker NDVI for the salinity management trial Tickera, SA 2024.

Treatment	**Establishment %**		**NDVI**	
	May 31	**July 9**	**July 12**	**Sept 11**
Control	0.3^{d}	50^{e}	0.191^{d}	0.244^{d}
Sand @ 130 t/ha	2.8^{cd}	70^{cd}	0.222^{cd}	0.502^{bc}
Sand @ 650 t/ha	55.0^{a}	91^{ab}	0.383^{a}	0.653^{a}
Sand @ 1300 t/ha	16.3^{bc}	98^{a}	0.276^{bc}	0.702^{a}
Straw @ 3.3 t/ha	3.1^{cd}	81^{bc}	0.230^{cd}	0.434^{c}
Straw @ 6.6 t/ha	6.3^{cd}	86^{ab}	0.268^{c}	0.603^{ab}
Straw @ 10 t/ha	21.9^{b}	96^{ab}	0.327^{ab}	0.622^{a}
Gypsum @ 10 t/ha	0.1^{d}	63de	0.197^{d}	0.279^{d}
P-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**
LSD (≤0.05)	**14.6**	**16**	**0.058**	**0.115**

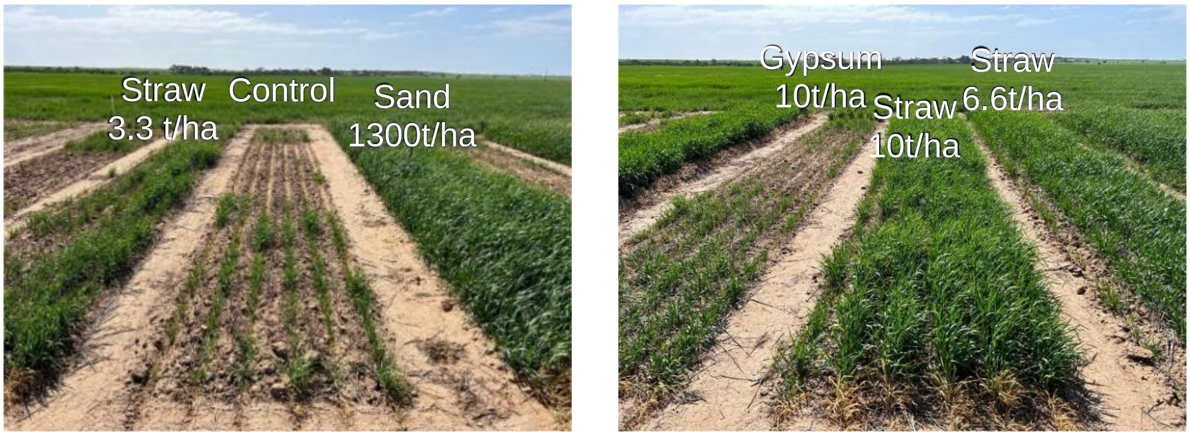

Figure 1. Commodus CL barley in the control and various sand and straw rates (labelled above) in the salinity management trial Tickera, SA August 30, 2024.

Grain yield and quality

Consistent with 2023, the two higher rates of sand (650 t/ha and 1300 t/ha) and straw (6.6 t/ha and 10 t/ha) improved barley grain yields compared to the control (Table 5). On average there was a 2.6 t/ha yield increase for these rates. The lower sand (130 t/ha) and straw (3.3 t/ha) rates also increased grain yield compared to the control, averaging a 1.1 t/ha yield improvement. These results show the sand and straw are providing significant benefits. Most likely through a mulching effect, reducing evaporation from the soil surface, retaining more moisture and reducing surface salinity. The higher rates of sand are also providing a layer of soil with lighter texture for crops to establish.

Similar to this season’s grain yield results, cumulative yields are also showing all rates of sand and straw have improved grain yield (Figure 2). For the sand rates, grain yield stabilises after approximately 650 t/ha. That is, application of sand rates beyond this point did not result in larger yield gains. For the straw rates there is a linear response in cumulative grain yield (Figure 2). This suggests the straw rates trialed have not maximised grain yield and further gains may be achieved from rates above 10 t/ha.

Gypsum applied at 10 t/ha has not improved grain yield or quality compared to the control in any season to date. The soil test results this season showed the gypsum has moved into the 0-10 cm layer and reduced sodicity. However, the primary constraint of salinity has not been improved, as such, crop performance continues to be limited by salinity despite a reduction in sodicity. Long-term monitoring of this site will be required to understand the full soil, crop and economic returns from these treatments.

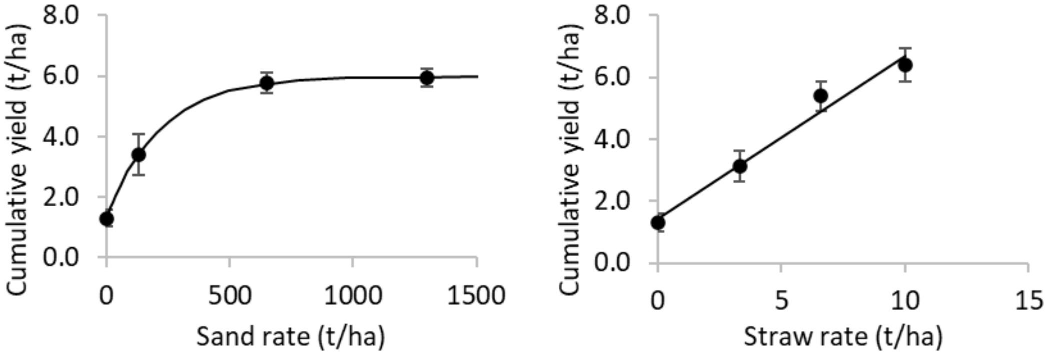

Figure 2. Cumulative (2022 lentil + 2023 wheat + 2024 barley) grain yield response in relation to sand (left, R^2 = 0.867) and straw (right, R^2 = 0.978) rates applied in salinity management trial Tickera, SA.

Grain quality from all the sand and straw treatments was higher (BAR1) compared to the control (BAR2) (Table 5). While Commodus CL has been approved for malt accreditation, all treatments within the trial had protein levels >12% (maximum level allowed). This reflects the below average growing season rainfall reducing grain fill in the trial which had lower yield potential (lower yield = higher protein).

Table 5. Barley grain quality, receival standard and gross income for salinity management trial 2024 Tickera, SA.

Treatment	**Protein %**	**Test weight kg/hL**	**Retention %**	**Screenings %**	**Receival standard**
Control	14.1^{ab}	61.5^{e}	71.3^{b}	8.9^{a}	BAR2
Straw at 3.3 t/ha	13.5^{abc}	64.5^{cde}	82.2^{a}	4.9^{b}	BAR1
Straw at 6.6 t/ha	12.5^{c}	67.1$^{a\text{-}d}$	86.1^{a}	2.6^{b}	BAR1
Straw at 10 t/ha	13.1^{bc}	68.5^{ab}	84.6^{a}	3.0^{b}	BAR1
Sand at 130 t/ha	14.2^{a}	64.9$^{b\text{-}e}$	80.4^{a}	5.0^{b}	BAR1
Sand at 650 t/ha	14.1^{ab}	68.4^{abc}	87.9^{a}	2.6^{b}	BAR1
Sand at 1300 t/ha	14.5^{a}	68.9^{a}	85.9^{a}	3.1^{b}	BAR1
Gypsum at 10 t/ha	13.9^{ab}	62.5^{de}	69.0^{b}	10.2^{a}	BAR2
P-value	**0.023**	**0.011**	**0.001**	**0.001**	

Partial gross margin analysis

Partial gross margin (PGM) analysis conducted on the three seasons of trial data shows positive returns for most treatments (Table 6). The highest PGM come from straw applications where the straw is sourced and spread cheaply. In this scenario cost recovery was achieved after two seasons for straw applied at 6.6 t/ha and was generating profit in the third season (Figure 3). However, sourcing straw at commercial value ($90 /t) and paying full contract rates for spreading reduced PGM below the control (<$500 /ha) after three seasons (Table 6). While spreading straw cheaply can be achieved on smaller areas of paddocks, it may not be practical over a larger area.

Despite the high costs of spreading sand as an amelioration strategy, it has produced positive PGM outcomes for the lower rates in the short term. The 130 t/ha and 650 t/ha have resulted in cumulative PGM of $838 /ha and $668 /ha, respectively (Table 6). Sand applied at 650 t/ha did not achieve cost recovery until the third season, whereas 130 t/ha had recovered costs in year 2 and was more profitable in year 3 (Figure 3). However, the trends of these lines would indicate that the higher cost 650 t/ha treatment will surpass the lower cost treatment in the near term. Currently the results show the 1300 t/ha sand application rate is too costly to apply and has a negative PGM. However, the longevity of all treatments will continue to be assessed and may impact the final economics on which product and rates will be optimal for the longer-term management of saline soils in the area.

Table 6. Treatment costs, grain yields (t/ha) and partial gross margin for 2022-2024 in the sand, straw and gypsum treatments at Tickera, SA.

Treatment	**Treatment cost* ($/ha)**	**2022 Lentil**	**2023 Wheat**	**2024 Barley**	**Cumulative**	**Cumulative partial gross margin****
		Grain yield (t/ha)				**($/ha)**
Control	$0	0.23^{b}	0.67^{c}	0.58^{c}	1.30^{c}	$526
Sand at 130 t/ha	$240	0.25^{ab}	1.26^{bc}	1.76^{b}	3.41^{b}	$838
Sand at 650 t/ha	$1,185	0.40^{ab}	1.97^{ab}	3.32^{a}	5.77^{a}	$668
Sand at 1300 t/ha	$2,370	0.62^{a}	2.26^{a}	3.16^{a}	5.95^{a}	-$315
Straw at 3.3 t/ha	$270-$625	0.40^{ab}	1.19^{c}	1.63^{b}	3.12^{b}	$854-$499
Straw at 6.6 t/ha	$545-$1,310	0.46^{ab}	1.95^{ab}	2.89^{a}	5.39^{a}	$1,222-$457
Straw at 10 t/ha	$825-$1,920	0.46^{ab}	2.42^{a}	3.50^{a}	6.38^{a}	$1,265-$170
Gypsum at 10 t/ha	$465	0.16^{b}	1.26^{c}	0.65^{c}	1.53^{c}	$219
P-value		**0.001**	**<0.001**	**<0.001**	**<0.001**	

**Treatment costs have been estimated based on contract rates for sand spreading in the area (where sand can be sourced is within 1 km of the paddock applied) and a combination of contract rates and estimates of 'do it yourself' straw spreading options. Gypsum prices are based on Everard gypsum delivered and spread at Tickera.*

***Cumulative partial gross margin assumes grain prices of $700 for lentil, $300-$320 for wheat and $260-$284 for barley depending on receival grade achieved.*

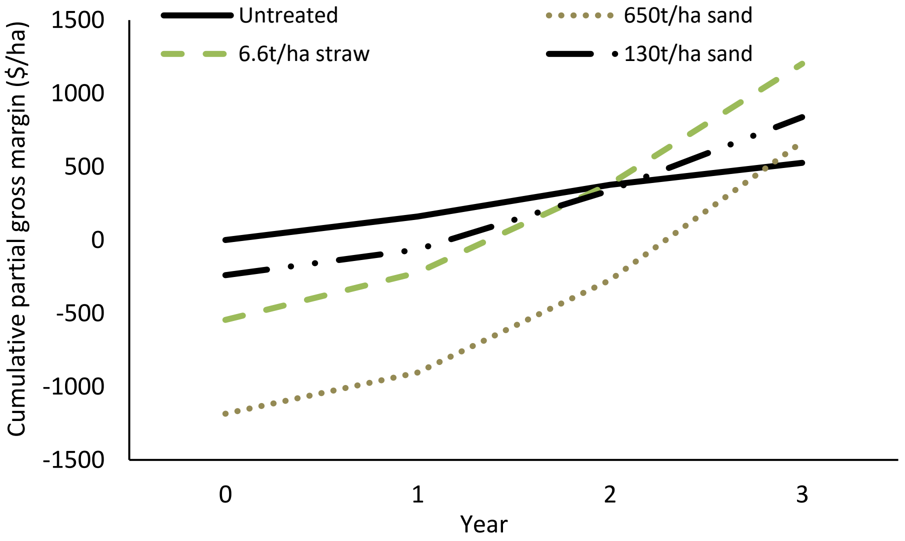

Figure 3. Cumulative partial gross margin ($/ha) over time from initial treatment application for selected treatments. Lower cost ($545 /ha) estimate of 'do it yourself' scenario used for straw applied at 6.6 t/ha.

Summary

All straw and sand rates are having a positive impact on grain yield three years after application to ameliorate this saline soil. However, the highest grain yields were achieved when at least 650 t/ha of sand or 6.6 t/ha of straw were applied. The application of sand at that rate is logistically difficult unless a source is located nearby. Where sand is not locally available, application of straw at a minimum of 6.6 t/ha would be more achievable.

Partial gross margin analysis has shown most treatments have produced a positive return compared to the control. It is expected that grain yields will continue to be maintained or improved in the short term now that consistent crop cover has been achieved and salinity levels have declined in response to treatment. It is likely this will continue to increase the PGM for all sand and straw treatments going forward. The longevity of response is important for these amelioration treatments due to the high implementation cost and this trial will be monitored for another three seasons (six total).

Acknowledgements

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Evaluating the importance of sowing rate, depth and time of sowing on canola emergence

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Key findings

- There was no crop establishment penalty for canola that remained in dry soil for an extended period of time (6-7 weeks) prior to the season break on May 30.
- Low density crops may be able to yield similarly to crops where target densities are achieved if seasonal conditions are favourable, however drought conditions experienced at Hart in 2024 resulted in poor seed set for all canola. Bird damage and severe weather events prior to harvest prevented canola trials from being harvested.
- A complementary trial showed that seed size (small vs. large) of HyTTec Trophy canola did not impact establishment (plants/m2) at Hart in 2024, however it did affect early vigour (NDVI) and biomass production (t/ha).

Background

Across the Mid North of South Australia in 2024, most broadacre crops were sown into dry soils due to unusually dry autumn conditions, with areas receiving less than 20 mm across three months (March-May).

Risks surrounding dry sowing have been associated with reduced plant establishment in marginal moisture conditions, with further information required on the impacts of this low establishment on profitability and productivity. The rewards of dry or early sowing have been seen as potential yield gains by earlier emergence increasing season length of crops and improving water use efficiency. Although poor establishment can lead to a reduction in yield, trials conducted across the Mid North have found that favourable growing conditions may allow lower density crops to perform similarly to those where establishment is high (Morgan et. al. 2023). In 2024, a canola time of sowing (TOS) trial was implemented at Hart, SA to investigate the relationship between plant establishment and yield at various plant densities. A secondary and complementary trial at Hart explored the impacts of low establishment on productivity to develop a response curve between canola establishment and grain yield.

These trials provide information on the effects of early and dry sowing, establishment conditions, seed size and plant density target to better understand the risk and reward associated with this management practice.

Methodology

Canola TOS

In 2024, a replicated canola trial was sown to Enforcer CT on a clay loam soil at Hart. The trial was a factorial split-split plot design with three sowing dates between late April and early July, three sowing depths (shallow (10 mm), standard (20 mm) and deep (30 mm)) and three plant densities (23, 45 and 68 seeds/m2) (Table 1). Sowing rates represent standard practice (45 plants/m2) +/- 50% target density. The low sowing rate (50% of standard practice) of 23 plants/m^2 was included to quantify the effects of poor establishment when sown at different times of sowing (TOS) and depths.

Plant counts were conducted to determine the effect of treatment on establishment (plants/m^2). Soil moisture in the top 10 cm was recorded with a hand-held moisture meter at sowing and monitored until final emergence of all TOS. Normalised Difference Vegetation Index (NDVI) was measured twice after emergence to monitor early plant growth and timing of key phenological events (e.g., flowering) was recorded for all plots (data not shown). This trial was not harvested due to drought conditions and bird damage affecting grain yield results. Hand harvested yield estimates from quadrats were both low yielding (<150 kg/ha) and highly variable, therefore no grain yield data is presented. All data was analysed using a REML spatial model (Regular Grid) and differences between means were assessed using Bonferroni test, in Genstat 24th Edition.

Table 1. Canola trial details for Enforcer CT at Hart, SA.

Enforcer CT	**TOS 1**	April 18	**Seeding fertiliser:**	DAP Zn 1% + Flutriafol @ 80 kg/ha
	TOS 2:	June 4		
	TOS 3:	July 3		
	Seeding depth:	10, 20 and 30 mm		
	Sowing rate:	23, 45, 68 plants/m^2		

Canola seed size x density

A replicated trial was sown at the Hart field site using HyTTec Trophy (Table 2). This trial was set-up as a two-way factorial design with two seed sizes by seven densities and three replicates. Trial seed was graded into small seed (294,118 seeds/kg) and large seed (188,679 seeds/kg) and sown at target densities of 5, 10, 20, 30, 40, 50 and 60 plants/m2. Crop establishment was measured as plants/m^2 and NDVI was recorded four and eight weeks after emergence. Interplant distance (cm) was measured between 20 plants in each plot to measure plant spacing uniformity between treatments. Plant height (cm) and branching (number of branches/plant) was recorded at the end of flowering to determine effects of seed size and plant density on the size of individual plants.

Crop biomass (t/ha) and grain yield (t/ha) estimates were calculated using harvest index cuts; however one replicate was removed from analysis due to bird damage. Data was analysed using a REML spatial model (Regular Grid) and differences between means were assessed using Bonferroni test, in Genstat 24th Edition.

Table 2. Trial details for HyTTec Trophy canola seed size x density trial at Hart, SA.

HyTTec Trophy	**Plot size:**	1.75 m x 10.0 m	**Seeding fertiliser:**	DAP Zn 1% + Flutriafol @ 80 g/ha
	Seeding date:	June 5		
	Seed weight (small):	3.4 g/1000 seeds		
	Seed weight (large):	5.3 g/1000 seeds		
	Crop history:	Oaten Hay (2023)		

Results

Canola TOS trial

Despite the dry start, crop establishment was high (75-90%) with no difference in final establishment recorded among the three TOS (Table 3). TOS 1 was sown into dry soil (<2% soil moisture) on April 18 and remained dry until the opening rains six weeks later on May 29 to June 1. Soil moisture remained below permanent wilting point (PWP) until the first week of June with TOS 1 emergence on June 11, almost one week after soil moisture exceeded the PWP (Figure 1). Despite this long dry period, crop establishment was not reduced.

Time of sowing two was sown into approximately 20% moisture and achieved similar establishment to TOS 1 despite the differences in soil moisture conditions. Emergence of TOS 2 occurred on June 18, emerging only one week after TOS 1. Soil moisture remained low throughout emergence of TOS 1 and TOS 2 and had not reached field capacity (FC) by the end of July.

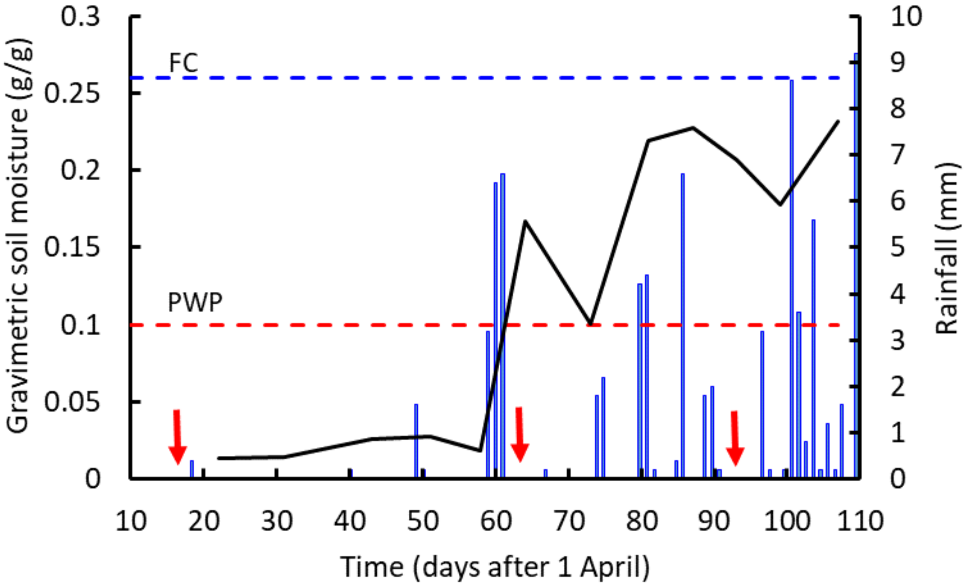

Figure 1. Soil Moisture Content (—) and rainfall (▮) in relation to the three times of sowing at Hart in 2024 (↓). The field capacity (FC) and permanent wilting point (PWP) moisture content shown are based on the moisture release curve for Hart soil (not shown).

Establishment counts showed that deep sowing canola to 30 mm slowed emergence, however this had no effect on final plant establishment (Table 3). Increasing sowing rate increased plant number proportionately, with differences between all three rates observed.

Depth of sowing effects on crop biomass are shown in Table 4. While deep sowing did not affect final plants/m^2, there was a penalty to early growth associated with deep sowing, possibly related to the delayed emergence.

Table 3. Treatment effects on final plant establishment (plants/m^2) and establishment (Est %) for canola. Significant differences in plant establishment between treatments are indicated by different letters after plant count (plants/m^2). Shaded values indicate the treatments with the highest plant establishment.

Effects of sowing date			**Effects of sowing depth**			**Effects of sowing rate**		
Sowing date	**Plants (m^2)**	**Est %**	**Sowing depth**	**Plants (m^2)**	**Est %**	**Sowing rate**	**Plants (m^2)**	**Est %**
April 18 (TOS1)	37	82	**Shallow**	40	89	**23/m^2**	17^a	74
June 4 (TOS2)	34	76	**Standard**	37	82	**45/m^2**	37^b	82
July 3 (TOS3)	41	91	**Deep**	34	76	**68/m^2**	58^c	85
P-value (≤0.05)	**NS**			**NS**			**<0.001**	

Table 4. Sowing depth and sowing rate effect on early biomass as measured by NDVI conducted eight weeks after emergence. Significant differences are indicated by different letters. Shaded values indicate best performing treatments.

Sowing depth	NDVI	Sowing rate	NDVI
Shallow	0.37^c	23/m^2	0.29^a
Standard	0.34^b	46/m^2	0.36^b
Deep	0.30^a	68/m^2	0.37^b
P-value (≤0.05)	**<0.001**		**<0.001**

Canola seed size x density trial

Seeding density had an impact on both plant establishment (plants/m^2) (Figure 2) and interplant distance (cm) in the canola density trial at Hart in 2024. As seeding rate increased, the distance between plants was reduced, as expected. Increased crop density reduced the ability of canola to branch out and maximise individual plant productivity due to greater competition, which was compounded by drought conditions in 2024.

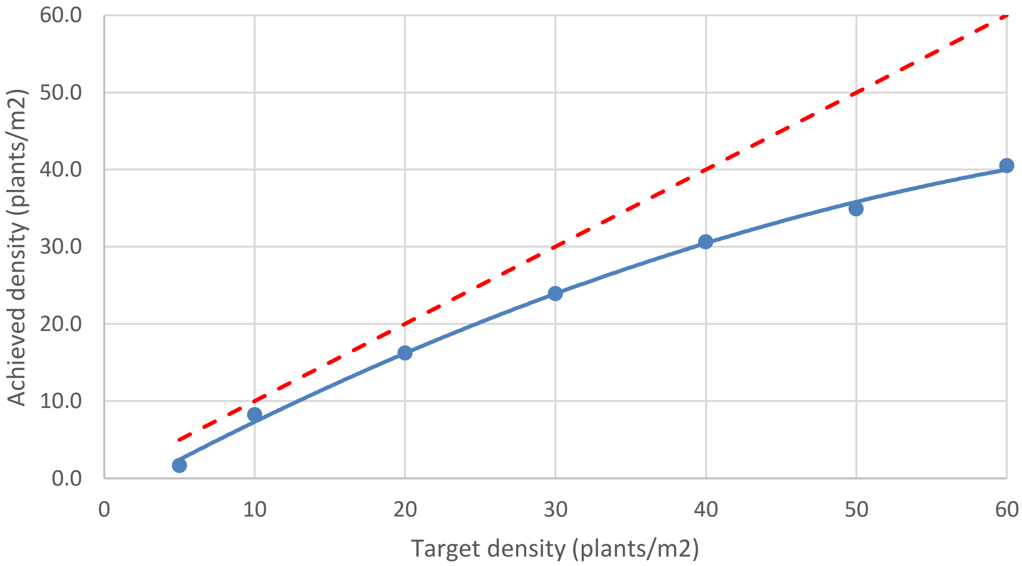

Figure 2. Target density (plants/m^2) and achieved plant establishment (plants/m^2) curve. The red line shows 100% plant establishment relevant to the target density. At higher plant densities, the gap between target and achieved yield is increased.

There was no effect of seed size on plant establishment or interplant distance (cm), however early ground cover measured as NDVI at eight- and twelve-weeks post-emergence, showed improved early vigour in large seed treatments (Table 5). This increase in early growth translated to biomass at maturity, with higher biomass (t/ha) observed where larger seed was used (p=0.021).

Despite these differences, large and small seed treatments yielded similarly for oilseed grain yield at Hart in 2024. It is important to note that drought conditions during the growing season resulted in low grain yields (>350 kg/ha).

Seeding density impacted biomass production, with higher density treatments producing more crop biomass (t/ha) than the 5 and 10 plants/m^2 treatments (Table 5). Despite biomass increasing with density, plant competition effects can be clearly identified by differences in plant weight (g/plant). Individual plants in the 5 plants/m^2 treatment weighed three times the amount of standard sowing density (40 plants/m^2), however increased plant density resulted in higher biomass production (t/ha) resulting from more plants per m^2.

Similarly, plants in low density treatments (5 plants/m^2) produced twice as much grain per plant (data not shown) as standard sown treatments (40 plants/m^2). Despite this result, no differences were noticed in grain yield (kg/ha), as higher density treatments offset reduced grain per plant through increased plant number.

Table 5. Impacts of seed size and seeding density on productivity as measured by NDVI, biomass (g/plant and t/ha) and grain yield (kg/ha). Significant differences are indicated by different letters. Shaded values indicate best performing treatments.

Treatment	NDVI 1	NDVI 2	Plant weight (g/plant)	Crop biomass (t/ha)	Grain yield (kg/ha)
Small seed	0.22	0.46	8.49	1.33	243
Large seed	0.26	0.50	9.50	1.51	208
P Value (≤0.05)	**0.01**	**0.006**	**0.007**	**0.021**	**NS**
5 plants/m^2	0.16^{a}	0.25^{a}	19.69^{c}	0.46^{a}	66
10 plants/m^2	0.17^{a}	0.35^{b}	13.3^{b}	1.12^{ab}	186
20 plants/m^2	0.24^{b}	0.48^{c}	8.14^{a}	1.23^{abc}	235
30 plants/m^2	0.26^{b}	0.55^{d}	6.68^{a}	1.5^{bc}	220
40 plants/m^2	0.25^{b}	0.57^{d}	5.22^{a}	1.96^{bc}	298
50 plants/m^2	0.31^{c}	0.56^{d}	5.22^{a}	1.64^{bc}	228
60 plants/m^2	0.31^{c}	0.58^{d}	4.68^{a}	2.02^{c}	349
P Value (≤0.05)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**NS**

Plant height and number of branches were recorded post-flower to identify sowing density and seed size effects. When sown at a target density of 5 plants/m^2 each canola plant produced on average 24 branches, however when sowing density exceeded 20 plants/m^2 branching was reduced to 4-6 per plant (Figure 3). In addition to reduced branching, plant height was significantly affected by increasing plant density, with a 30 cm reduction in height between the lowest (5 plants/m^2) and standard (40 plants/m^2) sowing rates.

Severe water stress throughout the growing season resulted in extreme differences in plant size between treatments (Figure 4). Despite increased branching and plant size in lower density treatments, drought conditions resulted in poor grain fill in all cases, therefore yield (t/ha) estimates from harvest index cuts were less than 350 kg/ha for all densities and showed no significant differences (Table 5).

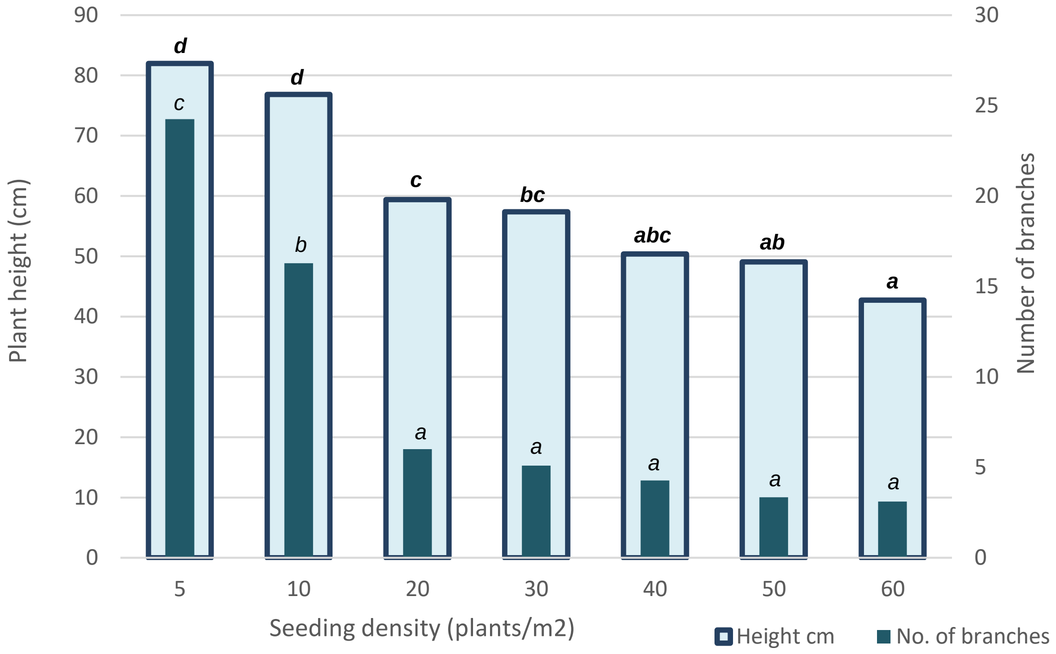

Figure 3. Plant height (cm) (▣)and number of branches (■) for seven seeding densities (plants/m^2). Significant differences between treatments are indicated by different letters above columns on the graph.

5 plants/m^2 **10 plants/m^2** **20 plants/m^2** **30 plants/m^2** **40 plants/m^2** **50 plants/m^2** **60 plants/m^2**

Figure 4. Plant size when sown at seven densities. The red line indicates the 50 cm mark on a 1 m ruler for plant height comparison.

Summary

Variable and poor plant establishment are two of the biggest risks associated with dry or early sowing. In a season where establishment occurs early, it is expected that lower density crops, particularly canola, may be able to yield similarly to crops with higher plant populations, as they are able to effectively fill in space to increase production per plant. This has been observed across previous canola field research.

The experiments showed that canola seed can remain viable over long periods of time in dry soil without any adverse effect on crop establishment, with similar results observed in 2024 pot experiments. Sowing deeper than 20 mm has shown to delay emergence and slow early crop vigour.

In 2024, severe moisture stress was experienced across all trials at Hart, resulting in low grain yields for all treatments. Even under these harsh conditions, canola growth showed considerable ability to adjust to differences in plant density, even if this was not translated into yield.

Where canola establishment was low, reduced competition increased biomass production per plant, however severe water stress during reproductive development and grain fill stages resulted in very low yields. Drought conditions reduced plant size, particularly where there were higher plant densities resulting in very low grain yields, regardless of late season rain.

Acknowledgements

We would like to acknowledge the South Australian Drought Resilience Adoption and Innovation Hub (project code: GRDC_23_03 and SAGIT_23_04) and the South Australian Grains Industry Trust (SAGIT) (project code: UAD1323) for their financial contributions to conduct these trials.

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A summary of recent experiments on soil moisture, germination and crop establishment

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Key findings

- Soil type has a large bearing on how sown crops respond to rainfall and the patterns of emergence across a paddock.
- Pot experiments and field trials conducted in 2023-2024 indicate seed can remain in dry soil for 4-6 weeks without reducing germination and emergence significantly.
- Approximately 15-20 mm of rainfall is required for emergence on a loamy soil type. Germination of sown seed can occur with smaller rainfall events, but seedlings may not emerge.
- Sowing deeper than normal into dry soil generally has not improved establishment. Sowing at standard or shallower depths will result in the best establishment rates.

Introduction

Soil water content is an important factor in the decision to sow, but often the question is how wet should the soil be before germination and emergence are assured. Understanding how water is held and released for plant growth in different soils can help explain the effects of rainfall on germination and emergence and how it varies with soil type. The information on this article is drawn mainly from pot and field trials conducted over the last two years that examined the influence of soil moisture on emergence and yield in canola and wheat.

Soil water basics

Not all soil water is equally available; its availability (or how tightly it is held by the soil) varies with soil moisture content and soil texture. Water is held within the pores of the soil and how tightly it is held depends on the size of the pore. As the pore size gets smaller, the water is held more tightly and is less available. Soils have a range of pore sizes, and as soil dries, a higher proportion of the water is held in small pores, meaning water is more tightly held by the soil and less available to plants. The major influence on pore size distribution is soil texture; whether the soil is sandy, a loam or a clay, and how compacted the soil is.

The measure of how tightly water is held within the soil is termed the ‘matric potential’ which has units of pressure (mega Pascals (MPa)). Matric potential is a negative number, and as the soil dries and the availability of water in the soil for plant growth declines, the matric potential becomes more negative. The matric potential of a saturated soil is close to 0 MPa, at field capacity the matric potential is -0.03 MPa and at permanent wilting -1.5 MPa. The laws of physics mean that water will flow down a water potential gradient, that is from a less negative matric potential (e.g. -0.1 MPa) to a more negative number (e.g. -0.5 MPa), which is the same principle that explains why water flows downhill.

The relationship between the soil water content and how available the soil water (the matric potential) is described by the water release curve. Examples of these curves for different soils in the lower and Mid North are shown in Figure 1. The water that is available for plant growth is defined by the moisture contents between the field capacity and the permanent wilting point. Some points to note are:

- Sandy soils require very little moisture to wet up to the available range, however, they cannot store a lot of moisture.
- As the clay content increases, the soil water content needs to be higher, hence more rainfall is required to wet it up to the available range.
- The red and black soils from Giles Corner, which commonly occur together, show different moisture release curves. As a result, the black soil needs a soil moisture content about 50% higher than the red soil to wet it up above the permanent wilting point.
- The two soils from Bute are representative of soils from a dune and swale. The very different water release curves means that germination and emergence will be slower and may be lower in the swale under low rainfall.

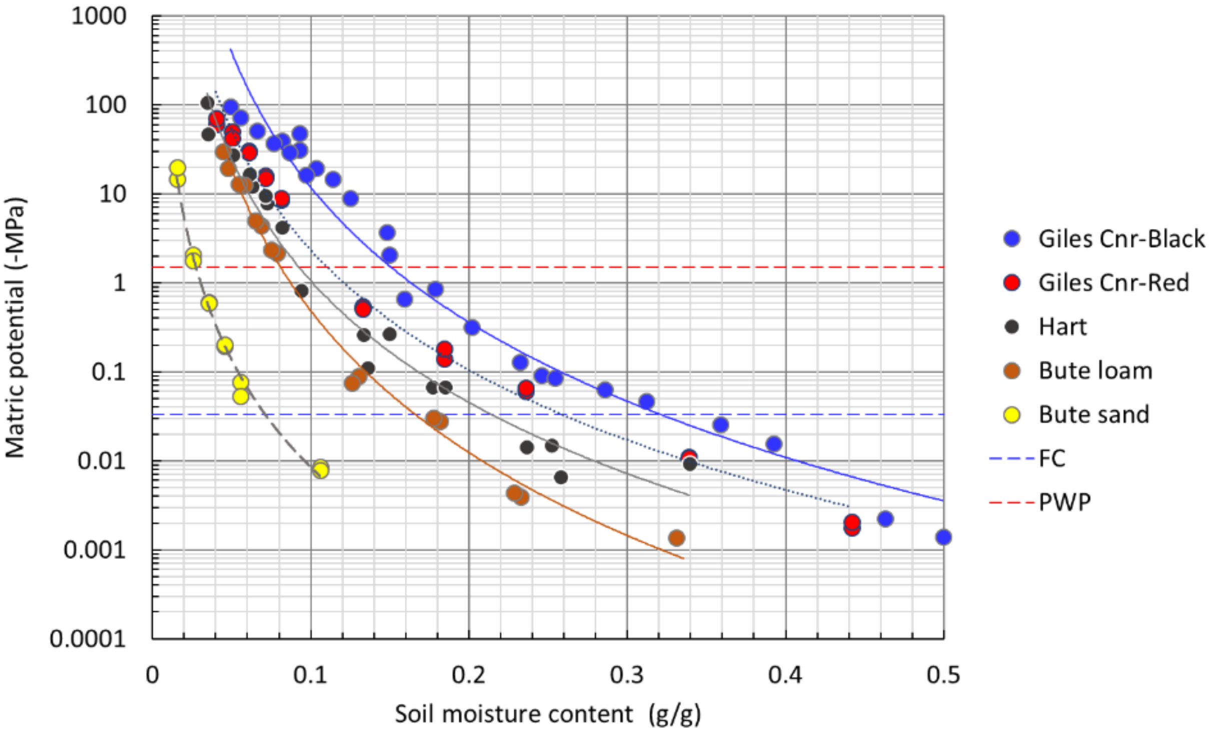


Figure 1. Soil water release curves for five soils with different textures. The field capacity (FC) and permanent wilting point (PWP) values are shown by the horizontal lines.

Can germination start in a dry soil?

Plants become stressed as the soil water content dries to permanent wilting point and plants can die from prolonged periods of very dry soil. Seeds are different; germination can occur even in soils close to the permanent wilting point (Figure 2). There are two reasons why this can occur:

- Dry seed has a very low water potential. A dry seed may have a water potential of -100 MPa while a soil at permanent wilting has a higher water potential (-1.5 MPa). Therefore, water will naturally move from the soil to the seed, even at permanent wilting point. This will occur even if the seed is dead.
- Seeds can absorb water as water vapour in the soil. In a very dry soil, for example: at permanent wilting, the relative humidity is close to 100% and dry seed can absorb water from the soil atmosphere even if it is not in direct contact with moisture.

Figure 2. Seed of Scepter wheat after three weeks in soil close to permanent wilting (top) compared to dry, unsown seed (bottom). The seed in soil has imbibed water, germination has started and the embryo has started to grow.

How does soil moisture affect germination and emergence?

The trigger for germination is the absorption of water by the dry seed, also called imbibition. As the seed absorbs water it goes through three distinct phases related to its seed moisture content (Figure 3).

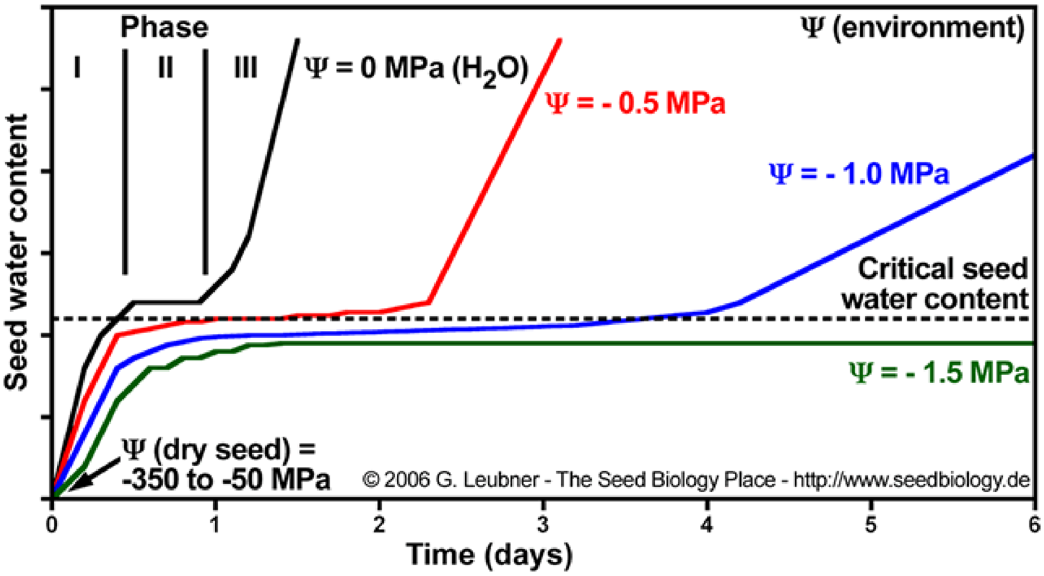


Figure 3. The uptake of water by a germinating seed. The three phases of water uptake are shown for a seed when water is not a limitation (black line, water potential = 0 MPa). As the soil becomes drier (red and blue lines, water potentials = -0.5 MPa and -1.0M Pa respectively) the rate of initial water uptake (Phase I) slows and the duration of Phase II increases delaying the growth of the root and shoot (Phase III). In dry soil (green line at the PWP, -1.5 MPa) the critical moisture content to allow complete germination and seedling growth is not reached.

Phase I is the rapid influx of water during imbibition. This occurs spontaneously in seeds even under very dry conditions. Water uptake slows when an equilibrium is reached.

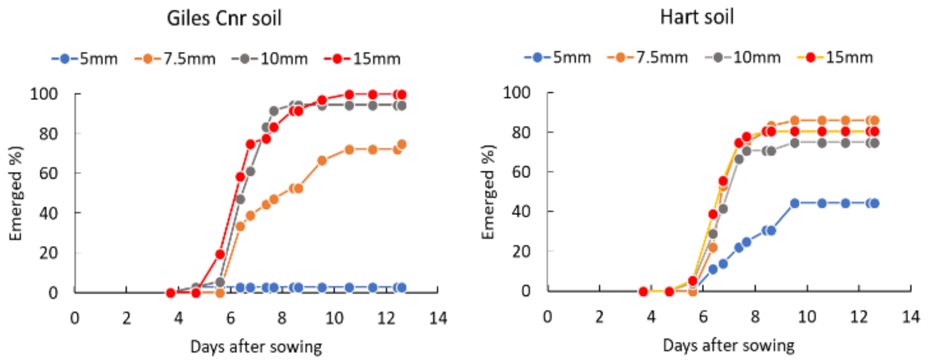
Phase II is the 'activation phase' when germination starts. The rehydration of the seed activates the enzymes that break down the seed food reserves, and the embryo starts to grow. The seed needs to reach a certain moisture content: the critical moisture content, for this to occur.

Phase III commences when the embryo in the seed expands and ruptures the seed coat causing uptake of water. During this phase the young root and shoot are clearly visible.

When seed is sown into dry soil, water is absorbed slowly and germination starts. Under these conditions, the length of Phase II is increased and the start of Phase III is delayed. In some circumstances the germinated seed remains in the soil swollen but the young root and shoot fail to grow (Figure 2).

Differences in soil moisture are reflected in the rates of emergence of seed from soil at different moisture contents (Figure 4). In drier soils, the time when emergence starts is delayed, the rate of emergence is slowed and the final emergence (%) can be reduced. Emergence may be staggered, with seedlings continuing to emerge 2-3 weeks after sowing. Soil texture has a large influence because it affects how tightly water is held by the soil particles. Compared to sandy soil, loams and clay loam soils require more rainfall to wet the soil up to the available range and low rainfall can have a larger effect on emergence from heavier textured soils. For example, when an equivalent of 5 mm of water was applied emergence failed in the heavy textured soil from Giles Corner in both canola and wheat whereas emergence occurred at Hart.

(a) Canola



(b) Wheat

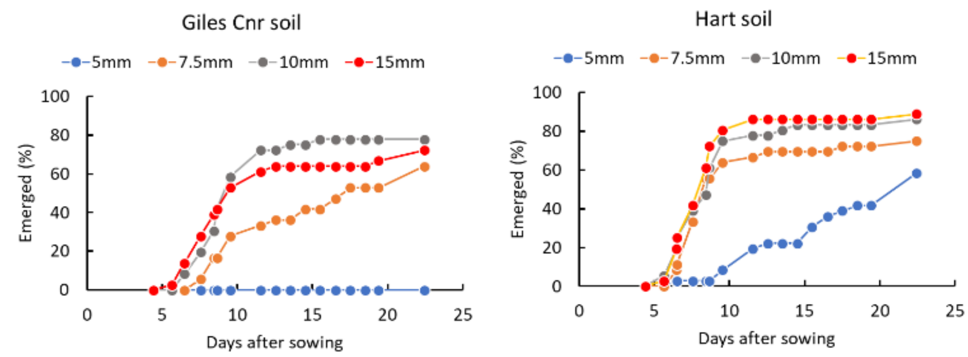


Figure 4. Results of a pot experiment showing emergence of (a) hybrid canola (Enforcer CT) and (b) wheat (Scepter) from two soils after different amounts of water were applied at sowing. The soil was from the surface 10 cm at each site. Soil from Giles Corner was a grey medium clay and the soil from Hart was a loam. In all cases evaporation from the soil was prevented to maintain a constant soil moisture content during germination. In the field higher rainfall would be required because of losses from soil evaporation.

How long can seed remain viable in dry soil?

We have seen that even in a dry soil, seed can absorb moisture from the soil, albeit very slowly, and cause germination to commence.

How long can seed remain in soil without affecting its viability? Experiments with canola and wheat found that seed can remain in dry soil for six weeks without significantly affecting emergence once the soil was watered (Table 1). In canola, there was an indication that emergence may have been enhanced when seed was in dry soil for two weeks.

In wheat more than 80% seed germination was measured for seed kept in dry soil for up to six weeks, however when seed remained in dry soil for four or six weeks a higher proportion of the germinated seed had not emerged after 2-3 weeks. Failure to emerge is not just related to seed gemination because the growth of the seedling through the soil before it emerges is also affected by soil moisture. Seeds may germinate but fail to emerge.

Table 1. The effect of length of time in dry soil on emergence (%) after watering in canola and wheat. The values are the averages across three soils. In wheat, seeds that did not emerge were recovered and classified as germinated but not emerged or not germinated.

	Time in dry soil (weeks)					
	0	**1**	**2**	**4**	**6**	Significance
			Canola			
Emerged	84^{ab}	75^{a}	90^{b}	71^{a}	79^{ab}	P=0.035
			Wheat			
Emerged	73	72	72	72	68	NS
Germinated, not emerged	13^{a}	13^{a}	10^{a}	16^{ab}	25^{b}	P=0.045
Not germinated	14	15	18	13	8	NS

How much rainfall is required for emergence?

If the soil is dry, pot experiments suggest 15-20 mm of rainfall is required to achieve maximum emergence in loam and clay loam soils. Little to no emergence would be expected if rainfall is less than 10 mm.

In sandier soils published data suggests approximately 10 mm may be sufficient for crops to emerge. Seed can germinate at lower soil moisture levels but may not emerge. An example is shown in Table 2 for hybrid canola.

Maximum establishment occurred with 15-20 mm, however all seed had germinated with as little as 7.5 mm of rainfall but had not emerged.

Table 2. The response in germination and establishment in hybrid canola to different rainfall equivalents in a loam soil from Hart. Seed was sown at 20 mm depth and was recovered 21 days after sowing.

Rainfall equivalent (mm)	Emerged	Germinated, not emerged	Not visibly germinated
		(%)	
5.0	0	43	57
7.5	0	93	7
10.0	3	97	0
12.5	37	63	0
15.0	67	33	0
20.0	63	33	0

Results from field experiments over two seasons illustrate the effect of soil type on soil water accumulation in the seedbed after rain (Figure 5). The loam at Hart was quicker to wet up and reached field capacity with less rainfall than the heavier soil at Giles Corner. At Hart 20 mm was required to reach the maximum soil water content whereas at Giles Corner 35 mm was required (Figure 5a). At Hart 15-20 mm of rainfall wet the soil up to field capacity whereas at Giles Corner there was insufficient rain received over the last two seasons to wet the soil completely to field capacity (Figure 5b).

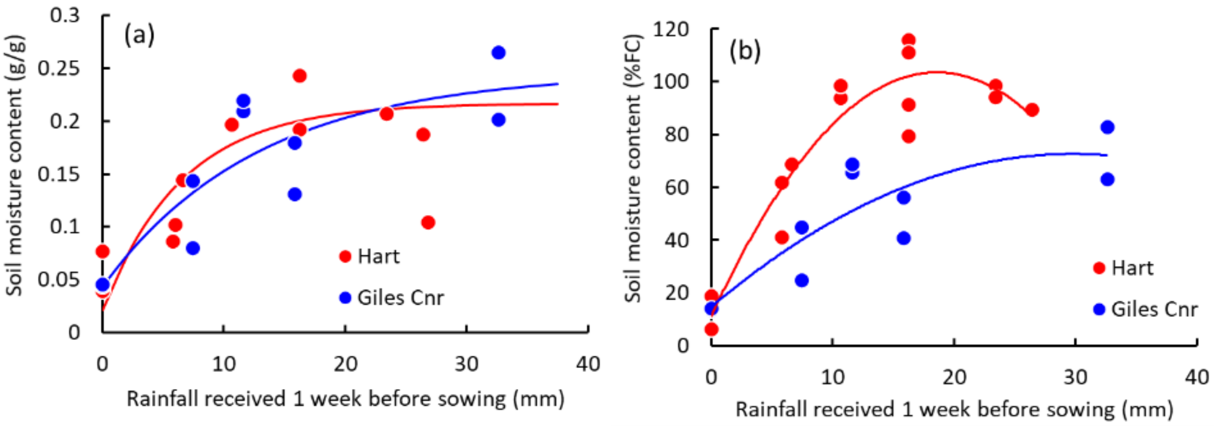


Figure 5. The relationship between soil moisture content in the surface 10 cm and rainfall received immediately prior to sowing from field experiments at two sites in 2023 and 2024. The soil at Hart is a loam and at Giles Corner a clay loam.

How important is sowing depth?

Unless it improves access to soil moisture, sowing deeply into dry soil will generally not improve establishment. Rainfall needs to infiltrate to the depth where the seed has been placed to allow seed to germinate quickly and for the seedling to grow through the soil to emerge. The rate of infiltration and the depth of initiation after rain are also influenced by soil texture: infiltration is more rapid with sandier soils and slower with heavier-textured soils. In a preliminary experiment using a column of surface soil from Hart, adding water equivalent to 5 mm rainfall resulted in water infiltrating to a maximum depth of 24 mm, while applying 15 mm resulted in infiltration to 71 mm. Additional water would be required when evaporative losses from soil are considered.

A field trial conducted in 2021 with OP and hybrid canola from the Victorian mallee demonstrated the penalty that can occur with deep sowing under low rainfall when there is no moisture at depth (Figure 6). There was little difference in emergence between sowing at 10 mm or 20 mm, however both were superior to a 35 mm sowing depth. Emergence of the OP variety Stingray occurred about 30 days after planting when approximately 10 mm of rainfall had been received but shallower sowing allowed emergence to occur after a smaller amount of rainfall. Emergence was earlier and occurred with less rainfall in the hybrid variety.

The observation that final establishment was high after the seed had been in dry soil for 29 days again shows that seed can survive dry conditions for long periods without greatly reducing seed viability.

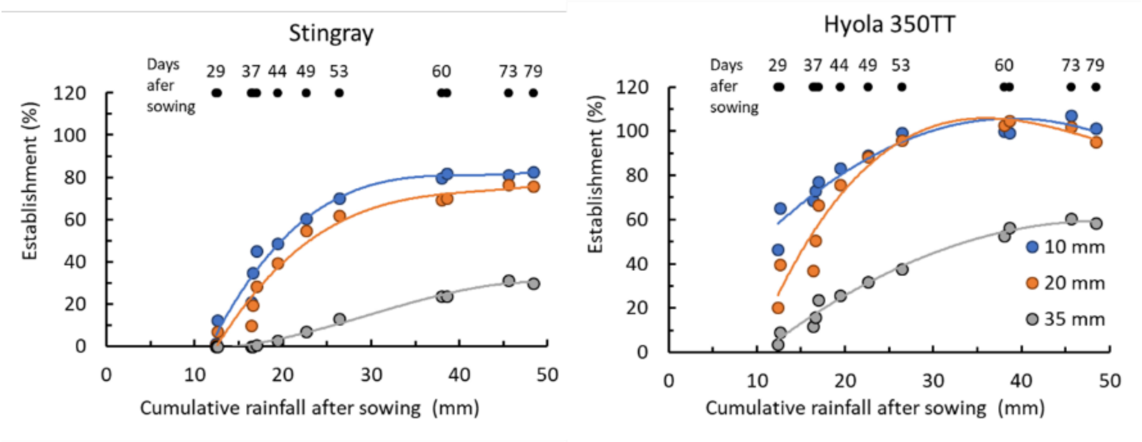


Figure 6. The responses to sowing depth in dry-sown Stingray (OP canola variety) and Hyola 350TT (hybrid canola). The experiment was conducted on a sandy-clay loam at a sowing rate of 50 seeds/m^2 and sown on April 19.

Surface structure

Emergence can also be restricted by physical barriers in the soil and high bulk density. Observations from the pot trials highlighted the importance of surface structure to emergence after low rainfall. In soils that are prone to slaking and dispersion, a hard crust can form as the surface dries after wetting. This can sometimes create a barrier to seedling emergence, which may already be slowed by the dry soil, causing further reductions in emergence. Maintaining good surface structure and minimising the potential to develop surface crusts are also strategies that can enhance emergence under dry conductions.

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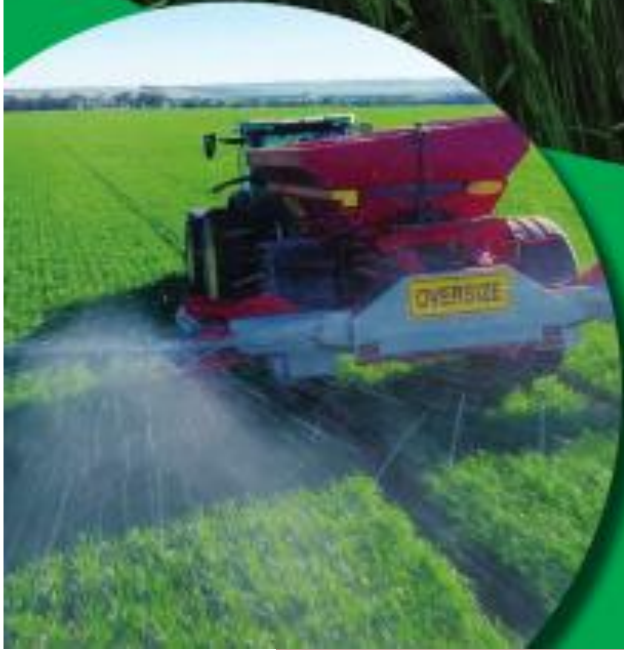
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