CORROWA NSW
FRIDAY 16
FEBRUARY 2024

GRAINS RESEARCH UPDATE

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GRDC 2024 Grains Research Update Welcome

Welcome to our summer series of northern GRDC Grains Research Updates for 2024.

We are pleased to bring growers and advisers another series of Grains Research Update events tailored to deliver the latest research, development and extension (RD&E) to enhance the profitability and reliance of grain production.

The past year has continued to present unique challenges and opportunities, building on our experiences from 2023 where we faced below-average rainfall in parts of Queensland and northern New South Wales and close to average rainfall in southern NSW. To date, we have seen higher than expected December and January rainfall in many regions despite an initial dryer than average outlook.

These conditions highlight the importance of our ongoing RD&E efforts in developing resilient and flexible farming practices, allowing growers to adapt to the diverse weather and climate changes we see in our region.

Sustainability within the profitable farming systems framework continues to be front of mind for our sector and an important consideration when it comes to future market access, government policy and community expectations. One quarter of GRDC's current RD&E investment portfolio has been identified as having direct environmental outcomes, with a significant portion contributing indirect environmental research outcomes. GRDC's Sustainability Initiative articulates our focus on emerging interests in sustaining and improving our soil resource and working to better understand and manage greenhouse gas emissions. We look forward to sharing further results from these investments at future Grains Research Updates.

2023 was a significant year for GRDC. After extensive consultation with growers and the grains industry we announced our RD&E 2023-28 plan and a commitment to invest more than a billion dollars in research, development and extension to deliver improved outcomes for Australian grain growers.

Across our regions, this strategic investment involves addressing critical concerns highlighted by growers and advisers through the National Grower Network (NGN) and RiskWi$e forums.

In the northern region, GRDC and NSW DPI have entered a strategic partnership *Unlocking Soil Potential* aimed at developing novel products to capture, store and use more soil water in grain production. Other major strategic investments include the National Risk Management Initiative, known as *RiskWi$e*, and work designed to quantify the response of deep phosphorus placement and means of improving phosphorus use efficiency, farming systems research comparing and improving crop sequence gross margins and of course our ongoing, extensive and well known National Variety Testing program.

These represent just a few of the investments designed to ensure the most pressing profitability and productivity questions are addressed from paddock to plate. GRDC places a high level of importance on grower and adviser engagement and we encourage you to look for opportunities to participate in regional NGN forums that capture insights for future RD&E.

While we're pleased to be able to facilitate plenty of face-to-face networking opportunities across this Updates series, we have also committed to continuing to livestream and record the main events for anyone who is unable to attend in person.

For more than a quarter of a century GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of our grains industry.

Sharing the results from this research is a key role of the annual GRDC Updates, which bring together some of Australia's leading grains research scientists and expert consultants. We trust they will help guide your on-farm decisions this season and into the future.

We would like to take this opportunity to thank our many research partners who have gone above and beyond this season to extend the significant outcomes their work has achieved for growers and advisers.

If you have concerns, questions or feedback please contact our team directly (details on the back of these proceedings) or email northern@grdc.com.au. Please enjoy the Update and we look forward to seeing you again next year.

Gillian Meppem
Senior Regional Manager – North

COROWA
GRDC Grains Research Update
Friday 16 February 2024

Corowa RSL, 30 Betterment Parade, Corowa NSW 2646
Registration: 8:30 AM for a 9:00 AM start, finish 2:50 PM

AGENDA

Time	Topic	Speaker(s)
9:00 AM	**GRDC welcome**	*GRDC*
9:10 AM	**Resistance management strategies for glyphosate resistant weeds, finessing pre-em herbicides and getting the early post-em space right**	*Chris Preston (Uni of Adelaide)*
9:50 AM	**Slugs - why did they appear in 2023 and are they likely to persist?** How do new slug products perform in wet conditions & on other establishment pests and how do you determine when it's economic to treat?	*Michael Nash (What Bugs You)*
10:30 AM	**MORNING TEA**	
11:00 AM	**Reducing losses from crown rot - Victrato® performance and stewardship and strategies to reduce inoculum load**	*Steven Simpfendorfer (NSW DPI)*
11:35 AM	**Drones for aerial weed mapping to drive spot spraying in fallow using conventional spray equipment and other uses**	*Tristan Steventon (Stevtech) & Ben Single (Single Shot)*
12:20 PM	**LUNCH**	
1:10 PM	**Farming systems, nitrogen and pulse crops**	*John Kirkegaard (CSIRO) & Mat Dunn (NSW DPI)*
2:05 PM	**Revisiting the economics of dual purpose crops under current meat and wool prices**	*John Francis (Agrista Pty Ltd)*
2:50 PM	**CLOSE**	

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Resistance management strategies for glyphosate resistant weeds, finessing pre-emergent herbicides, and getting the early post-emergent space right

Christopher Preston[1], Jenna Malone[1], Patricia Adu-Yeboah[1], Michael Widderick[2], Navneet Aggarwal[3]

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Key words

glyphosate resistance, pre-emergent herbicides, double knock

GRDC code

UOA2007-007RTX

Take home message

- Glyphosate resistance is increasing in incidence in Australia in both summer growing and winter growing weeds
- Management strategies that do not include glyphosate can be better than the double knock in managing glyphosate resistant populations
- Choosing the right pre-emergent herbicide strategy for the situation improves annual ryegrass control.

Glyphosate resistance

Recent weed resistance surveys are indicating an increase in glyphosate resistant weeds. This includes annual ryegrass, as well as summer growing weed species (Table 1). While the double knock has been the main management tactic for glyphosate resistant weeds it has sometimes been difficult to institute and other tactics, such as glyphosate mixtures, have been used instead. Management is further complicated by the evolution of paraquat resistance in both annual ryegrass and flaxleaf fleabane.

Table 1. Extent of resistance to glyphosate in various weed species collected in a random survey of cropping fields across Australia in 2020/2021. Samples were considered resistant if more than 20% of the individuals survived herbicide treatment. Annual ryegrass and common sowthistle were collected across Australia, while the other species were only collected in northern NSW and Queensland.

Weed species	Samples tested	Resistance to glyphosate (% of samples)
Annual ryegrass	1354	19
Common sowthistle	517	0.2
Flaxleaf fleabane	104	59
Feathertop Rhodes grass	128	97
Awnless barnyard grass	75	28
Sweet summer grass	26	58

The mechanism of resistance to glyphosate may also influence the results of management strategies. There are three main mechanisms of glyphosate resistance that have been identified in weeds in

Australia: target site mutations; reduced glyphosate translocation through vacuolar sequestration; and gene amplification. Recently, it was found that applying glyphosate to glyphosate resistant barley grass increased the level of glyphosate resistance through increasing the number of copies of the EPSPS gene in the plants (Figure 1).

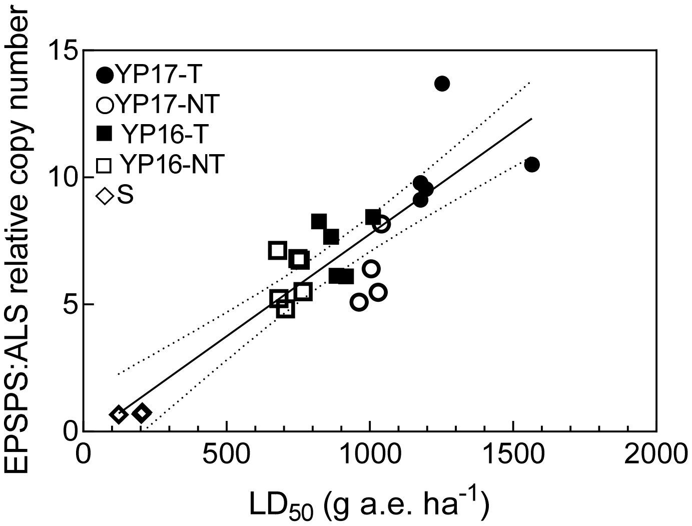

Figure 1. Increase of LD_{50} and EPSPS gene copy number in the progeny of glyphosate-resistant barley grass clones from 2 populations treated or not treated with glyphosate. Individual plants were divided into 2 clones. One clone from each individual was treated with 405 g ha^{-1} glyphosate and the other clone was untreated. Seed was collected from each clone. The LD_{50} was calculated from a dose response of progeny from each clone. The copy number of EPSPS for each set of progeny was determined by qPCR. Open symbols are progeny from clones not treated with glyphosate and closed symbols are progeny of clones treated with glyphosate.

This result suggests that management strategies using glyphosate will result in higher levels of resistance in weeds with the gene amplification mechanism. Other weeds with this resistance mechanism are windmill grass and brome grass. Flaxleaf fleabane, feathertop Rhodes grass, common sowthistle, barnyard grass and annual ryegrass all have populations with target site resistance and are likely to respond differently. Most glyphosate-resistant annual ryegrass plants have reduced translocation of glyphosate.

Managing glyphosate resistant weed populations

Experiments have been established exploring different management strategies on populations of glyphosate resistant weeds. Preliminary results for common sowthistle (Table 2) and feathertop Rhodes grass (Table 3) show that double knocks are better than using glyphosate alone; however, using herbicides other than glyphosate is better at keeping glyphosate resistant populations low. For barley grass, a double knock is better than glyphosate mixtures with Group 14 herbicides.

Table 2. Survival (%) of two glyphosate-resistant common sowthistle populations after herbicide treatment in the second year of the trial at Hermitage Research Facility, Warwick QLD. Populations containing 30% resistant individuals were sown and treated over 2 consecutive seasons with the same herbicide strategies.
fb = followed by.

Herbicide strategy	**Survival (%)**	
	ST white	**ST yellow**
Double knock alternative – 2,4-D fb paraquat + diquat (Spray.Seed®)	1.1	0
Double knock – glyphosate fb paraquat + diquat (Spray.Seed®)	0.1	0.6
Single knock – glyphosate applied morning	8	7
Single knock – glyphosate applied midday	20	13
Residual herbicide – Balance®	0	0

Table 3. Survival of feathertop Rhodes grass with different mutations in EPSPS after herbicide treatment in the second year of the trial at Hermitage Research Facility QLD. Populations containing 30% resistant individuals were sown and treated over 2 consecutive seasons with the same herbicide strategies. fb = followed by.

Herbicide strategy	**Mutation**		
	Pro 196 Leu	**Pro 196 Ser**	**Pro 196 Thr**
Double knock alternative – haloxyfop fb paraquat	16	55	0
Double knock – glyphosate fb paraquat	92	59	51
Single knock – glyphosate	80	54	71
Residual herbicide – s-metolachlor (Dual Gold®)	0	0	0

A challenge for the management of glyphosate and paraquat resistant annual ryegrass is that neither herbicide in the double knock will be effective on its own. An alternative approach to manage glyphosate resistant annual ryegrass when the seasonal conditions are appropriate is to dry sow and use pre-emergent herbicides and crop competition. However, with dry sowing it is important to choose the pre-emergent herbicides wisely. For dry sowing, more persistent herbicides are better than using less persistent herbicides, such as s-metolachlor + prosulfocarb (Boxer Gold®) (Table 4). Including an early post-emergent application of s-metolachlor + prosulfocarb (Boxer Gold), prosulfocarb (Arcade®) or aclonifen+diflufenican+pyroxasulfone (Mateno® Complete) can provide better control of annual ryegrass and provide insurance against poor control of weeds by pre-emergent herbicides due to seasonal conditions (Table 4).

Table 4. Annual ryegrass control in a dry sown wheat trial at Concordia, SA in 2023. Weed counts were made 49 days after sowing. fb = followed by, early post-emergent herbicide products applied 21 days after sowing.

Herbicide active(s)	**Trade name**	**Formulation(s)**	**Rate(s)**	**Annual ryegrass (plants m^{-2})**
Nil	Nil			76.8 a
Trifluralin	TriflurX®	480 g/L	2 L/ha	24.9 b
Pyroxasulfone	Sakura® Flow	480 g/L	210 mL/ha	13.2 bc
Prosulfocarb + S-metolachlor	Boxer Gold	800 g/L + 120 g/L	2.5 L/ha	37.6 ab
Cinmethylin	Luximax®	750 g/L	0.5 L/ha	15.2 bc
Aclonifen+ Pyroxasulfone+ Diflufenican	Mateno Complete	400 g/L 100 g/L 66 g/L	0.75 L/ha	24.0 b
Aclonifen+ Pyroxasulfone+ Diflufenican	Mateno Complete	400 g/L 100 g/L 66 g/L	1 L/ha	15.2 bc
Bixlozone	Overwatch®	400 g/L	1.25 L/ha	14.2 bc
Trifluralin fb (Aclonifen+ Pyroxasulfone+ Diflufenican)	TriflurX fb Mateno Complete	480 g/L fb (400 g/L 100 g/L 66 g/L)	2 L/ha fb 0.75 L/ha	14.7 bc
Trifluralin fb (Aclonifen+ Pyroxasulfone+ Diflufenican)	TriflurX fb Mateno Complete	480 g/L fb (400 g/L 100 g/L 66 g/L)	2 L/ha fb 1 L/ha	6.8 bc
Bixlozone fb (Aclonifen+ Pyroxasulfone+ Diflufenican)	Overwatch fb Mateno Complete	400 g/L fb (400 g/L 100 g/L 66 g/L)	1.25 L/ha fb 1 L/ha	0.5 c
Trifluralin fb (Prosulfocarb + S-metolachlor)	TriflurX fb Boxer Gold	480 g/L fb (800 g/L + 120 g/L)	2 L/ha fb 3 L/ha	8.3 bc
	P			0.0004

Getting better control of annual ryegrass with pre-emergent and early post-emergent herbicides

There are four main causes for pre-emergent herbicides to fail to control weeds: herbicide resistance in weeds; too little herbicide persistence; too much rainfall that moves the herbicide below the weed root zone; or too little rainfall to properly activate the herbicide.

There is relatively little resistance to pre-emergent herbicides present in NSW, with some resistance to trifluralin, prosulfocarb and s-metolachlor + prosulfocarb (Boxer Gold) in annual ryegrass. If resistance to these herbicides is known to be present, alternative products should be chosen.

Too little persistence is a problem for products such as s-metolachlor + prosulfocarb (Boxer Gold), prosulfocarb (Arcade®) and metazachlor (Tenet®), where the efficacy of the herbicide declines rapidly after application. This allows later emerging weeds to avoid the herbicide. This is also more likely to be a problem in higher rainfall zones or in longer seasons. The solution is to use longer persistence products and mixtures of pre-emergent herbicides.

Loss of herbicide out of the root zone of the germinating weeds mostly occurs with the more soluble herbicides, such as metazachlor (Tenet®) and cinmethylin (Luximax) and generally on lighter soil types. However, this can be a problem for many herbicides with sufficient rainfall. In higher rainfall regions, using herbicides with lower water solubility will manage this problem.

Too little rainfall after application of the herbicide is normally a problem for the less soluble products, such as pyroxasulfone (Sakura), propyzamide and aclonifen+diflufenican+pyroxasulfone (Mateno® Complete). This typically occurs where there has been good rainfall prior to application of the herbicide that causes annual ryegrass to germinate. Without sufficient follow-up rainfall after herbicide application, the herbicides are not activated in time to control the weeds. Mixtures with herbicides that have different properties can overcome this problem. Useful mixtures have been pyroxasulfone (Sakura) plus tri-allate (Avadex® Xtra) and pyroxasulfone (Sakura) plus trifluralin.

An early post-emergent application of s-metolachlor + prosulfocarb (Boxer Gold), prosulfocarb (Arcade) or aclonifen+diflufenican+pyroxasulfone (Mateno® Complete)can be used in combination with the pre-emergent herbicide to manage the potential issues with pre-emergent herbicides. All of these herbicides require rainfall after application to activate them. S-metolachlor + prosulfocarb (Boxer Gold)is the most water-soluble product, requiring the least amount of rainfall, followed by prosulfocarb (Arcade), whereas aclonifen+diflufenican+pyroxasulfone (Mateno® Complete)is much less water soluble. S-metolachlor + prosulfocarb (Boxer Gold)and prosulfocarb (Arcade) are best applied when annual ryegrass is at the 1 to 2-leaf stage. Aclonifen+diflufenican+pyroxasulfone (Mateno® Complete), because of the higher rainfall requirement, is best applied as a strategic application rather than for salvage and at the 2-leaf stage of the crop, preferably before additional annual ryegrass has emerged. Aclonifen+diflufenican+pyroxasulfone (Mateno® Complete) will control new emergence of annual ryegrass after rainfall has occurred but will not control larger annual ryegrass plants.

Acknowledgements

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

The trial at Gawler was funded by the South Australian Drought Resilience Adoption and Innovation Hub funded by the Department of Agriculture, Fisheries and Forestry through the Future Drought Fund. The trial was conducted in collaboration with Elders.

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Herbicide resistance status of weed species across the cropping regions of New South Wales and Queensland

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Key words

herbicide resistance, ryegrass, wild oats, sowthistle

GRDC code

UCS2008-001

Take home message

- Resistance to post-emergence herbicides including glyphosate is widespread in the northern grain cropping region with the greatest frequency in southern NSW
- Resistance in ryegrass was only recorded to two pre-emergent herbicides (trifluralin and prosulfocarb + S-metolachlor) and at lower frequency than resistance in ryegrass collected from other Australian states
- Wild oat resistance is more common in NSW and Qld than in populations from other states
- Widespread sulfonylurea resistance was identified in sowthistle populations

Background

Herbicide resistance surveys have been conducted across the Australian grain cropping region for many years with the initial surveys in WA, NSW and Vic conducted to determine the extent of resistance in annual ryegrass in the early 1990's (Gill 1993; Pratley *et al.,* 1995; Henskens 1997). Subsequently surveys were conducted to determine the level of resistance in wild oats (Pratley *et al.,* 1996; Nietschke 1997). Since then, surveys have been conducted across many sections of the cropping regions at regular intervals looking at many different weed species (Llewellyn and Powles 2001; Walsh *et al.,* 2001; Owen *et al.,* 2007; Broster *et al.,* 2011, 2012; Boutsalis *et al.,* 2014; Owen *et al.,* 2014, 2015a, 2015b). However, it was not until 2016 that every region of the Australian cropping region had been surveyed at least once (Broster *et al.,* 2018).

While all the cropping regions had been surveyed by 2020 each of the organisations undertaking the surveys had used different methods for sample collection, preparation, chemical application, assessment and reporting. In some states, parts of the state were surveyed and screened each year, while in others the entire state was surveyed in a single year with the resistance screening occurring in subsequent years.

The 2020 survey was the first national survey to use a consistent methodology across all these criteria for each species, to the extent that each individual species is screened for resistance at a single location, not at different locations.

This paper presents the results from the winter cropping weed samples obtained from NSW and Qld paddocks during the random field surveys for herbicide resistance conducted in 2020 and 2021 and compares them to the overall survey findings from across Australia.

Results

Samples collected Australia wide

Across Australia 3053 paddocks were visited during the most recent round of surveys, 2688 paddocks with winter crop and 465 (all in NSW or Qld) with summer crop or fallow (Figure 1). From these paddocks the following seed samples were collected; 1486 ryegrass, 677 wild oats, 272 barley grass, 383 brome grass, 581 sowthistle, 136 wild radish, 35 Indian hedge mustard, 124 fleabane, 144 feathertop Rhodes grass, 111 awnless barnyard grass and 27 sweet summer grass.

Samples collected NSW and Qld

From the 878 winter crop paddocks (33% of all winter crop paddocks across Australia) surveyed in NSW (634) and Qld (244) (Figure 1), 337 (23% of total samples) ryegrass samples were collected along with 345 (51%) wild oats, 55 (20%) barley grass, 34 (11%) brome grass, 387 (67%) sowthistle and 27 (20%) wild radish samples. As all of the summer cropping or fallow paddocks surveyed were from NSW or Qld, all of the feathertop Rhodes grass, awnless barnyard grass and sweet summer grass samples collected nationally came from these states. All but two populations of fleabane were from Qld and NSW with two collected from WA as part of their winter survey.

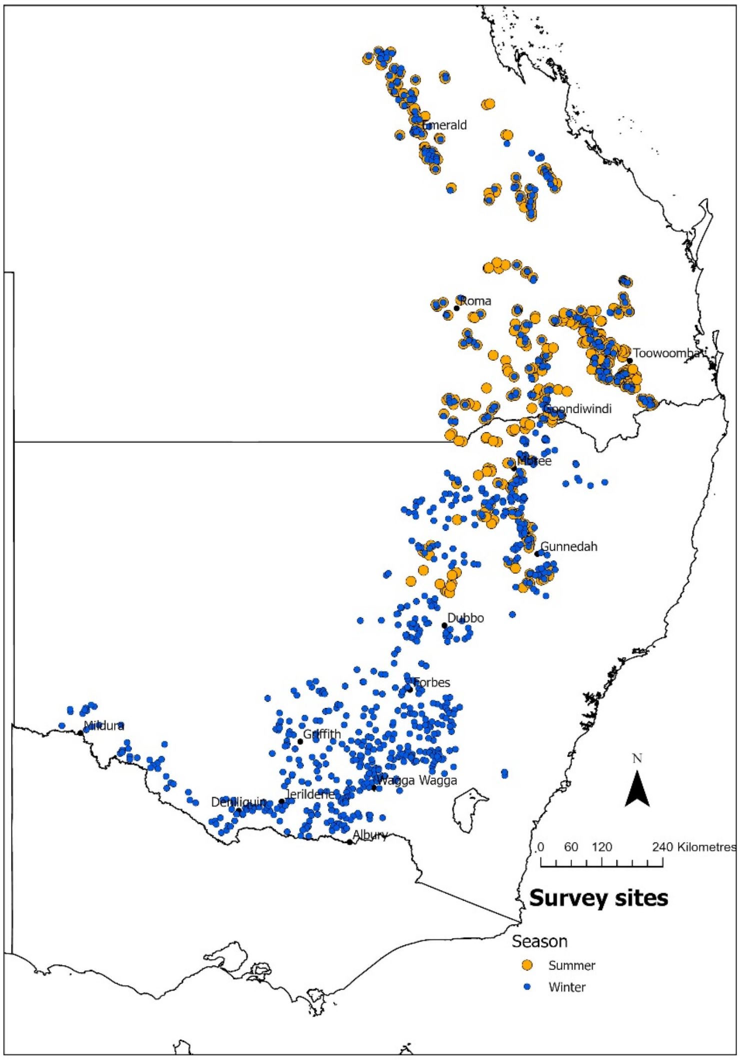

Figure 1. Winter and summer survey sites

Ryegrass

Ryegrass was only found in NSW paddocks with the majority of the samples collected south of Dubbo (southern NSW). Due to previous surveys across Australia finding that 90% plus of samples from most regions were resistant to Group 1 'fop' herbicides, this herbicide sub-group was not tested in samples collected during this survey. While the percentage of samples from southern NSW resistant to each of the post-emergent herbicides was similar to the overall survey findings, the extent of resistance for northern (north of Dubbo) NSW was lower for all herbicides (Table 1). Over 70% of samples from southern NSW were resistant to Group 1 'den' and Group 2 'SU' and 'Imi' herbicides compared with less than 50% from northern NSW. About 20% of southern NSW samples were resistant to clethodim (Group 1 'dim') and glyphosate (Group 9) compared with 10% for northern NSW (Table 1).

Resistance to the pre-emergent herbicides was much lower with resistance recorded for only trifluralin (Group 3) and prosulfocarb + S-metolachlor (Group 15) in southern NSW only, and at a lower level than the overall survey (Table 1).

Table 1. Percentage of ryegrass samples from NSW resistant (>20% survivors) to different herbicides compared with the overall survey.

Herbicide	Group	Northern NSW	Southern NSW	Australia (including NSW)
Clethodim	1 'dim'	6	19	23
Pinoxaden	1 'den'	26	79	71
Iodosulfuron	2 'SU'	44	91	91
Imazamox + Imazapyr	2 'Imi'	24	73	79
Glyphosate	9	14	24	16
Paraquat	22	0	0	0
Trifluralin	3	0	2	12
Prosulfocarb + S-metolachlor	15	0	1	2
Pyroxasulfone	15	0	0	0
Propyzamide	3	0	0	0
Cinmethylin	30	0	0	0
Bixlozone	13	0	0	0

Only 6% of the southern NSW ryegrass samples were susceptible to all herbicides, the same as for the overall survey, much lower than the 47% of northern NSW ryegrass samples susceptible to all herbicides (Figure 2).

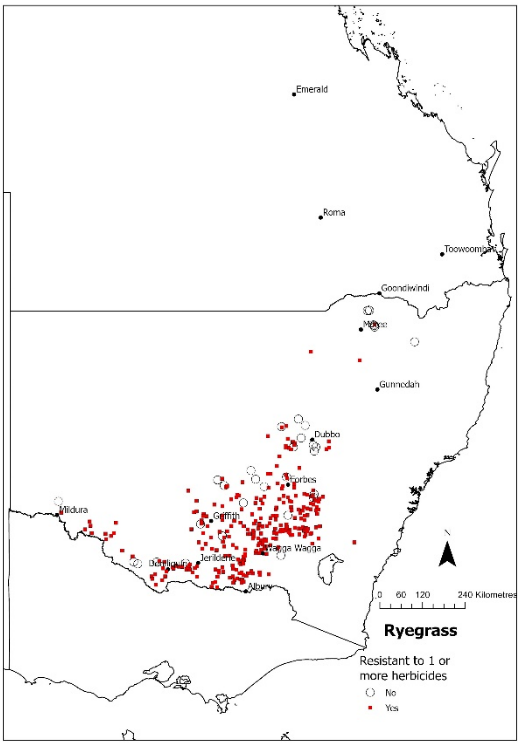

Figure 2. Ryegrass populations susceptible to all tested herbicides (open circles) or resistant to one or more herbicides (red/darker squares)

Wild oats

Wild oats were found evenly across the entire area surveyed in NSW and Qld and at a greater frequency than in the other states. Fifty percent of national wild oat samples were collected in NSW and Qld from only 33% of all winter crop paddocks visited.

The wild oat resistance to the Group 1 and 0 herbicides was higher in northern NSW than southern NSW, Qld and the overall survey (Table 2). For both southern NSW and Qld the level of resistance for these herbicide groups, while lower than in northern NSW, was also either higher, or similar, to the overall national survey. A significant percentage of the samples from all regions were classed as developing resistance, that is they had plants that survived the herbicide application but at less than 20% (Table 2).

No samples were considered to be resistant (i.e. greater than 20% survivors) to triallate but the seed from some 'developing resistance' populations that had surviving plants have been collected for re-testing to see if they survived due to resistance or other reasons.

Table 2. Percentage of wild oat samples from NSW and Qld resistant (>20% survivors) or developing resistance (in brackets; 5-20% surviving plants) to different herbicides compared with the overall survey.

Herbicide	Group	Northern NSW	Southern NSW	Queensland	Australia (including NSW & Qld)
Clodinafop	1 'fop'	27 (10)	25 (20)	21 (15)	16 (15)
Clethodim	1 'dim'	2 (0)	0 (3)	0 (3)	0 (1)
Pinoxaden	1 'den'	14 (8)	9 (22)	5 (14)	5 (12)
Mesosulfuron	2 'SU'	0 (9)	0 (10)	2 (3)	1(8)
Flamprop	0	11 (9)	6 (23)	8 (18)	7 (25)
Triallate	15	0 (25)	0 (19)	0 (16)	0 (15)

Thirty three percent of northern NSW wild oat samples were resistant to one or more herbicide groups compared with 29% of southern NSW and 26% of Qld samples (Figure 3). This is higher than the 20% for the overall survey.

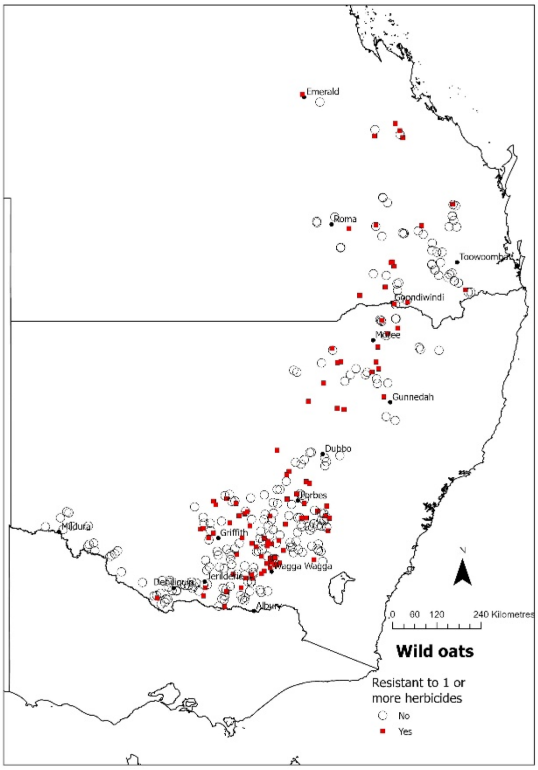

Figure 3. Wild oat populations susceptible to all tested herbicides (open circles) or resistant to one or more herbicides (red/darker squares)

Sowthistle

Sowthistle was collected in 387 paddocks across NSW and Qld with 111 of these populations collected during the summer survey from 465 paddocks. The highest incidence of resistance to the sulfonylurea herbicides was in southern NSW with 87% of samples confirmed resistant, compared with 75% in northern NSW, 67% in Qld, and 73% for the whole survey. However, 2,4-D resistance was highest in Qld at 8% of samples compared to 3% in NSW and Australia overall (Table 3). At 5% of populations when combined across the region, this is the first reported incidence of 2,4-D resistance in sowthistle from northern surveys. Of additional concern, a further 33% of populations were rated as developing resistance (1-19% survivors). In this survey no samples were found to be resistant to glyphosate, however a previous 2016-18 survey (Broster *et al.,* 2023) identified 8% glyphosate resistance across the northern region. Further investigations into this are on-going.

Table 3. Percentage of sowthistle samples from NSW and Qld resistant (>20% survivors) to different herbicides compared with the overall survey

Herbicide	**Group**	**Northern NSW**	**Southern NSW**	**Queensland**	**Australia (including NSW & Qld)**
Chlorsulfuron	2 'SU'	75	87	67	73
2,4-D amine	4	3	3	8	3
Glyphosate	9	0	0	0	0

Note: chlorsulfuron is not registered for control of sowthistle. Chlorsulfuron was included in this screen to check current resistance levels to SU herbicides.

Other species

A small number of other species (barley grass, brome grass and wild radish) were collected from NSW and Qld (wild radish only) during the survey.

All the barley grass and brome grass samples from NSW were susceptible to quizalofop, clethodim, glyphosate, imazamox + imazapyr and paraquat (barley grass only). While all barley grass samples were susceptible to sulfosulfuron, 27% of brome grass populations were resistant to that herbicide. For both paraquat and sulfosulfuron there was one barley grass population with some surviving plants (developing resistance) and three populations (7%) of brome grass were classed as developing resistance to sulfosulfuron.

No wild radish populations from NSW or Qld were resistant to diflufenican (Group 12) although populations from NSW were classed as developing resistance (4 out of 15). Populations from NSW were resistant to chlorsulfuron (5/16) and imazamox + imazapyr (3/14) and developing resistance to 2,4-D amine (6/21) and chlorsulfuron (1/16) while samples from Qld were resistant to 2,4-D amine (1/5) and imazamox + imazapyr (3/4) and developing resistance to 2,4-D amine (3/5) and chlorsulfuron (3/4). Due to limited seed, not all samples were tested to all herbicides.

Future work

Screening of some wild oat populations that required seed increase to have sufficient volume of seed for testing is continuing, as are investigations into glyphosate resistance in sowthistle. A number of wild oat populations with varying levels of survival to clodinafop are also being screened to haloxyfop to check on any similarities or differences in resistance status between Group 1 ‘fop’ herbicides.

References

Boutsalis P, Kleemann SGL, Gill GS, Preston C (2014) A hidden threat: widespread Group B herbicide resistance in brome across south-eastern Australia. In 'Proceedings of the 19th Australasian Weeds Conference' (Ed. M Baker) pp. 202-205. (Tasmanian Weed Society: Hobart, Tasmania, Australia).

Broster JC, Chambers AJ, Jalaludin A, Widderick MJ, Walsh MJ (2018) The extent of herbicide resistance in ryegrass and wild oats in New South Wales and Queensland. In 'Proceedings of the 21st Australasian Weeds Conference' (Eds SB Johnson, LA Weston, H Wu, BA Auld) pp. 145. (Weed Society of New South Wales: Sydney, NSW)

Broster J, Jalaludin A, Widderick M, Chambers A and Walsh M (2023) Herbicide Resistance in Summer Annual Weeds of Australia’s Northern Grains Region. Agronomy 13(7):1862.

Broster JC, Koetz EA, Wu H (2011) Herbicide resistance levels in annual ryegrass (*Lolium rigidum* Gaud.) in southern New South Wales. Plant Protection Quarterly 26, 22-28.

Broster JC, Koetz EA, Wu H (2012) Herbicide resistance frequencies in ryegrass (*Lolium* spp.) and other grass species in Tasmania. Plant Protection Quarterly 27, 36-42.

Gill GS (1993) Development of herbicide resistance in annual ryegrass in the cropping belt of Western Australia. In 'Proceedings of the 10th Australian and 14th Asian-Pacific Weeds Conference' pp. 282-285.Brisbane, Qld)

Henskens F (1997) Management of herbicide resistance in ryegrass and other weed species in cropping systems in south-eastern Australia. Project Final Report (DAV-266SR) (GRDC).

Llewellyn RS, Powles SB (2001) High levels of herbicide resistance in rigid ryegrass (*Lolium rigidum*) in the wheat belt of Western Australia. Weed Technology 15, 242-248.

Nietschke BS (1997) Integrated strategies for wild oat (*Avena* spp.) management in southern Australian farming systems. PhD thesis, University of Adelaide.

Owen, MJ, Martinez, NJ, Powles, SB (2014a) Multiple herbicide-resistant Lolium rigidum (annual ryegrass) now dominates across the Western Australian grain belt. Weed Research 54, 314-324.Owen MJ, Martinez NJ, Powles SB (2015a) Herbicide resistance in *Bromus* and *Hordeum* spp. in the Western Australian grain belt. Crop and Pasture Science 66, 466-473.

Owen MJ, Martinez NJ, Powles SB (2015b) Multiple herbicide-resistant wild radish (*Raphanus raphanistrum*) populations dominate Western Australian cropping fields. Crop and Pasture Science 66, 1079-1085.

Owen MJ, Walsh MJ, Llewellyn RS, Powles SB (2007) Widespread occurrence of multiple herbicide resistance in Western Australian annual ryegrass (*Lolium rigidum*) populations. Australian Journal of Agricultural Research 58, 711-718.

Pratley JE, Broster JC, Slater PD (1996) Herbicide resistance in wild oats in southern New South Wales. Project Final Report (UCS-8) (GRDC).

Pratley JE, Leys AR, Graham RJ, Baines PR, Kent JH (1995) The extent of herbicide resistance in annual ryegrass (*Lolium rigidum*) in southern New South Wales. Project Final Report (UCS-2F) (GRDC).

Walsh MJ, Duane RD, Powles SB (2001) High frequency of chlorsulfuron-resistant wild radish (*Raphanus raphanistrum*) populations across the Western Australian wheatbelt. Weed Technology 15, 199-203.

Acknowledgements

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

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Slugs – why did they appear in 2023 and are they likely to persist?

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Key words

canola establishment, crop protection, integrated pest management, slugs, molluscicide baits

GRDC code

DAS00127 & DAS00134, MAN2204_001SAX

Take home message

- To manage we must understand a pest's ecology
- Unlike insects, slugs do not have a set lifecycle, they breed when conditions are favorable: for example, during the recent triple La Nina event; and
- Dry spring conditions may have reduced slug breeding in 2023, however as slugs can live for two years, they are likely to still pose a risk in 2024.

Background

Research conducted supported by GRDC and industry indicates that the timing of bait applications is critical to protect emerging crops from slugs. Understanding when individual species are active, mating and breeding underpins successful management of slugs.

Slugs are hermaphrodites: both mating individuals can produce eggs that are laid in batches into moist soil. All slugs can delay breeding when conditions are dry, hence should be considered adaptive strategists. Although all slugs require moist environments to feed and breed, each have specific biology that determines when they are active, what time they breed, and when is the best time to apply baits to protect crops when they pose a threat.

The other factor to consider is that black keeled slugs can live for over five hundred days, with research indicating that they are capable of breeding in the second year of their life. The current recommendation is to be prepared to bait to protect emerging crops from slugs again next year. To support this, continuing GRDC investments aim to develop decision support tools to aid seasonal projections of likely slug risk.

Some key points from 2022 that enabled successful management of slugs in 2023

1. High soil moisture is the main predictor of high slug activity.
2. Wet winters extending into long cool springs, combined with bulky crops, provide ideal conditions for breeding.
3. Proactive management strategies gave the best results and return on investment. Long-term monitoring of slugs in spring is vital to provide information on population dynamics.
4. The use of a long-lasting slug and snail bait that is resistant to rainfall, attractive, palatable, and capable of being spread uniformly was found to be effective at protecting establishing crops.

Results and discussion

Large populations of slugs were observed up until harvest 2022. These observations highlighted the population's ability to increase numbers in wet spring conditions. Contrary to previous knowledge, black keeled slugs do breed late into spring (end of November) when conditions are favourable. Some learnings from an extremely high-pressure year (2023), as predicted from spring 2022 monitoring of slugs, snails, and spring weather conditions, are presented below.

1. Growers that did not order baits and have them on hand were often unable to source product in a timely manner, causing poor results.
2. A full moisture profile throughout summer and autumn led to slugs being active much earlier than other seasons, leading to some growers applying an early knockdown. However, due to high densities of slugs feeding, follow-up applications were required. Due to the high numbers, wet conditions and continued emergence of slugs from the soil long-lasting baits were found to be more effective than continual re-application of short-lasting baits.
3. A wave of black keeled slugs emerged in June, despite the absence of late autumn rain. Large numbers were already active from early April where there was a full moisture profile. This pattern suggests that black keeled slugs, like grey field slugs, exhibit an extended period of emergence from the soil over several months, with not all individuals in the population becoming active at the soil surface at the same time.
4. Many growers that waited to apply bait after sowing, or after the first application was consumed, had to resow some areas.
5. Monitoring bait remaining 1–2 days after the first application gave the best results.
6. Bait rate was the most crucial factor in 2023 for successful crop establishment; sufficient metaldehyde had to be applied in response to the large numbers of slugs observed actively feeding at the soil surface.
7. Baiting must be part of an integrated approach; rolling after sowing and before the first application of bait led to improved results.
8. Slugs can also damage lentils, faba beans and cereals, with an unprecedented amount of molluscicides applied to those crops in 2023.
9. Slugs were found damaging crops in regions and soil types not traditionally associated with slug damage: that is, on better quality soils away from creek lines in NSW and in new areas across the northern Wimmera of VIC.

Effective bait rate

With new molluscicide products continuing to being registered, choosing what to apply becomes increasingly challenging. Examples to add to the list (from Nash 2023):

- Sluggit Prima 30 Slug and Snail Bait (30 g/kg metaldehyde) #91239 3 kg/ha
- 4Farmers Iron Chelate Snail and Slug Bait (60 g/kg iron EDTA complex) #90221 5–16 kg/ha
- OCP™ eco-shield® Organic Snail & Slug Killer (10 g/kg iron powder) #90408 5–16 kg/ha
- MethioSHIELD™ Snail & Slug Bait (20 g/kg methiocarb) #92530 5.5 or 11-22 kg/ha

So, to revisit *What makes a good bait* (adapted from Nash 2022[c]), for baits to work, some basic principles are relied upon:

Individuals must first encounter a pellet, which requires:

- Individual activity – slugs must be actively searching for food.
- The number of baits to be distributed evenly – pellets/m^2. Pellets need to be evenly applied across the full width of application. Consistent pellet size, weight and density ensure no area is missed. Patchy control can occur when products with high variability in pellet weight are used and/or application equipment is not calibrated or able to spread the full width.
- Attractiveness of bait – individuals display non-random movement towards attractive pellets (true definition of bait). For example, grey field slugs are attracted to bran-based baits from 4 cm away, whereas modern products claim grey field slugs are attracted from 6 cm away.

Once individuals have encountered a bait, they must consume a lethal dose, which requires:

- Palatability – addition of feeding enhancers ensures individuals consume enough active ingredient to ingest a lethal dose. In the case of metaldehyde, which causes paralysis, consumption of a sub-lethal dose can be an issue with some products, because individuals cannot ingest enough to destroy their mucous cells.

- Enough bait for the target population – if product does not remain after a couple of days following application, it is usually due to large pest populations consuming it all. Re-application to those 'hot spots' will be required.
- Enough toxicant in the bait – the loading of active ingredient determines the amount consumed; hence low loadings require more total product to be applied. In wet conditions, small pellets with greater surface area to volume ratios lose more active ingredient, hence less toxicant will be consumed.

RATE & ATTRACTIVENESS ARE IMPORTANT, not just pellet points.

Some manufacturers have focused on producing small pellets in order to increase the chance of encounter, hence some of these products do not rely on attractiveness as a factor for individuals to find pellets. This theory assumes that slugs and snails randomly encounter pellets. Research (SARDI) has demonstrated Italian snails have non-random (Chi^2 test, $P < 0.01$, n = 100) movement towards bait. Hunter & Symonds (1970) calculated the probability of encounter was related to the attractiveness of a bait (x), a grey field slug's movement (y), and the pellet area or attractiveness (A):

$$P = 1 - e^{-2xy/A}$$

Where attractiveness (x) = 4 cm, movement (y) = 0.85 m/overnight and the pellet area (A) = 0.04 m^2, the commonly advised pellets/m^2 of 30 would achieve a probability of encounter of 95% (Figure 1). Thus, the probability of encounter can be calculated based on the manufacture's claims regarding attractiveness. Actual values calculated are presented in Figure 2, with a product that claims no attractiveness (e.g. Metakill®) resulting in lower probability of encounter, despite having a greater number of pellets/m^2 when applied at its label rate, compared to other products that claim to be attractive: for example, Metarex Inov® x = 6 cm, Snailex x = 4 cm.

To increase probability of encounter some manufacturers have decreased their pellet's size, hence increased the surface area to volume ratio. These smaller pellets have reduced efficacy after rainfall due to greater loss of metaldehyde (Nash 2023). That loss of active ingredient can result in an increased probability of delivering a sub-lethal dose. In 2023, it was evident that the quantity of metaldehyde applied was important. This was primarily due to the high numbers of active slugs.

Table 1 is provided to demonstrate, in theory, the effective probability of encounter and the number of slugs that could be killed by each product based on an amount of metaldehyde delivered at minimum label rates and the lethal dose required for black keeled slugs: that is, LD_{50} 190 – 210 µg/g. The more expensive wet extruded products that contain optimal levels of metaldehyde (e.g. Axcela®, Metarex Inov®) when applied at minimum label rates ensure an optimal probability of encounter when compared to cheap bran-based products (e.g. Snailex) or products that are not attractive (e.g. Metakill®) (Table 1).

Observations in 2023 support research that fewer slugs are killed by applying low rates of molluscicide. Greater slug numbers in 2023 often needed frequent reapplication of baits, especially where low rates were used. In some instances, products were applied four times to protect canola from slug damage. In cases where these products were less effective, the cumulative rate of metaldehyde applied significantly exceeded European metaldehyde stewardship guidelines. These guidelines recommend a maximum of 700 g metaldehyde/ha/calendar year, with no more than 210 g/ha/application.

Growers adhering to the International Sustainability & Carbon Certification (ISCC EU 202-2 or ISCC Plus 202-02) programs and use products containing metaldehyde, need to ensure they meet the requirements for maximum application rates, in accordance with these programs.

Table 1. Comparison of commonly used metaldehyde baits demonstrating effective baits/m^2, baits/m^2 at minimum label rate and the number of black keeled slug individuals (BKS) killed at the minimum label rate.

Product	A.I. (g/kg)	APVMA #	Label rate (kg/ha)	Bait/m^2 Pr 90%	Bait/m^2	No of BKS killed
Snailex	15	68580/139802	5–7.5	34	12	54
Axcela®	30	87576/134693	5–7	29	37	71
Delicia® Sluggoff®	30	60931/116048	3	29	28	48
Metarex Inov®	40	88160/120463	4–5	23	24	84
Imtrade Metakill®	50	64990/117488	5–8	135	29	95
IA Transcend®	50 + 1.5 fipronil	88733/130091	2–8	135	14	48

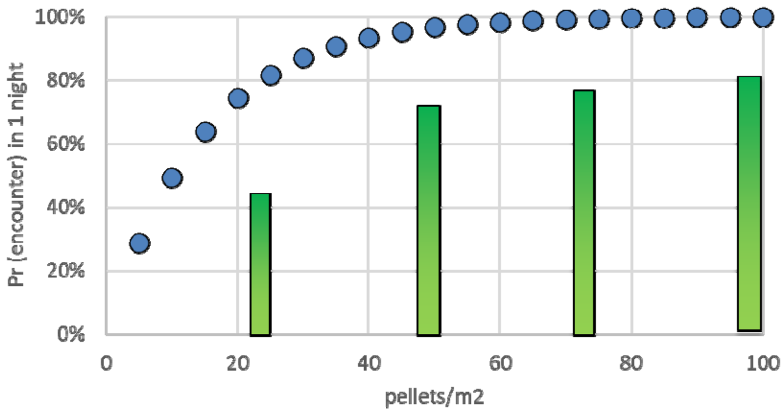

Figure 1. The probability of an individual grey field slug encountering a bran-based bait in one night as estimated by the equation $P = 1 - e^{-2xy/A}$ (dots) compared to data obtained from SARDI trials using round snails and bran-based bait (columns).

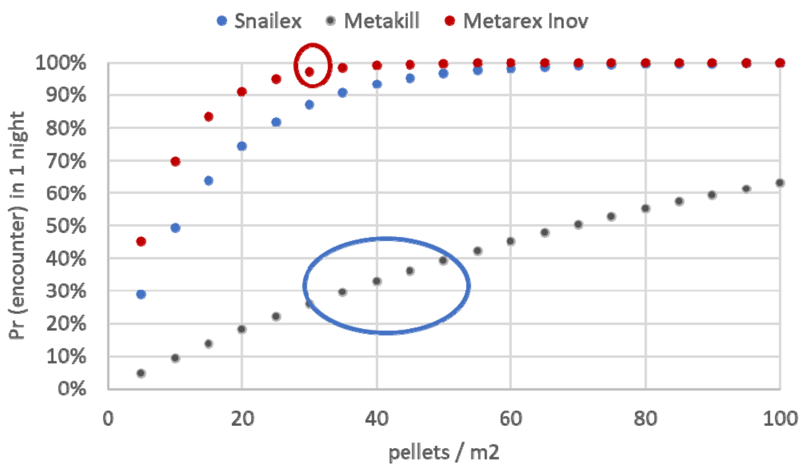

Figure 2. The theoretical probability of an individual slug encountering different products in one night as estimated by the equation $P = 1 - e^{-2xy/A}$ based on manufacturers claims regarding attractiveness. Note: despite a smaller pellet leading to greater pellets/m2 because the pellet is not attractive the chance of encounter (marked by large blue ellipse) is lower than a true bait that is attractive (marked by small red ellipse).

Conclusions

What can we predict for 2024? One would hope for lower slug numbers considering the lower-than-average late winter early spring rainfall. However, observations in southern NSW indicated that black keeled slugs were still active in September. Another observation is that high numbers of small slugs are damaging establishing fodder crops, despite the dry sowing conditions.

Understanding when individual slug species are active in your patch underpins successful management of them. Knowledge of pest population dynamics will avoid molluscicide supply shortfalls by ordering bait early, thus facilitating proactive baiting.

References

Hunter PJ and Symonds BV (1970) The distribution of bait pellets for slug control. Annals of Applied Biology 65: 1-7.

Nash M (2022[a]) Slug Control Fact Sheet - Successful crop protection from slugs. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2022/slug-control-identification-and-management

Nash M (2022[b]) Slugs In Crops: The Back Pocket Guide ISBN: 978-1-922342-31-7 https://grdc.com.au/resources-and-publications/all-publications/publications/2022/slugs-in-crops-the-back-pocket-guide

Nash M (2022[c]) Slugs – what can we learn from 2022. GRDC Update Papers 27 Jul https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/07/slugs-what-can-we-learn-from-2022

Nash M (2023) How do new molluscicide products perform in wet conditions. GRDC Update Papers 22 Feb 2023 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/how-do-new-molluscicide-products-perform-in-wet-conditions

Acknowledgements

The author would like to thank GRDC, growers, retail agronomists and commercial clients that supported the research presented in this paper. The author would also like to thank GRDC for support of extension of this research.

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Leveraging seed treatments and management strategies to effectively minimise loss from Fusarium crown rot

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Key words

barley, fungicide seed treatments, wheat, yield loss

GRDC codes

DAN00213, DAN00175

Take home message

- Current fungicide seed treatments registered for the suppression of Fusarium crown rot (FCR) inconsistently reduce the extent of yield loss from FCR.
- Victrato® had consistent, strong activity on limiting yield loss from FCR.
- However, under high infection levels, substantial yield loss may still occur in drier seasons. Victrato **does not** provide complete control of FCR, with efficacy likely reduced when prolonged dry soil conditions occur around the seed zone.
- Fungicide seed treatments, including Victrato, should not be considered standalone control options for FCR.
- Seed treatments should be used as an additional tool within existing integrated disease management strategies for FCR.

Introduction

Fusarium crown rot (FCR), caused predominantly by the fungal pathogen *Fusarium pseudograminearum* (*Fp*), is a major constraint to winter cereal production across Australia. A range of integrated management strategies including crop rotation, varietal selection, inter-row sowing, sowing time, stubble and fallow management are required to minimise losses. A number of fungicide seed treatments have been registered for the suppression of FCR in recent years, with a further product Victrato® from Syngenta likely to be available to Australian growers in 2024. Although chemical companies conduct their own widespread field evaluation across Australia, growers and their advisers value independent evaluation of the potential relative fit of these fungicide seed treatments within integrated management strategies for FCR.

What we did

A total of 15 replicated plot experiments (generally 2m x 10m with minimum of three replicates) were conducted across NSW from 2018–2021, with one additional field experiment conducted in Victoria (Horsham) and two in WA (Merredin and Wongan Hills) in 2018 only (Table 1). The winter cereal crop and number of varieties differed between experiments with wheat (W), barley (B) and/or durum (D) evaluated in each experiment (Table 1).

Six fungicide seed treatments: Nil, Vibrance® (difenoconazole + metalaxyl-M + sedaxane at 360mL/100kg seed), Rancona® Dimension (ipconazole + metalaxyl at 320mL/100kg seed), EverGol® Energy (prothioconazole + metalaxyl + penflufen at 260mL/100kg seed) and the unregistered product Victrato (Tymirium™ technology based on cyclobutrifluram at 40 and/or 80g active ingredient/100kg seed). All fungicide seed treatments were applied in 1kg to 3kg batches using a small seed treating unit to ensure good even coverage of seed. Note that not all six seed treatments were examined in 2020 and 2021.

All field experiments used an inoculated vs uninoculated randomised complete block design with inoculated plots infected by *Fp* inoculum grown on sterilised wheat grain added at 2.0g/m of row at sowing. This ensures high (>80%) FCR infection in inoculated plots, with uninoculated plots only exposed to background levels of *Fp* inoculum naturally present across a site. This design allows comparison between the yield effects of the various fungicide seed treatments in the presence and absence (background levels) of FCR. Yield loss from this disease is measured as the difference between inoculated and uninoculated treatments.

What did we find

Averaged across all cereal entries

Lower levels of in-crop rainfall between March and September generally lowered the yield potential at each site in each season, but also increased the extent of FCR yield loss. This was highlighted in the nil seed treatments where yield loss ranged from 11% to 48% in 2018, 14% to 20% in 2019, 11% to 37% in 2020 and 9% to 11% in 2021 (Table 1).

Table 1. Effect of various fungicide seed treatments on yield loss (%) associated with Fusarium crown rot infection in 18 replicated inoculated vs uninoculated field experiments – 2018 to 2021.

Year	Location	Crop[A]	Rainfall[B] (mm)	Yield[C] (t/ha)	%Yield loss from Fusarium crown rot[D]					
					Nil	Vibrance	Rancona Dimension	EverGol Energy	Victrato 40gai[E]	Victrato 80gai[E]
2018	Merriwagga, NSW	2W	63	1.44	44	nd[F]	nd	32	25	18
	Mallowa, NSW	2W	73	1.73	48	nd	nd	nd	26	24
	Gilgandra, NSW	2W	93	2.14	42	35	27	28	16	9
	Merredin, WA	2W	182	2.66	35	nd	nd	nd	23	13
	Horsham, Vic	2W	185	2.56	21	nd	nd	nd	+2[I]	+5
	Wongan Hills, WA	2W	291	3.27	11	nd	nd	nd	1	0
2019	Gulargambone, NSW	W/B	141	3.12	20	2	5	9	-[G]	+2
	Narrabri, NSW	W/B	200[H]	4.01	14	10	9	7	-[G]	6
2020	Boomi, NSW	3W/D	202	4.91	37	nd	28	nd	24	18
	Gurley, NSW	W/B	234	6.50	13	nd	nd	nd	-[G]	1
	Rowena, NSW	W/B	247	6.21	12	7	nd	4	-[G]	2
	Trangie, NSW	3W/D	412	4.13	26	20	23	19	4	2
	Gilgandra, NSW	3W/D	420	4.07	12	6	7	7	3	0
	Armatree, NSW	3W/D	425	4.37	11	nd	nd	7	3	+1
2021	Boomi, NSW	3W/D	349	5.74	10	-[G]	-[G]	-[G]	2	+1
	Armatree, NSW	3W/D	404	6.67	11	-[G]	-[G]	-[G]	2	1
	Wongarbon, NSW	3W/D	424	5.68	9	-[G]	-[G]	-[G]	6	4
	Rowena, NSW	3W/D	454	6.80	11	-[G]	-[G]	-[G]	1	0

[A] Winter crop type variety numbers where W = wheat variety, B = barley variety and D = durum variety.

[B] Rainfall in-crop from March to September at each site. Critical time for fungicide uptake off seed and expression of FCR.

[C] Yield in uninoculated treatment (average of varieties) with nil seed treatment.

[D] Average percentage yield loss from FCR for each seed treatment (averaged across varieties) compared with the uninoculated/nil seed treatment.

[E] gai = grams of active ingredient. Victrato is an unregistered product.

[F] nd = no difference, % yield loss from FCR with fungicide seed treatment not significantly different from the nil seed treatment. Values only presented when reduction significantly lower than the nil seed treatment.

[G] All treatments not included at these sites.

[H] Included two irrigations at GS30 and GS39 of 40mm and 30mm respectively due to drought conditions.

[I] Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (that is, the treatment reduced impact from both the added FCR inoculum as well as natural background levels of Fusarium present at that site.

Vibrance and Rancona Dimension significantly reduced the extent of yield loss from FCR in six of fourteen experiments, whilst EverGol Energy reduced FCR yield loss in eight of fourteen field trials (Table 1). However, the unregistered product Victrato significantly reduced yield loss from FCR in 14 of 14 trials at the 40gai rate and 18 of 18 field experiments at the 80gai rate (Table 1). The reduction in yield loss was also generally stronger with this product compared with the other fungicide seed treatments and better at the 80gai than the 40gai rate (Table 1).

Significant yield loss (9% to 26%) still occurred with Victrato at drier sites. These dry conditions increased the yield loss from FCR (>35% in nil seed treatment). However, the 80gai rate at these disease conducive sites at least halved the yield loss compared with the nil seed treatment (Table 1). Yield loss from FCR was lower at the wetter sites (<26%). Victrato reduced yield loss to <6%, with increased yields at some sites due to the effects of background levels of FCR infection being reduced (Table 1). Moisture stress during grain filling exacerbates yield loss from FCR and favours the growth of *Fp* within the base of infected plants. Dry soil conditions throughout the season at the seeding depth, is likely to restrict the movement of fungicide actives off the seed coat and into surrounding soil and restrict uptake by root systems. This would reduce movement of the fungicides into the sub-crown internode, crown and tiller bases where FCR infection is concentrated. It is currently not clear if reduced efficacy of Victrato under drier conditions may be related to one or both of these factors.

What about durum

Durum wheat is known to have increased susceptibility to FCR compared with many wheat and barley varieties. The increased prevalence of FCR in farming systems aided by the adoption of conservation cropping practices, including retention of cereal stubble, has often seen durum removed from rotations due to this risk. The durum variety DBA Lillaroi⦶ was compared with three bread wheat varieties at four sites in 2020 (Table 1).

Table 2. Effect of Victrato seed treatment at two rates on the extent of yield loss[A] (%) from Fusarium crown rot in three bread wheat (W) and one durum (D) variety at three sites in 2020. Note: Victrato is not yet registered.

Variety	Boomi 2020			Trangie 2020			Gilgandra 2020			Armatree 2020		
	Nil[B]	Victrato 40gai	Victrato 80gai	Nil	Victrato 40gai	Victrato 80gai	Nil	Victrato 40gai	Victrato 80gai	Nil	Victrato 40gai	Victrato 80gai
LRPB Lancer⦶ (W)	29	23	20	30	10	8	13	2	0	9	4	+7[C]
Mitch⦶ (W)	39	18	11	13	+2	+5	9	2	1	5	0	0
LRPB Trojan⦶ (W)	34	22	18	20	4	2	12	1	0	14	2	2
DBA Lillaroi⦶ (D)	48	32	24	45	11	6	16	5	+2	14	6	+2

[A] Average percentage yield loss from FCR for each seed treatment compared with the uninoculated/nil seed treatment for that variety.

[B] Nil = no seed treatment.

[C] Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (that is, the treatment reduced impact from both the added FCR inoculum, as well as natural background levels of Fusarium present at that site).

The extent of yield loss from FCR with nil seed treatment was generally higher in the durum variety (14% to 48%) compared with the three bread wheat varieties (5% to 39%). The bread wheat variety Mitch⦶ tended to have reduced yield loss from FCR compared with the other entries, apart from the Boomi site (Table 2). Yield loss from FCR was reduced with Victrato in both the bread wheat and durum varieties (Table 2). Even in the higher loss site at Boomi in 2020, the 80gai rate halved the extent of yield loss in the durum variety Lillaroi⦶, with better efficacy in the other three sites.

Conclusions

Current fungicide seed treatments registered for the suppression of FCR can inconsistently reduce the extent of yield loss from this disease. Victrato, due to be registered in 2024, appears to have more consistent and stronger activity on limiting FCR yield loss. In the absence of fungicide seed treatments, average yield loss from FCR infection across the 18 sites over three seasons was 21.5%. The 80gai rate of Victrato significantly reduced the level of yield loss from FCR down to an average of 4.9% across these 18 field experiments. Under high infection levels, as created with artificial inoculation in these experiments, significant yield loss may still occur (up to 24% measured), particularly in drier seasons.

Dry soil conditions around the seeding depth throughout a season may reduce the uptake of fungicides applied to the seed coat. Drier seasons also exacerbate FCR expression, which would place additional pressure on fungicide seed treatments. However, even under these conditions, Victrato at the 80gai rate still at least halved the level of yield loss from FCR.

Fungicide seed treatments, including Victrato (once registered), should not be considered standalone control options for FCR. Rather, they should be used as an additional tool within existing integrated disease management strategies for FCR.

Integrated management of FCR

To manage the risk of yield losses in cereals, firstly identify paddocks at highest risk of Fusarium crown rot. High-risk paddocks generally include durum, bread wheat or barley crops being sown into a paddock with a history of stubble retention and tight cereal rotations (including oats). Other considerations are to use effective weed management programs to reduce grass weed hosts in-crop and fallow situations which serve as alternate hosts for the FCR fungus. Also remember, the larger the grass weed when controlled, the longer that residue serves as a potential inoculum source. Furthermore, given the recent Fusarium head blight epidemic in 2022, ensure that you are sowing seed free of Fusarium infection, as infected seed introduces FCR infection into paddocks.

All other management options are prior to sowing, so knowing the risk level within paddocks is important. This can either be through PreDicta B testing (SARDI) or stubble testing (NSWDPI).

If medium to high FCR risk, then:

- Sow a non-host break crop (for example, lentil, field pea, faba bean, chickpea, canola). A two-year break may be required if FCR inoculum levels are very high.

If still considering sowing a winter cereal:

- Consider stubble management options in terms of both impacts on FCR inoculum but also fallow soil moisture storage.
  - ***Cultivation*** accelerates stubble decomposition which can decrease FCR risk (as the causal pathogen is stubble-borne) **but** it takes moisture and time. Cultivation also increases the spread of Fusarium crown rot inoculum across a paddock in the short term and increases exposure of below ground infection points (coleoptile, crown and sub-crown internode) in cereal plants to contact with stubble fragments infected with the FCR fungus. Cultivation close to sowing therefore increases the incidence of plants which get infected with FCR. Cultivation can also substantially reduce soil moisture storage during fallow periods.
  - ***Stubble baling*** removes a proportion of the above ground inoculum from a paddock, potentially reducing FCR risk. The pathogen will then be concentrated in the shorter stubble butts and below ground in the previous rows. Hence, baling in combination with inter-row sowing is more likely to reduce FCR risk. Reduced ground cover after bailing and removal of cereal straw can reduce fallow efficiency.

  - ***Stubble burning*** depending on the completeness of the burn, above ground inoculum is destroyed. Burning has no effect on the survival of the FCR fungus below ground in crown tissue, even with a hotter summer burn. Hence, the pathogen will be concentrated below ground in the previous rows, with survival between seasons dependent on the extent of summer rainfall. Burning of cereal stubble can considerably reduce fallow soil moisture storage, so a 'late-Autumn' burn is preferable to an 'early-Summer' burn. Stubble burning in combination with inter-row sowing is more likely to reduce FCR risk.
  - ***Reducing cereal stubble height*** limits the length of stubble which the FCR fungus can vertically grow up during wet fallow periods, restricting the overall inoculum load within a paddock. When relative humidity is >92.5%, the FCR fungus can colonise vertically up retained standing cereal stubble in a process termed 'saprotrophic growth'. At 100% relative humidity, this saprotrophic growth can occur at a maximum rate of 1 cm per day (Petronaitis et al. 2020). The FCR fungus can therefore saprotrophically grow to the cut height of the cereal stubble under prolonged or accumulated periods of rainfall. Consequently, harvesting and leaving retained cereal stubble longer (for example, stripper fronts) leaves a greater length of stubble for subsequent potential saprotrophic growth of the FCR fungus. This is not a major issue in terms of FCR risk if the retained infected cereal stubble is left standing and kept intact. However, if the infected stubble is disturbed and redistributed across a paddock through grazing, mulching, cultivation or the subsequent sowing process, then this can increase the incidence of FCR infection. Recent research in NSW has also demonstrated that increased cereal harvest height allowed saprotrophic growth of the FCR fungus above the harvest height of a following chickpea crop. This resulted in FCR infected cereal stubble being spread out the back of the header during the chickpea harvest process, increasing FCR risk for the next cereal crop (Petronaitis et al. 2022). Consider matching cereal stubble height at or after harvest in paddocks planned for a following shorter status break crop, such as chickpea or lentils, to prevent redistribution of retained FCR infected cereal stubble during the break crop harvest process.
- Select a cereal type and variety that has more tolerance to FCR ***and*** that is best suited to your region. Yield loss from FCR is generally durum>bread wheat>barley>oats. Recent research has shown that cereal type and varietal resistance has no impact on saprotrophic growth of the FCR fungus after harvest. Hence, cereal crop and variety choice does not have subsequent benefits for FCR risk within a paddock.
- Consider sowing a variety earlier within its recommended sowing window for your area. This will bring the grain filling period forward slightly and can reduce water and heat stress which exacerbates FCR expression and yield loss. However, this needs to be weighed against the risk of frost damage. Research across locations and seasons in NSW has shown that sowing at the start versus the end of a three-week recommended planting window can roughly half the yield loss from FCR.
- If previous cereal rows are intact, consider inter-row sowing to increase the distance between the new and old plants, as most inoculum is in the stem bases of the previous cereal crop. Physical contact between an infected piece of stubble and the coleoptile, crown or sub-crown internode of the new cereal plants is required to initiate FCR infection. Research across locations and seasons in NSW (30–35cm row spacings in stubble retained systems) has shown that inter-row sowing can roughly halve the number of wheat plants that become infected with FCR. Precision row placement can also provide greater benefits for FCR management when used in combination with rotation to non-host crops.

- Ensure nutrition is appropriate for the season. Excessive nitrogen will produce bulky crops that hasten moisture stress and make the expression of FCR more severe. Whitehead expression can also be made more severe by zinc deficiency.
- Consider a seed fungicide treatment to suppress FCR. Fungicide seed treatments are not a stand-alone treatment and must be used as a part of an integrated management approach.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The author would also like to thank their advisers and acknowledge the ongoing support for northern pathology capacity by NSW DPI. National trials conducted in 2018 in Victoria (Horsham) and Western Australia (Merredin and Wongan Hills) were in collaboration with Dr Grant Hollaway (Ag Vic) and Dr Daniel Huberli (DPIRD) with biometric support from Clayton Forknall (DAFQ). Technical support provided by Chrystal Fensbo, Robyn Shapland, Tim O'Brien, Finn Fensbo, Patrick Mortell and Jason McCulloch (all NSW DPI) is gratefully acknowledged. A number of field experiments were contracted through AMPS Research (Matt Gardner) or NSW DPI (Peter Matthews) which is also gratefully acknowledged.

Useful resources

PreDicta®B sampling procedure (Sampling_protocol_Predicta_B_South_and_West_V2.pdf (pir.sa.gov.au))

Petronaitis T, Forknall C, Simpfendorfer S, Backhouse D (2020) (Stubble Olympics: the cereal pathogen 10cm sprint)

Petronaitis T, Forknall C, Simpfendorfer S, Flavel R, Backhouse D (2022) (Harvest height implications for Fusarium crown rot management)

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Implications of sowing Fusarium infected wheat seed in 2023

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Key words

Fusarium head blight, Fusarium crown rot, yield, fungicide seed treatment

GRDC code

DPI2207-004RTX: Integrated management of Fusarium crown rot in Northern and Southern Regions

Take home message

- Sowing wheat or durum seed with ≤5% Fusarium grain infection had limited impact on yield even when no fungicide seed treatment was applied
- Sowing seed with 7.5% to 10% Fusarium grain infection had an average yield penalty of 13% (range 4% to 23%) with no seed treatment but was largely eliminated by the application of the seed treatment
- Sowing seed with >10% Fusarium grain infection had an average yield penalty of 27% (range 17% to 40%) with no seed treatment which was nearly halved to an average yield loss of 15% (range 9% to 27%) with the application of the seed treatment
- Implications on the incidence and severity of Fusarium crown rot introduced through Fusarium infected grain should also be considered.

Introduction

The prevalence of fusarium head blight (FHB) across large areas of eastern Australia in 2022 was unprecedented with implications for seed retained from infected crops (Simpfendorfer and Baxter 2023). Fusarium grain infection reduces germination and vigour of seed retained for sowing along with causing seedling blight (death) in plants arising from infected grain. The fungus replaces the contents of infected seed with its own mycelium, so while seed treatments can help reduce the level of seedling blight, they cannot restore the quality of heavily infected seed sources. Sowing Fusarium infected seed also introduces fusarium crown rot (FCR) into paddocks. Sourcing quality seed for sowing created issues in some regions in 2023.

Based on north American experience the general advice if retaining seed for sowing is:

- <1% Fusarium grain infection = no issues
- 1% to 5% Fusarium grain infection = consider using seed treatment (e.g. full rate Vibrance® or EverGol® Energy) to limit seedling blight, and slightly increase sowing rate
- >5% Fusarium grain infection = source cleaner seed if possible.

The opportunity was taken to test the effect of varying levels of Fusarium grain infection on yield and FCR incidence under Australian conditions using grower retained seed lots from 2022 across the northern grain region.

Fusarium grain infection levels in 2022

A ‘free’ seed testing service was offered to growers to support them in determining Fusarium grain infection levels. In total 1,934 seed lots from the 2022 harvest were tested consisting of 1,595 bread wheat, 191 durum and 148 barley samples (Table 1). The biggest issue with Fusarium grain infection levels was in durum wheat, which is very susceptible to FCR and FHB, with 82% of 2022 seed lots having greater than the recommended 5% level of Fusarium infection. Fusarium grain infection levels were still a widespread issue in bread wheat and barley seed retained from 2022 with 33% of bread wheat and 26% of barley seed lots having greater than the recommended 5% level of infection (Table 1).

Table 1. *Fusarium* spp. grain infection levels in bread wheat, durum wheat and barley seed lots harvested across eastern Australia in 2022.

Region	**Bread wheat**			**Durum wheat**			**Barley**		
	<5%	**>5%**	**Max**	**<5%**	**>5%**	**Max**	**<5%**	**>5%**	**Max**
SE NSW	163	27	16%				3	1	6%
SW NSW	149	57	43%	12	47	71%	12	4	9%
CE NSW	147	76	37%	0	2	30%	18	4	49%
CW NSW	257	169	43%	0	2	45%	20	12	19%
NE NSW	88	99	42%	16	87	69%	28	12	34%
NW NSW	62	39	28%	1	16	68%	13	4	13%
Sth Qld	118	25	26%	0	1	23%	10	1	7%
Victoria	71	37	33%	1	1	35%	6	0	5%
South Aus	9	0	2%	5	0	2%			
Tasmania	2	0	1%						

Values are the number of grower seed lots with less than or greater than 5% Fusarium grain infection.
Max = maximum level of Fusarium grain infection (%) measured in each cereal crop type and region.

Levels of FHB infection and resulting Fusarium grain infection were prevalent across eastern Australia in 2022 but varied between regions. For example, in bread wheat the incidence of grain infection levels greater than 5% was most common in north-east NSW (53% of samples) followed by central-west NSW (40% of samples), north-west NSW (39% of samples), central-east NSW and Victoria (both 34% of samples) and south-west NSW (28% of samples). Fusarium grain infection levels in bread wheat greater than 5% were less prevalent in Qld (17% of samples) and south-east NSW (14% of samples) with the lowest level in South Australia and Tasmania (0% of samples; maximum 2% or 1% infection, respectively) from limited testing (9 and 2 samples, respectively) conducted from those states (Table 1).

What we did

Seven replicated small plot field experiments were conducted across the northern grain region in 2023 using locally sourced grower retained seed lots of a single variety. Seed lots (SL) were selected based on varying levels of Fusarium grain infection with SL1 lowest (0% to 1.7%), SL2 minor (3.3% to 5.0%), SL3 intermediate (7.5% to 10.0%) and SL4 highest (11.8% to 57.5%; Table 2). All sowing rates were adjusted to target 100 plants/m^2 based on seed size (1000 grain weight) and percentage germination. With each seed lot there were separate replicated plots sown comparing no seed treatment versus treatment with Vibrance (180 mL/100 kg seed) + Victrato® (400 mL/100 kg seed) (not currently registered for use within Australia). Field trials had a complete randomised block design with three replicates of each seed lot by seed treatment combination. Establishment, yield, grain quality and Fusarium crown rot incidence and severity were measured on all plots.

Table 2. Fusarium grain infection levels (%) in four local grower seed lots (SL) of different wheat or durum varieties tested at 7 locations in 2023. Note only three seed lots tested at Westmar.

		Seed lot			
Location	**Variety**	**SL1**	**SL2**	**SL3**	**SL4**
Westmar	LRPB HellfireΦ	0.3%	5.0%	-	18.8%
Walgett	LRPB HellfireΦ	1.7%	5.0%	9.5%	19.5%
Coonamble	LRPB HellfireΦ	1.0%	4.0%	7.5%	14.5%
Nyngan	LRPB LancerΦ	0.0%	4.0%	8.3%	29.0%
Wellington	ScepterΦ	0.5%	3.0%	7.5%	11.8%
Lake Cargelligo	ScepterΦ	0.5%	3.3%	9.5%	18.0%
Deniliquin	DBA VittaroiΦ	1.0%	4.0%	10.0%	57.5%

What did we find?

Plant establishment

Average plant establishment did not achieve the target plant population of 100 plants/m^2 except for ScepterΦ SL4 at Wellington (103 plants/m^2). Average plant populations established across the local seed lots at each site were highest at Westmar and Wellington (88 plants/m^2), then Deniliquin (85 plants/m^2), Nyngan (84 plants/m^2), Coonamble (71 plants/m^2), Lake Cargelligo (70 plants/m^2) down to Walgett (66 plants/m^2). The interaction between seed lot and seed treatment was only significant with VittaroiΦ durum at Deniliquin. Seed lot 4 at this site had the highest Fusarium grain infection level (57.5%) of all tested which significantly reduced establishment in the absence of seed treatment (Table 3). However, in the presence of seed treatment this same seed lot had significantly higher establishment than the other three seed lots with lower Fusarium grain infection levels. This is potentially through the seed treatment reducing the level of seedling blight in this heavily infected seed lot. Except for this site, differences in plant establishment between treatments did not appear to have a major influence on yield outcomes which highlights the importance of adjusting sowing rates for germination and seed weight of individual seed lots.

Table 3. Effect of VittaroiΦ seed lot (SL) and seed treatment on plant establishment (plants/m^2) at Deniliquin in 2023.

	Minus seed treatment				Plus seed treatment			
Location	**SL1**	**SL2**	**SL3**	**SL4**	**SL1**	**SL2**	**SL3**	**SL4**
Deniliquin	81 b	93 b	78 b	55 c	83 b	91 b	85 b	114 a

Values followed by the same letter not significantly different at the 95% confidence level.

Yield

In the absence of seed treatment, the minor increase in Fusarium infection levels between SL1 (0% to 1.7%) and SL2 (3.3% to 5%) only reduced yield at Nyngan (11% yield loss; Table 4). A further increase in Fusarium infection level with SL3 (7.5 to 10.0%) reduced yield by between 4% (Wellington) to 23% (Nyngan) at 5 of 7 locations (except Coonamble where not significant and Westmar where no SL3 treatment) compared with the lowest levels in the SL1 treatment. The highest Fusarium infection levels in SL4 (11.8% to 57.5%) had an associated yield loss of between 17% (Westmar and Wellington) to 40% (Deniliquin) compared with the lowest Fusarium infection levels in SL1 in the absence of seed treatment (average 27% yield loss; Table 4).

Table 4. Yield (t/ha) of local grower seed lots of different wheat or durum varieties with varying levels of Fusarium grain infection at 7 locations in 2023 without and with fungicide seed treatment.

	Minus seed treatment				**Plus seed treatment**				
Location	**SL1**	**SL2**	**SL3**	**SL4**	**SL1**	**SL2**	**SL3**	**SL4**	**Con**
Westmar	2.94 a	3.03 a	-	2.45 c	2.97 a	3.05 a	-	2.65 b	96%
Walgett	1.75 a	1.73 a	1.48 b	1.26 c	1.76 a	1.72 a	1.74 a	1.50 b	90%
Coonamble	3.10 a	2.93 a	2.90 ab	2.23 c	3.04 a	3.09 a	2.96 a	2.72 b	99%
Nyngan	0.96 a	0.85 b	0.74 c	0.62 d	0.99 a	0.95 a	0.87 b	0.78 c	86%
Wellington	2.23 b	2.27 ab	2.13 c	1.85 d	2.34 a	2.28 ab	2.28 ab	2.07 c	82%
Lake Cargelligo	2.52 ab	2.56 ab	2.14 d	1.97 d	2.55 ab	2.61 a	2.40 bc	2.33 c	89%
Deniliquin	4.57 b	4.66 ab	4.16 c	2.73 e	4.70 ab	4.89 a	4.80 ab	3.45 d	97%

Values followed by the same letter not significantly different at the confidence (con) level at each location. Lettering only applies within individual locations.

When the seed treatment was applied, there was generally no yield difference between SL1, SL2 and SL3 treatments at each location (Table 4). Exceptions were at Nyngan where SL3 was 12% lower yielding than SL1 and 8% lower yielding than SL2, along with Lake Cargelligo where SL3 was 8% lower yielding than SL2 but equivalent to SL1. Application of the seed treatment reduced but did not eliminate the extent of yield loss between the lowest (SL1) and highest (SL4) Fusarium grain infection levels which ranged from 9% (Lake Cargelligo) to 27% (Deniliquin) with an average across locations of 15% (Table 4).

Grain quality and pathology

Unfortunately, this data was not available at the time of writing this report. However, visual inspection of some sites during grain filling had a noticeable increase in the incidence of whiteheads in SL4 plots especially in the absence of seed treatment. Pathology assessments to determine the incidence and severity of FCR in each plot are currently being conducted.

Summary

Sowing wheat or durum seed with low (<5%) Fusarium grain infection had limited impact on yield when no seed treatment was used and no impact when the seed treatment was applied. Sowing seed with moderate (7.5% to 10%) Fusarium grain infection had an average yield penalty of 13% at 5 of 6 locations (not present in Westmar trial) when no seed treatment was used and no impact at 5 of 6 locations when the seed treatment was applied. Sowing seed with high (11.8% to 57.5%) Fusarium grain infection had an average yield penalty of 27% in the absence of seed treatment which was roughly half at 15% when the seed treatment was applied.

Based on only yield, this data broadly supports current north American recommendations around sowing cereal seed with varying levels of Fusarium grain infection. This data indicates that growers may still be able to consider sowing cereal seed with 5 to 10% Fusarium grain infection if the seed treatment is used without negatively impacting on yield. However, this does not consider the potential introduction of FCR into paddocks and subsequent inoculum issues for following cereal crops.

This was not a fungicide seed treatment study and only examined one option known to have stronger Fusarium activity that was used for experimental purposes with Victrato® not currently registered for use within Australia. This does not indicate what activity may be achieved with other registered fungicide seed treatments or a lower rate of this unregistered product which is anticipated for commercial release in 2024.

References

Simpfendorfer S and Baxter B (2023) Fusarium head blight and white grain issues in 2022 wheat and durum crops, GRDC Update paper

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers and their advisers through their support of the GRDC. The author would also like to acknowledge the ongoing support for northern pathology capacity by NSW DPI. This research would also not have been possible without the support of growers and advisors through submission of grain samples for testing. The efforts of Peter Matthews & team (NSW DPI) in running NSW sites and Kaylx in running the Qld site (Westmar) is also gratefully acknowledged.

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A foe in the fallow: what happens with Fusarium crown rot between seasons?

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Key words

cereal stubble, stubble management, integrated disease management, post-harvest, wheat, barley, durum wheat, oat, Fusarium

GRDC codes

BLG211: Grains Agronomy & Pathology Partnership (GAPP) PhD, a GRDC & NSW DPI co-investment
DAQ00208: Statistics for the Australian Grains Industry (North)
DPI2207-004RTX: Integrated management of Fusarium crown rot in Northern and Southern Regions
DAQ2007-002RTX: Northern Farming Systems

Take home message

- Cereal varieties with better partial resistance can still experience significant (up to ~6-fold) increases in *Fusarium pseudograminearum* (*Fp*) colonisation after senescence (crop maturity)
- Colonisation of cereal stubble by *Fp* after harvest can be maintained at high levels for at least 1 year under natural field conditions
- Post-harvest colonisation of cereal stubble by *Fp* could contribute inoculum for future seasons, particularly if infected stubble is disturbed and redistributed e.g., via harvest of a shorter-stature break crop (e.g., chickpea)
- Lowering the harvest height of cereal crops infected with *Fp* can prevent colonisation of retained stubble after harvest and may be a useful management strategy in high-risk scenarios.

Introduction

Fusarium crown rot (FCR) is a chronic disease of cereals in Australia and causes significant damage to infected crops through yield loss and reduced grain quality. In the northern region (northern NSW and Qld), the disease is primarily caused by the fungus *Fusarium pseudograminearum* (*Fp*), but *F. culmorum* and *F. graminearum* can also cause FCR. These fungi can survive three or more years in cereal stubble (Summerell and Burgess 1988), which has become increasingly problematic due to cereal stubble retention.

Recent research has confirmed that *Fp* can also continue to colonise cereal stubble after harvest, known as saprotrophic colonisation. Over a 6-month summer fallow, saprotrophic colonisation by *Fp* resulted in a 60 to 70% increase in the height that *Fp* was detected in standing stubble at two sites in northern NSW (Petronaitis *et al.,* 2022). Post-harvest colonisation of stubble by *Fp* may therefore contribute to the build-up of FCR inoculum in stubble-retention systems.

Saprotrophic colonisation of cereal stubble by *Fp* has not been well-characterised. During plant development, *Fp* will colonise stems more aggressively in hosts which are more susceptible to FCR (e.g., durum wheat) (Knight and Sutherland 2017). This can lead to more inoculum accumulation during the growing season. It is unknown whether aggressive colonisation continues after harvest in more susceptible hosts, and whether using cereals with improved levels of genetic resistance provides any subsequent inoculum benefit (e.g., by slowing or preventing *Fp* colonisation of stubble). This is important to investigate, as crop and variety selection are among the most popular strategies that growers and advisors use to manage FCR (Figure 1).

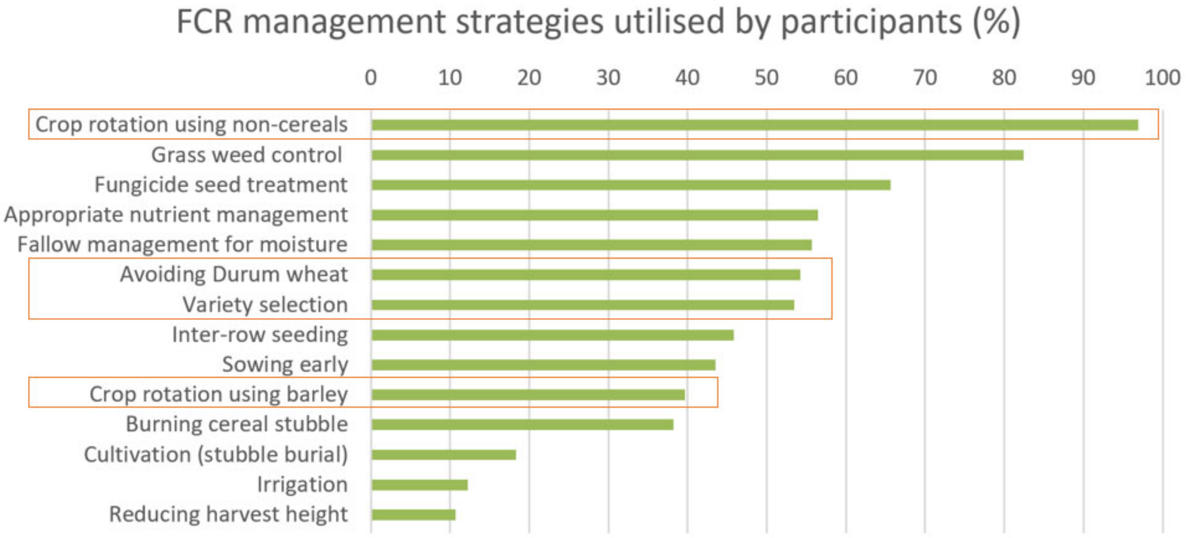

Figure 1. Strategies used in the last 2 years to manage FCR by 130 participants who completed the Fusarium crown rot survey: a grower and agronomist questionnaire conducted in August 2023 under the GRDC and DPI co-investment (DPI2207-004RTX). Strategies that involve crop and variety selection are circled. Participants include growers and agronomists from Qld, NSW, SA, and Vic.

Glasshouse experiment method

Ten cereal cultivars with a range of FCR ratings (Table 1) were selected and the movement of *Fp* tracked within the stems, from seedlings through to post-harvest stubble.

Table 1. Ten cultivars were selected for the study based on their relevance to the northern region and covering a range of crop types and FCR resistance ratings.

Cultivar name	Crop species	FCR resistance rating
LRC2012-122	Bread wheat	MR–MS to MR[1]
LRPB Hellfireⓓ	Bread wheat (APH)	MS–S
LRPB Lancerⓓ	Bread wheat (APH)	MS–S
LRPB Stealthⓓ	Bread wheat (APH)	S
LRPB Kittyhawkⓓ	Dual purpose wheat (APH)[2]	S–VS
DBA Lillaroiⓓ	Durum wheat	S–VS
Oxfordⓓ	Barley	MS–S
Commanderⓓ	Barley	S
Spartacusⓓ	Barley	S
Eurabbie	Oat	NA

[1] Germplasm and FCR rating kindly supplied by Cassy Percy, University of Southern Queensland, 2021.

[2] For simplification, Kittyhawkⓓ was considered as a bread wheat in the analyses.

Abbreviations: Australian Prime Hard (APH), Durum Breeding Australia (DBA), Fusarium crown rot (FCR), Leslie Research Centre (LRC), Longreach Plant Breeders (LRPB), moderately resistant (MR), moderately susceptible (MS), not applicable (NA), susceptible (S), very susceptible (VS).

The experiment was conducted in a glasshouse at Tamworth Agricultural Institute (Tamworth, NSW). Two seeds of an individual cultivar were placed in grow bags containing potting mix and covered with a 2 cm layer of *Fp* grain inoculum-potting mix combination (1% grain inoculum by weight). Plants were thinned to one plant per bag after 10 days. Plants were assessed at four sampling times (in days after planting, or DAP) at various targeted growth stages (GS): stem elongation (80 DAP, GS32), anthesis (113 DAP, GS61), maturity (147 DAP, GS90), and post-harvest (166 DAP, GS90 + 2 weeks), the latter following regular moisture treatment. Plants were washed and rated visually for severity of FCR (stem browning). The main tiller was retained for culturing, and any remaining tillers were dried at 30 °C for 24 hours and submitted to the South Australian Research and Development Institute (Adelaide, South Australia) for qPCR analysis of *Fp* DNA.

Main tillers were surface sterilised using 5% sodium hypochlorite solution (5 mL sodium hypochlorite solution, 45 mL distilled water, 50 mL >98% ethanol) for 1 minute then washed three times with sterile reverse osmosis water and dried for 2 hours in a laminar flow. The tillers were aseptically trimmed into 1 cm segments and numbered sequentially starting from the crown. Segments were cultured on 1/4 potato dextrose agar (PDA) + novobiocin and incubated under alternating white and near ultraviolet lights for a 12 h photoperiod of 66.6% alternating fluorescent (FL36W/865, Sylvania, East Sussex, United Kingdom) and 33.3% blacklight blue (F36T8 BLB, Crompton lighting, Bradford, United Kingdom) for 5 days at 25 °C. The incidence of stem colonisation was determined by scoring each tiller section for the growth of *Fp* based on colony morphology. Maximum colonisation was defined as the highest tiller section at which *Fp* was detected within the tiller and reported as a height (in cm).

The factorial combination of treatments, being all combinations of cultivar and sampling time, were assigned to tubs according to a split-plot design. In this case, sampling times were randomly assigned to main plots, where a main plot was defined as a group of 10 grow bags arranged in a 2 x 5 configuration. Using this configuration of grow bags, and due to the size of the tubs, two main plots occurred within each plastic tub. Cultivars were randomly assigned to individual grow bags within main plots. All treatment combinations were replicated six times.

The response variable, maximum height of colonisation, was analysed using a linear mixed model framework, whereby cultivar, sampling time and their interaction, were fit as fixed effects, while terms describing the experimental design structure were fit as random. The model was fit using the ASReml-R package in the R statistical computing environment.

Glasshouse experiment results – what did we find?

Analysis of maximum colonisation revealed a significant interaction between cultivar and sampling time. During the growing season (stem elongation and anthesis), *Fp* did not colonise as high up main tillers in oat var. Eurabbie compared with most of the other cultivars (Figure 2). This was the only case in which host resistance to FCR significantly suppressed *Fp* colonisation in the living plant. By maturity, improved genetic resistance did not appear to suppress colonisation by *Fp* in any of the cultivars tested (including oat). Some of the cultivars with better FCR resistance ratings experienced the highest increase in *Fp* colonisation, for example LRPB Lancer (~4-fold increase) and LRC2012-122 (~6-fold increase) (Figures 2 and 3). As such, *Fp* colonisation of stems around the time of harvest did not relate comparatively with the reported host resistance ratings of the different cultivars tested.

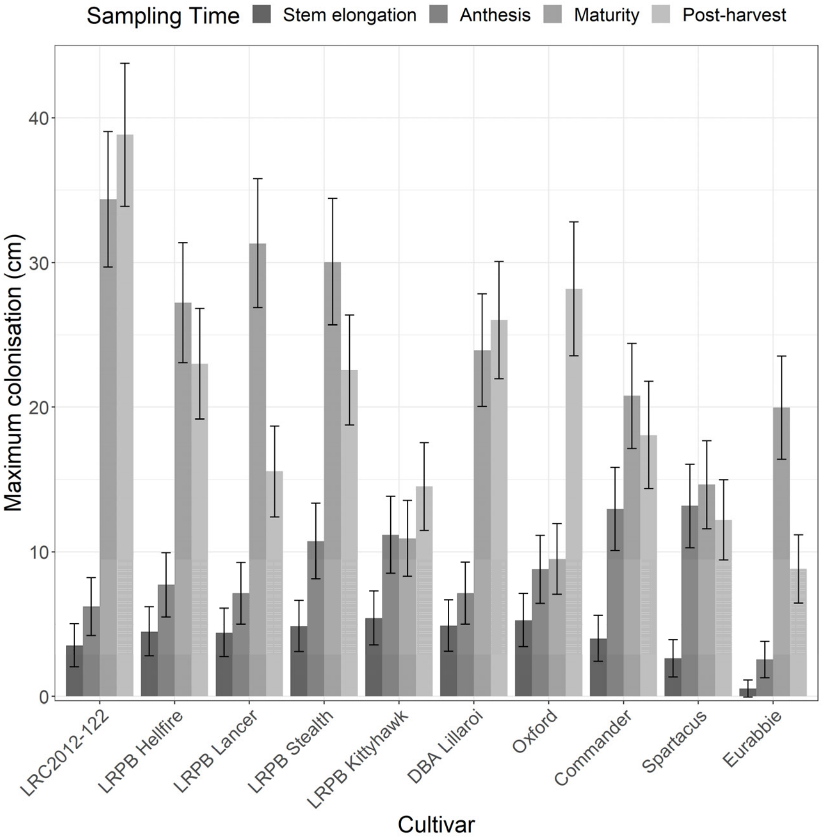

Figure 2. Maximum vertical colonisation (cm) of the main stem of different cereal cultivars by *Fp* at four different time points: stem elongation, anthesis, maturity, and post-harvest. Error bars represent the approximate back-transformed standard error of the mean.

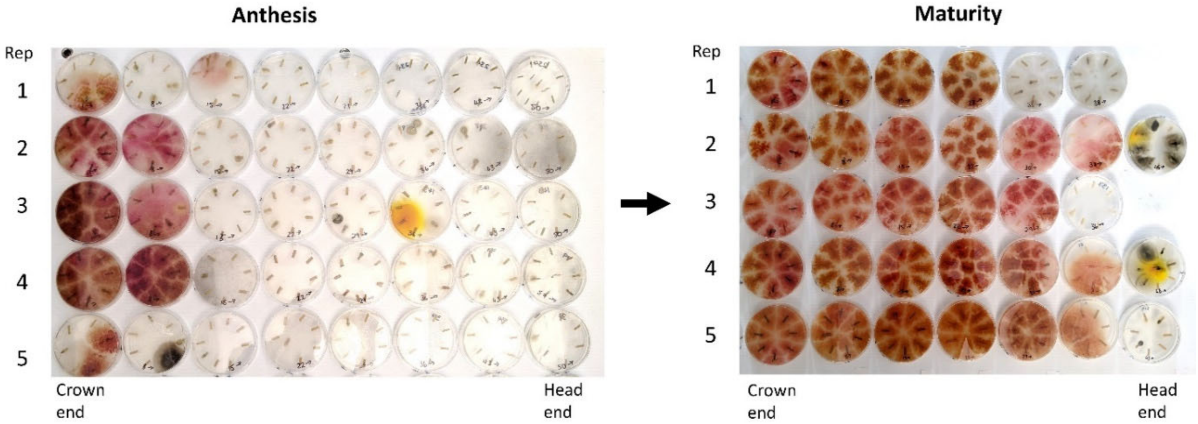

Figure 3. Example of the large increase in *Fp* colonisation observed between anthesis and maturity in the partially FCR-resistant wheat germplasm LRC2012-122. The *Fp* colonies appear as dark patches surrounding the stubble pieces (colonies are red when printed in colour). This shows extensive colonisation of the plant by *Fp* following plant senescence. Samples are representative of all six replicates in the experiment.

The *Fp* DNA levels and crown rot index (CRI) results aligned well with the FCR ratings (data not shown), confirming that we achieved the desired range of different infection and disease severity levels. Interestingly, the MR–MS to MR line LRC2012-122 had relatively low *Fp* DNA and CRI, but the highest height of *Fp* colonisation at maturity and post-harvest. Conversely, the two cultivars with the highest *Fp* DNA levels and CRI (S-rated barley cv. Commanderⓓ and S–VS wheat cv. LRPB Kittyhawkⓓ) were among the cultivars with the lowest height of *Fp* colonisation from maturity onwards (Figure 2). These results showed that lower levels of stem colonisation (determined via culturing) did not translate to lower DNA levels or disease symptoms in the plant, and vice-versa. This could be explained by more susceptible cultivars accumulating higher levels of DNA in-season due to aggressive colonisation by *Fp* (Knight and Sutherland 2017), which is not experienced during saprotrophic colonisation.

Additional watering of the stubble between maturity and post-harvest did not consistently increase saprotrophic colonisation by *Fp*. This is contrary to prior work, which showed the FCR pathogen can colonise sterile cereal stubble at a rate of up to 1 cm/day under consistently high humidity (Petronaitis *et al*., 2020). In the field, *Fp* can increase by up to 21 cm (or to the final cut height of stubble) over a 6-month summer fallow (Petronaitis *et al.,* 2022). We suspect further saprotrophic colonisation might have been detectable via culturing in the present study if the post-harvest period had been extended beyond 2 weeks. The good news is that there may not be significant change in *Fp* colonisation during shorter periods, e.g., a harvest window. This may allow for additional time to test *Fp* levels in stubble and/or manage, if needed, to prevent further post-harvest colonisation.

Crop/variety selection is still a useful tool for managing FCR

The glasshouse experiment supports the use of cereal cultivars with partial resistance as part of an integrated management strategy for FCR. The more (partially) resistant cultivars were generally associated with a reduction in *Fp* DNA and disease severity, which can protect against yield and quality losses to FCR. The preliminary results from the FCR questionnaire show that growers and agronomists already employ this strategy frequently. Further education of industry is still required about which crops and varieties are most suitable, as almost 40% of participants indicated they have implemented a barley in their rotation in the last 2 years to reduce FCR risk. However, barley is susceptible to FCR, and exhibited the largest *Fp* DNA accumulation of all crop types in the glasshouse experiment. The general earlier maturity of barley compared with wheat can reduce exposure to heat and/or moisture stress during grain filling. This can be protective against FCR expression and associated yield loss from FCR in barley but is not guaranteed to reduce *Fp* inoculum levels.

Infection of more FCR-resistant cultivars by *Fp* can be difficult to detect visually, as basal browning symptoms are milder. Growers may therefore be unaware of *Fp* infection and/or the extent of colonisation in crops with minimal FCR symptoms. In our study, oat var. Eurabbie had lower (but still detectable) basal browning symptoms compared with barley and wheat cultivars. Oat may therefore be affected by FCR more frequently than previously thought, with visible detection via basal browning possible. The oat also contained similar levels of *Fp* DNA compared to several of the bread wheat cultivars in our experiment. Oat is therefore not recommended as a break crop for the purpose of reducing FCR risk within a cropping sequence. Still, oat crops may present a more diverse option for managing FCR as the stubble can decompose more rapidly than wheat and barley (to potentially displace *Fp*). It may also have the advantage of being grazed by stock which can also reduce stem colonisation by FCR pathogens (Nelson and Burgess 1995).

What are the dangers of post-harvest colonisation of stubble?

Saprotrophic colonisation of cereal stubble by *Fp* could contribute additional inoculum for future seasons. This is particularly important given that less-susceptible cereal crop types/cultivars can still experience extensive colonisation by *Fp* after harvest. In the glasshouse study, it appeared that plants which were less affected by FCR (e.g., oat and LCR2012-122) experienced higher levels of saprotrophic colonisation – possibly because the plants were able to grow taller and healthier due to improved partial resistance to FCR. This additional *Fp* inoculum, which is often not accounted for in integrated disease management, may be contributing to the persistence of FCR within cropping systems.

Previous work has shown that *Fp* can persist for at least 12 months in upper parts of cereal stubble that have been saprotrophically colonised after harvest (Petronaitis *et al.,* 2022). Inoculum maintained long-term in this section of the stubble may become problematic if standing stubble is disturbed, perhaps by being knocked over or distributed prior to sowing a new cereal crop. Examples of this include light tillage (e.g., Kelly chaining) or when harvesting a shorter stature break crop (e.g., chickpea or lentil) which have been sown into cereal stubble infected by *Fp*. This is because the infected stubble is likely to be spread at harvest when collecting pods low to the ground. Reducing the height of infected cereals at the time of cereal harvest can prevent saprotrophic colonisation (Petronaitis *et al.,* 2022). This strategy may be useful in high FCR risk scenarios where shorter-stature break crops (e.g., chickpea and lentil) are planned in the rotation, to prevent the spread of *Fp* inoculum during break crop harvest.

Further field evidence of saprotrophic colonisation by *Fp*

Preliminary data from Northern Farming Systems (DAQ2007-002RTX) trials at four sites in northern NSW have provided further evidence of saprotrophic colonisation of post-harvest stubble by *Fp*. Stubble naturally infected with *Fp* was collected from four experimental sites from plots containing cereals (barley and/or wheat) in late 2022 and re-sampled 12 months later. Locations include 2 experimental sites at Trangie (one characterised as ‘grey soil’ and one ‘red soil’), one at Spring Ridge, and one at Narrabri. Main tillers from 25 stubble butts per plot were sterilised and cultured as described above, except that stem pieces were assessed in 5 cm increments. Note the average *Fp* incidence for each sampling time have been reported here without statistical analysis (Figure 4).

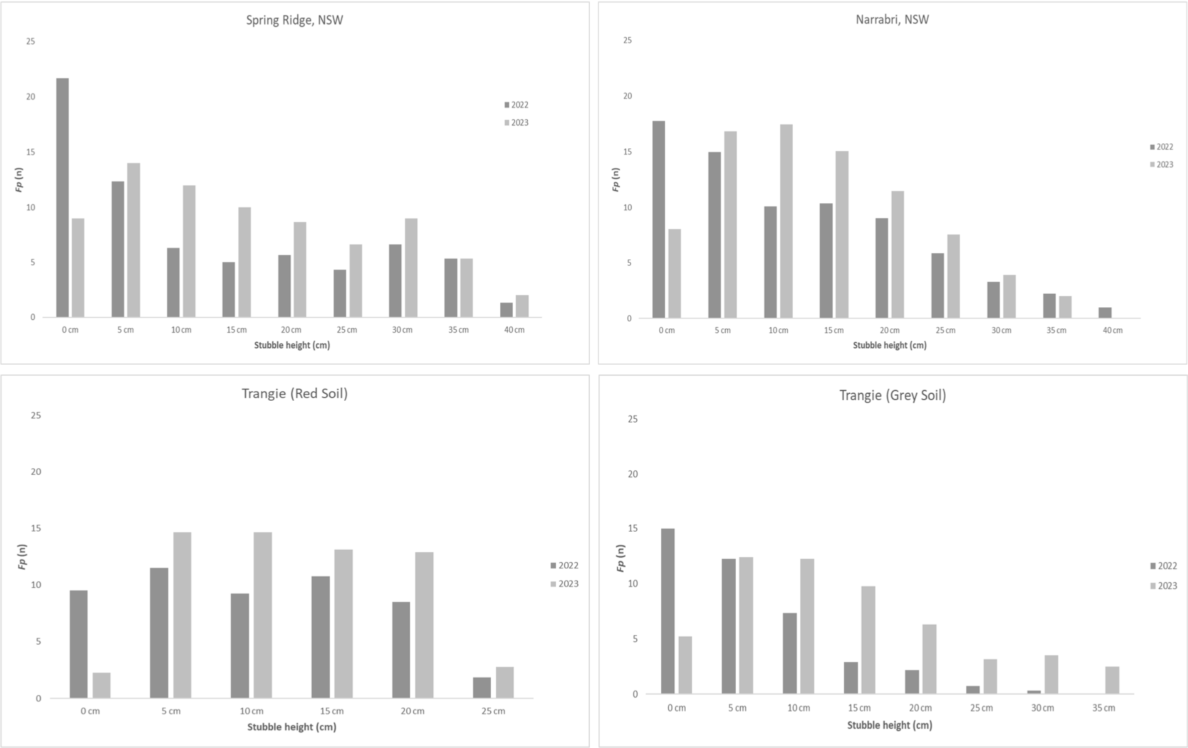

Figure 4. Preliminary data of the incidence of *Fp* recovery (*Fp* (n) being number of tillers producing *Fp* colonies) at 5 cm increments along the stubble length (stubble height, cm) at four different Northern Farming Systems experimental sites in northern NSW.

These preliminary data appear to have a similar pattern occurring at all four sites over the 12 months: there has been a general reduction in pathogen recovery in the crown (0 cm), maintenance of *Fp* incidence in the lower stem (5 cm) and then an increase in *Fp* incidence from approximately 10 cm and above (Figure 4). This reflects the rapid displacement of *Fp* from the crown by other soil microbes in the first year, but also reinforces how persistent *Fp* can be in the upper parts of retained cereal stubble. These results are in line with findings from randomised and replicated field experiments conducted on inoculated durum wheat stubble from 2019 to 2020 (Petronaitis *et al.,* 2022), suggesting that the pattern of saprotrophic colonisation is repeatable across different cereal crops, seasons and environments. Extensive stubble survey work conducted under a FCR co-investment (GRDC and NSW DPI, project code DPI2207-004RTX) will be used to further explore the frequency and extent of saprotrophic colonisation of stubble by *Fusarium* species in grower paddocks. This will help to better understand what factors may promote saprotrophic colonisation of retained cereal stubble by *Fp* in the farming system.

Conclusions

Preventing infection of cereal plants by *Fp* offers the greatest protection from FCR. For now, partial resistance to FCR offers benefits like slowing infection and reducing yield loss. Even the more resistant winter cereals such as oat can still get infected by *Fp* but can be asymptomatic (i.e., do not always express FCR) so *Fp* may go undetected in these crops. Inoculum may then accumulate after harvest once plant defence mechanisms are no longer active. Preliminary field results are showing that *Fp* incidence increases within the stems of stubble across a range of environments and crop types in the first year after harvest. More work is needed to understand what drives saprotrophic colonisation and the implications for FCR risk in future seasons.

References

Knight NL, Sutherland MW (2017) Assessment of *Fusarium pseudograminearum* and *F. culmorum* biomass in seedlings of potential host cereal species. Plant Disease 101:2116-2122.

Nelson KE, Burgess LW (1995) Effect of rotation with barley and oats on crown rot of wheat in the northern wheat belt of New South Wales. Australian Journal of Experimental Agriculture 35:765-770

Petronaitis T, Forknall C, Simpfendorfer S, Backhouse D and Flavel R (2022) Harvest height implications for Fusarium crown rot management. GRDC Update, online, 2 March 2022 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/harvest-height-implications-for-fusarium-crown-rot-management

Petronaitis T, Forknall C, Simpfendorfer S, Backhouse D (2020) Stubble Olympics: the cereal pathogen 10cm sprint. GRDC Update, Goondiwindi, March 2020 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2020/08/stubble-olympics-the-cereal-pathogen-10cm-sprint

Summerell BA and Burgess LW (1988) Stubble management practices and the survival of *Fusarium graminearum* Group 1 in wheat stubble residues. Australasian Plant Pathology, 17:88-93

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. Thanks also to the Grains Agronomy and Pathology Partnership (GRDC and NSW DPI) which co-funded part of this research through Dr Petronaitis' GAPP PhD scholarship.

Thanks also to Dr Cassy Percy for providing germplasm for the glasshouse experiment, and Branko Duric for providing stubble from the Northern Farming Systems project. Additional technical support provided by Nicole Dunn, Barbara Jones, Alana Roe, and Caroline Stewart is gratefully acknowledged.

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Increased wheat plant population: the interaction with variety, Fusarium crown rot and nitrogen

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Key words

Fusarium crown rot, *Fusarium pseudograminearum*, wheat, plant population, nitrogen, yield stability, variety, screenings

GRDC codes

GOA2006-001RTX
DPI2207-004RTX

Take home message

- Fusarium crown rot (FCR) pressure had a greater impact on wheat yield and quality than plant population or nitrogen (N) status under low to moderate yield conditions.
- The interaction of FCR pressure, N status and plant population varied depending upon variety.
- Beckomɸ and LRPB Flankerɸ outyielded LRPB Raiderɸ and LRPB Lancerɸ, but suffered greater yield loss from FCR. Despite this, under higher FCR pressure both Beckomɸ and LRPB Flankerɸ out yielded LRPB Lancerɸ and LRPB Raiderɸ.
- Higher plant populations either increased yield or had no impact at the three sites.
- Under higher FCR pressure in moderate yield environments of 3–4.5 t/ha, increasing plant populations appeared to reduce the impact of FCR.

Background

Growers are urged to use other weed control tactics besides herbicides to continue to farm sustainably in the future. One option is to increase crop competition against weeds. This reduces the ability of the weed to compete for limited resources like moisture and nutrients in the short term, but also benefits in the medium to longer term through reduced weed seed set.

Increasing crop competition can be achieved through crop choice, row spacing or plant populations. The first 2 options are restricted by several factors, such as crop suitability, growing environments and profitability, as well as the need to invest in new machinery and/or modification to change plant row spacings. However, changing plant populations is a relatively easy option achieved by simply adjusting sowing rates.

Many growers and advisors are concerned that increasing plant populations could lead to an increased risk of yield and grain quality instability, ultimately reducing crop profitability. This view is more common in the lower rainfall growing areas where relatively low plant populations are the norm. If growers were confident that increasing plant population did not carry the risk of reduced yield or poor grain quality, it would be an easy and relatively low-cost option in the battle against weeds and herbicide resistance.

In response, Grain Orana Alliance (GOA), with the support of the Grains Research and Development Corporation (GRDC), has for the past 4 years conducted a series of trials investigating the impact of wheat population on yield and quality in the low rainfall environments of the GOA region (central west NSW). It is clear from this data set of 10 trials (over 5 years; 2018, 2020-2023, and 15 varieties) that increasing plant population resulted in higher yield (**Figure**) with fewer screenings in the majority of cases. There were cases where yield was reduced and/or screenings increased, however the impact was less frequent and severe compared to the yield benefits of higher plant populations.

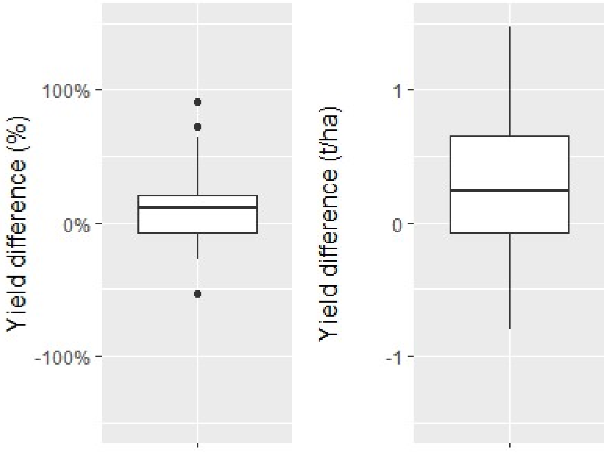


Figure 1. Yield difference % (left) and t/ha (right) moving from the lowest to the highest wheat population averaged across 5 trial years, 10 sites and 15 varieties.

It has been hypothesised that fusarium crown rot (FCR), may be contributing to a common commercial perception of higher plant populations having reduced yield and increased screenings. Previous trials were largely conducted in low FCR risk situations, such as following canola or pulse break crops, which may explain the differing outcomes. But for growers it is not always possible to sow into low disease risk paddocks.

FCR impacts the crown and lower stem bases of infected wheat plants reducing its ability to transport water which is most influential on yield and quality in hot and/or dry springs during seed set and grain filling. Growers and advisors in the region question whether increased plant population could further exacerbate stress during this period and hence further exacerbate the impact of FCR. In addition, will increasing nitrogen (N) rates exacerbate the yield impact of FCR through excessive moisture use before grain fill, leading to increased stress during grain filling.

In 2023 three collaborative trials, between NSW DPI, Brill Ag and GOA with the support of GRDC, were established across central west and southern NSW to investigate if there is an interaction between plant variety, populations, FCR and N nutrition.

The trials

Three small-plot trials were established. At the Coonamble and Nyngan sites, trials were randomised, complete block factorial designs and at Ganmain trials were a split-plot (with nitrogen as main block) factorial design, all examining the 4 variables outlined in Table 1.

Table 1. Treatments implemented in 2023 trials at Ganmain, Coonamble and Nyngan, NSW.

Wheat variety	Target plant population (pl/m^2)	N strategy	FCR inoculum
Beckom⦶	Moderate (targeting 70 plants/m^2)	-N (40 kg/ha added at Ganmain, 25 kg/ha at Nyngan and Coonamble)	-FCR (background level)
LRPB Flanker⦶			
LRPB Lancer⦶	High (targeting 150 plants/m^2)	+ N (130 kg/ha added at Ganmain, 100 kg/ha at Nyngan and Coonamble)	+FCR (plots inoculated)
LRPB Raider⦶			

Plant population

Seed was accessed from the GRDC experimental seed supply program to ensure trueness to type and was not treated with any seed dressings. Seeding rates were calculated based on individual variety germination rates, seed size (1000 seed weight) and assumed establishment percentages. Individual sowing rates are shown in Table 2.

Table 2. Seeding rates used for varieties tested at two contrasting plant populations in 2023 at Ganmain, Coonamble and Nyngan, NSW.

Variety	**Seeding rate (kg/ha)**	
	Moderate	**High**
Beckom⦶	29	61
LRPB Flanker⦶	37	79
LRPB Lancer⦶	35	76
LRPB Raider⦶	37	80

FCR

The +FCR plots were inoculated at sowing with non-viable wheat seed colonised by *F. pseudograminearum* (mixture of 5 isolates) at the rate of 1.4 g/m row (100 grams/plot) to establish a medium to high disease pressure (Forknall *et al.,* 2019). The -FCR plots received no artificial inoculation. PreDicta® B tests were conducted confirming Coonamble, Nyngan and Ganmain sites had FCR inoculum levels below detection (BDL) and all had canola as the previous crop. The Coonamble site was burnt to enable sowing, Nyngan was Kelly disced, and Ganmain was treated with a stubble cruncher.

Nitrogen

All N was applied as urea and incorporated by sowing, except Ganmain which had 40 kg N/ha broadcast over all treatments on 4 August.

Table 3. Site details for the 3 trials in 2023. FCR status, BDL = below detection limit, GSR = growing season rainfall

Trial location	**FCR status**	**Sowing date**	**Starting N (0–60 cm)**	**GSR (May–Sept)**
Coonamble	BDL	19 May 2023	80 kg/ha	53 mm
Nyngan	BDL	18 May 2023	98 kg/ha	54 mm
Ganmain	BDL	24 May 2023	55 kg/ha	140 mm

Results summary

The results presented were analysed using ASReml and any references to differences are statistically significant to 95% confidence. Results presented with the same letter are not significantly different (*P*=0.05). A factorial analysis of the trials resulted in the following findings.

Nyngan

- High plant population had no impact on yield, but increased screenings from 3.3% to 4.0% compared to moderate plant population.
- The +N treatment reduced yield by ~0.16 t/ha (12%) and increased screenings from 3.5% to 3.8% compared to the -N treatment.
- The +FCR reduced yield by ~0.38 t/ha (26%) and increased screenings from 2.1% to 5.2% compared to the -FCR treatment.

Coonamble

- High plant population increased yield by ~0.35 t/ha (~9%), and reduced screenings from 2.3% to 2.0% compared to moderate plant population.
- The +N treatment increased yield by ~0.29 t/ha (8%) and had no impact on screenings compared to the -N treatment.
- The +FCR reduced yield by ~0.61 t/ha (-16%) and increased screening from 1.9% to 2.4% compared to the -FCR treatment.

Ganmain

- High plant population increased yield by ~0.39 t/ha (12%) and increased screenings from 1.8% to 1.9% compared to moderate plant population.
- The +N treatment increased yield by 0.29 t/ha (9%) increased screenings from 1.6% to 2.1% compared to the -N treatment.
- The +FCR reduced yields by ~0.39 t/ha (-10%) and increased screenings from 1.1% to 2.6% compared to the -FCR treatment.

Beckom⍉ yielded the highest or equal highest across all sites. LRPB Flanker⍉ was the lowest yielding at Ganmain and Coonamble, LRPB Lancer⍉ and LRPB Raider⍉ were equally the lowest at Nyngan. Differences between the lowest to the highest yielding varieties at Nyngan was 0.46 t/ha (+30%), Coonamble was 0.49 t/ha (+14%), and at Ganmain 0.97 t/ha (24%).

In summary across all sites, increasing plant population improved yield by 0–12%. Whereas +FCR had the largest negative effects of between 10–-27% yield reduction. Whilst there is a clear message in this alone, investigation of the influence of population on various combinations of variety, N and FCR pressure, revealed some interesting interactions.

Detailed results

The following results are based on an ANOVA and compare “paired” treatments, the pairs being +FCR and -FCR, or moderate versus high plant population whilst other parameters such as variety and N nutrition remains the same.

In the Tables 4 to 9 shading denotes a significant difference between the treatments within the comparison. The lettering is across all treatments but only within either yield or screenings.

Nyngan

The effect of +FCR was significant (Table 4), negatively impacting three of the varieties (except LRPB Lancerⓓ) in at least three N and population scenarios. LRPB Flankerⓓ was the most affected by +FCR, with up to 0.94 t/ha yield loss in similar plant population and N nutrition scenarios. Beckomⓓ and LRPB Raiderⓓ were less affected with up to 0.56 t/ha yield loss. LRPB Lancerⓓ was least affected by +FCR, with yield reduced by a maximum of 0.21 t/ha, in the +N, high population treatment (Table 4).

Adding FCR increased screenings in all variety, population and N combinations, with screenings ranging from 1.4% up to 6.1%, with LRPB Flankerⓓ and Beckomⓓ being the most affected.

Table 4. Impact of FCR pressure on yield and screenings of various combinations of wheat variety (Var), N nutrition and plant population (Pop), Nyngan 2023.

Var	**N**	**Pop**	**Yield (t/ha)**				**Δ Yield (t/ha)**	**Screenings (%)**				**Δ SCN (%)**
			-FCR		**+FCR**			**-FCR**		**+FCR**		
Beckom	+N	High	1.36	efgh	1.53	def	NS	2.3	jklmno	6.0	cd	3.8
		Moderate	1.77	abcd	1.25	ghij	-0.52	2.1	klmno	5.9	cde	3.7
	-N	High	1.81	ab	1.27	ghij	-0.54	2.5	ijklmn	7.2	ab	4.7
		Moderate	2.00	a	1.44	efg	-0.56	1.6	no	4.7	fg	3.1
Flanker	+N	High	1.55	def	0.90	mno	-0.65	3.0	ijk	6.6	bc	3.6
		Moderate	1.31	fghi	0.89	mno	-0.42	2.0	klmno	8.1	a	6.1
	-N	High	1.76	bcd	0.82	o	-0.94	2.6	ijklm	6.7	bc	4.0
		Moderate	1.79	abc	0.93	lmno	-0.86	2.0	lmno	5.0	ef	3.0
Lancer	+N	High	1.08	ijklmn	0.87	no	NS	2.2	klmno	3.9	gh	1.7
		Moderate	1.04	jklmno	1.02	klmno	NS	1.6	no	3.2	hij	1.6
	-N	High	1.29	ghi	1.11	ijklm	NS	1.8	mno	3.4	hi	1.6
		Moderate	1.24	ghijk	1.05	jklmno	NS	1.4	o	2.8	ijkl	1.4
Raider	+N	High	1.20	ghijk	0.95	lmno	-0.25	2.3	jklmno	5.3	def	3.0
		Moderate	1.21	ghijk	0.89	mno	-0.32	1.9	lmno	4.5	fg	2.6
	-N	High	1.56	cde	1.06	jklmn	-0.5	2.5	ijklmn	5.0	ef	2.5
		Moderate	1.26	ghij	1.14	hijkl	NS	1.8	mno	4.8	fg	3.1

When comparing the effects of plant population (Table 5), there were 3 paired comparisons where yield increased with population by 0.24–0.30 t/ha or 18–24% – Beckomⓓ with +N and +FCR, LRPB Flankerⓓ with +N and -FCR and LRPB Raiderⓓ with -N and -FCR.

Only in Beckomⓓ with +N and -FCR was there a yield decrease (0.41 t/ha or 23%) with the high plant population. All other comparisons of high and low population resulted in no yield impact (Table 5).

Table 5. Impact of plant population on yield and screenings of various combinations of wheat variety (Var), N nutrition N and FCR, Nyngan 2023.

VAR	N	FCR	Yield (t/ha)				Δ Yield (t/ha)	Screenings (%)				Δ SCN (%)
			Moderate population		High population			Moderate population		High population		
Beckom	+N	+FCR	1.25	ghij	1.53	def	0.28	5.9	cde	6.0	cd	NS
		-FCR	1.77	abcd	1.36	efgh	-0.41	2.1	klmno	2.3	jklmno	NS
	-N	+FCR	1.44	efg	1.27	ghij	NS	4.7	fg	7.2	ab	2.5
		-FCR	2.00	a	1.81	ab	NS	1.6	no	2.5	ijklmn	NS
Flanker	+N	+FCR	0.89	mno	0.90	mno	NS	8.1	a	6.6	bc	-1.5
		-FCR	1.31	fghi	1.55	def	0.24	2.0	klmno	3.0	ijk	NS
	-N	+FCR	0.93	lmno	0.82	o	NS	5.0	ef	6.7	bc	1.7
		-FCR	1.79	abc	1.76	bcd	NS	2.0	lmno	2.6	ijklm	NS
Lancer	+N	+FCR	1.02	klmno	0.87	no	NS	3.2	hij	3.9	gh	NS
		-FCR	1.04	jklmno	1.08	ijklmn	NS	1.6	no	2.2	klmno	NS
	-N	+FCR	1.05	jklmno	1.11	ijklm	NS	2.8	ijkl	3.4	hi	NS
		-FCR	1.24	ghijk	1.29	ghi	NS	1.4	o	1.8	mno	NS
Raider	+N	+FCR	0.89	mno	0.95	lmno	NS	4.5	fg	5.3	def	0.8
		-FCR	1.21	ghijk	1.20	ghijk	NS	1.9	lmno	2.3	jklmno	NS
	-N	+FCR	1.14	hijkl	1.06	jklmn	NS	4.8	fg	5.0	ef	NS
		-FCR	1.26	ghij	1.56	cde	0.3	1.8	mno	2.5	ijklmn	NS

There were 3 paired treatments where screenings increased (between 0.8% and 2.5%) at higher plant population, each +FCR (see Table 5, shaded cells): Beckomⓓ -N, LRPB Flankerⓓ -N, and LRPB Raiderⓓ +N. LRPB Flankerⓓ +N resulted in lower screenings at the high plant population compared with the moderate plant population. All other comparisons of plant population resulted in no effects on screenings.

Coonamble

The addition of +FCR reduced yield by up to 1.20 t/ha (32%) in all paired combinations of variety, population, and N rate, except for one (Table 6). Beckomⓓ and LRPB Flankerⓓ were affected more than LRPB Lancerⓓ and LRPB Raiderⓓ by +FCR. Screenings in LRPB Flankerⓓ increased with +FCR, regardless of N or population. Several other comparisons showed increases in screenings, but none resulted in screenings greater than 5%, the limit for milling wheat (Table 6).

Table 6. Impact of FCR pressure on yield and screenings of various combinations of wheat variety (Var), N nutrition and plant population (Pop), Coonamble 2023

Var	N	Pop	Yield (t/ha)				Δ Yield (t/ha)	Screenings (%)				Δ SCN (%)
			-FCR		+FCR			-FCR		+FCR		
Beckom	+N	High	4.43	a	3.96	cde	-0.47	1.5	j	1.9	fghij	NS
		Moderate	4.41	a	3.45	hijk	-0.96	2.1	efgh	2.2	defg	NS
	-N	High	4.34	ab	3.60	ghi	-0.74	1.4	j	1.6	hij	NS
		Moderate	3.68	efgh	3.12	mn	-0.56	1.4	j	2.0	fghi	0.6
Flanker	+N	High	4.12	bc	3.35	ijklmn	-0.77	1.8	ghij	2.4	cdef	0.6
		Moderate	3.83	defg	2.61	o	-1.22	2.2	defg	2.8	abc	0.6
	-N	High	3.94	cde	3.06	n	-0.88	1.9	fghij	2.6	bcde	0.7
		Moderate	3.41	hijkl	2.69	o	-0.72	2.2	defg	3.3	a	1.2
Lancer	+N	High	3.98	cd	3.53	hij	-0.45	1.5	ij	1.9	fghij	NS
		Moderate	3.55	ghi	3.24	jklmn	-0.31	1.9	fghij	2.2	defg	NS
	-N	High	3.62	fghi	3.12	lmn	-0.5	1.5	ij	2.1	defghi	NS
		Moderate	3.19	klmn	3.07	n	NS	2.1	defgh	2.6	bcd	NS
Raider	+N	High	4.14	abc	3.52	hij	-0.62	2.2	defg	2.4	cdef	NS
		Moderate	4.07	bcd	3.37	ijklm	-0.7	2.1	efgh	2.4	cdef	NS
	-N	High	3.90	cdef	3.46	hijk	-0.44	2.1	defgh	3.1	ab	0.9
		Moderate	3.50	hij	3.18	klmn	-0.32	2.0	fghi	2.6	bcde	0.5

Increasing population from a moderate to high had no impact in six comparisons (Table 7). Yield increased by 8% to 28% or up to 0.74 t/ha in the remaining ten comparisons of plant population.

In no comparisons did increasing plant population from moderate to high increase screenings. Three of the 16 comparisons at Coonamble resulted in lower screenings (0.4–0.7%) when plant population was increased (Table 7). In no cases were screenings >5%, the threshold for milling wheat. There was no impact of plant population on screenings in LRPB Raider.

Table 7. Impact of population on yield and screenings of various combinations of wheat variety (Var.), N nutrition and FCR, Coonamble 2023.

VAR.	N	FCR.	Yield (t/ha)		Δ Yield (t/ha)	Screenings (%)		Δ SCN (%)
			Moderate population	High population		Moderate population	High population	
Beckom	+N	+FCR	3.45 hijk	3.96 cde	0.51	2.2 defg	1.9 fghij	NS
		-FCR	4.41 a	4.43 a	NS	2.1 efgh	1.5 j	-0.6
	-N	+FCR	3.12 mn	3.60 ghi	0.48	2.0 fghi	1.6 hij	NS
		-FCR	3.68 efgh	4.34 ab	0.66	1.4 j	1.4 j	NS
Flanker	+N	+FCR	2.61 o	3.35 ijklmn	0.74	2.8 abc	2.4 cdef	NS
		-FCR	3.83 defg	4.12 bc	0.29	2.2 defg	1.8 ghij	NS
	-N	+FCR	2.69 o	3.06 n	0.37	3.3 a	2.6 bcde	-0.7
		-FCR	3.41 hijkl	3.94 cde	0.53	2.2 defg	1.9 fghij	NS
Lancer	+N	+FCR	3.24 jklmn	3.53 hij	NS	2.2 defg	1.9 fghij	NS
		-FCR	3.55 ghi	3.98 cd	0.43	1.9 fghij	1.5 ij	NS
	-N	+FCR	3.07 n	3.12 lmn	NS	2.6 bcd	2.1 defghi	NS
		-FCR	3.19 klmn	3.62 fghi	0.43	2.1 defgh	1.5 ij	-0.6
Raider	+N	+FCR	3.37 ijklm	3.52 hij	NS	2.4 cdef	2.4 cdef	NS
		-FCR	4.07 bcd	4.14 abc	NS	2.1 efgh	2.2 defg	NS
	-N	+FCR	3.18 klmn	3.46 hijk	NS	2.6 bcde	3.1 ab	NS
		-FCR	3.50 hij	3.90 cdef	0.4	2.0 fghi	2.1 defgh	NS

Ganmain

Most paired comparisons of +/-FCR had no impact on yield (Table 8). There was no effect of FCR in LRPB Lancerɸ, however LRPB Raiderɸ and LRPB Flankerɸ yield was lower at moderate populations when FCR pressure was increased, but there was no impact at higher populations regardless of N. Beckomɸ yield was reduced under +N and high population. Screenings increased with +FCR for all but 2 comparisons: LRPB Lancerɸ -N at both moderate and high plant population.

Table 8. Impact of FCR pressure on yield and screenings of various combinations of wheat varietiy (Var), N nutrition and plant population (Pop), Ganmain 2023.

Var.	N	Pop.	Yield (t/ha)				Δ yield (t/ha)	Screenings (%)				Δ SCN (%)
			-FCR		+FCR			-FCR		+FCR		
Beckom	+N	High	4.77	a	4.31	bc	-0.46	1.2	klmn	2.4	fgh	1.2
		Moderate	4.08	bcde	3.69	efghi	NS	1.0	mn	3.0	de	2.0
	-N	High	4.08	bcde	3.69	efghi	NS	0.9	n	1.7	ijk	0.8
		Moderate	3.95	bcdef	3.56	fghijk	NS	0.9	n	1.4	klm	0.5
Flanker	+N	High	3.64	efghij	3.20	jklmn	NS	1.1	mn	2.9	de	1.8
		Moderate	3.17	klmn	2.49	op	-0.68	1.0	mn	3.3	cd	2.3
	-N	High	3.47	ghijkl	3.04	lmn	NS	0.9	n	2.8	def	1.9
		Moderate	2.91	mno	2.41	p	-0.5	1.1	lmn	2.7	efg	1.5
Lancer	+N	High	3.67	efghi	3.34	ijklm	NS	0.9	n	2.0	hi	1.1
		Moderate	3.45	ghijkl	3.21	jklm	NS	0.9	n	1.4	klm	0.5
	-N	High	3.40	hijkl	3.41	hijkl	NS	1.0	n	1.1	lmn	NS
		Moderate	2.92	mno	2.73	nop	NS	1.0	mn	1.1	lmn	NS
Raider	+N	High	4.29	bcd	4.02	bcdef	NS	2.0	hij	5.2	a	3.2
		Moderate	4.43	ab	3.65	efghij	-0.78	1.5	jkl	4.2	b	2.7
	-N	High	4.01	bcdef	3.83	defgh	NS	1.3	klmn	3.5	c	2.2
		Moderate	3.90	cdefg	3.40	hijkl	-0.5	1.4	klm	2.2	gh	0.8

Increasing the plant population at Ganmain did not reduce yield (Table 9). There were 8 cases with no impact, and for the remaining eight, yield increased 0.47–0.71 t/ha (19–29%) with increased plant population. LRPB Flankerⓓ responded in all 4 population comparisons, +/- N and +/- FCR. Beckomⓓ responded in two comparisons, both +N and +/- FCR, as did LRPB Lancerⓓ for the -N treatment. LRPB Raiderⓓ did not respond to plant population.

Three comparisons resulted in higher screenings with increased population but only one was >5% (Table 9). Screenings were slightly lower in Beckomⓓ with +N and +FCR.

Table 9. Impact of plant population (Pop) on yield and screenings of various combinations of wheat variety (Var), N nutrition and FCR, Ganmain 2023.

VAR	N	FCR	Yield: (t/ha)				Δ Yield (t/ha)	Screenings (%)				Δ SCN (%)
			Moderate population		High population			Moderate population		High population		
Beckom	+N	+FCR	3.69	efghi	4.31	bc	0.62	3.0	de	2.4	fgh	-0.6
		-FCR	4.08	bcde	4.77	a	0.69	1.0	mn	1.2	klmn	NS
	-N	+FCR	3.56	fghijk	3.69	efghi	NS	1.4	klm	1.7	ijk	NS
		-FCR	3.95	bcdef	4.08	bcde	NS	0.9	n	0.9	n	NS
Flanker	+N	+FCR	2.49	op	3.20	jklmn	0.71	3.3	cd	2.9	de	NS
		-FCR	3.17	klmn	3.64	efghij	0.47	1.0	mn	1.1	mn	NS
	-N	+FCR	2.41	p	3.04	lmn	0.63	2.7	efg	2.8	def	NS
		-FCR	2.91	mno	3.47	ghijkl	0.56	1.1	lmn	0.9	n	NS
Lancer	+N	+FCR	3.21	jklm	3.34	ijklm	NS	1.4	klm	2.0	hi	0.6
		-FCR	3.45	ghijkl	3.67	efghi	NS	0.9	n	0.9	n	NS
	-N	+FCR	2.73	nop	3.41	hijkl	0.68	1.1	lmn	1.1	lmn	NS
		-FCR	2.92	mno	3.40	hijkl	0.48	1.0	mn	1.0	n	NS
Raider	+N	+FCR	3.65	efghij	4.02	bcdef	NS	4.2	b	5.2	a	1.0
		-FCR	4.43	ab	4.29	bcd	NS	1.5	jkl	2.0	hij	NS
	-N	+FCR	3.40	hijkl	3.83	defgh	NS	2.2	gh	3.5	c	1.3
		-FCR	3.90	cdefg	4.01	bcdef	NS	1.4	klm	1.3	klmn	NS

Discussion

The 3 trial sites in 2023 could be broadly categorised into 2 yield environments: low at Nyngan ~1 t/ha and moderate at both Ganmain and Coonamble, yielding up to ~4.7 t/ha. Despite this, all sites showed significant impacts from the addition of FCR. Nyngan had the largest percentage yield loss across all varieties and N levels from +FCR (26% or ~0.38 t/ha). Ganmain had only ~12% average yield loss across all varieties and N levels from +FCR. Interestingly, the actual tonnage of yield loss from FCR at Ganmain was 0.39 t/ha which was equivalent to the 0.38 t/ha loss associated with FCR infection at Nyngan even though these two sites had vastly different yield potentials in 2023. Individual varieties suffered much bigger losses. At Nyngan, individual varieties had yield reductions of up to 53%, Coonamble up to 32% and Ganmain up 21%, due increased FCR.

The effects of +FCR on screenings at Nyngan was substantial and impacted all treatment combinations. In many situations, +FCR resulted in screenings above 5%, which generally pushed the samples out of higher priced milling grades. Similarly, +FCR at Ganmain increased screenings in all but two comparisons. Only in one comparison were screenings >5% in response to +FCR.

The N impact varied between sites. There were slight yield reductions and increased screenings at Nyngan, possibly displaying typical haying off, a common concern of growers in these environments. However, the impacts were quite minimal in comparison to the effects of +FCR at this site. At Ganmain +N had no impact on yield and only a small increase in screenings. Again, the effects of this are dwarfed by that of +FCR. At Coonamble there was a large increase in yield and no impact on screenings from the +N application.

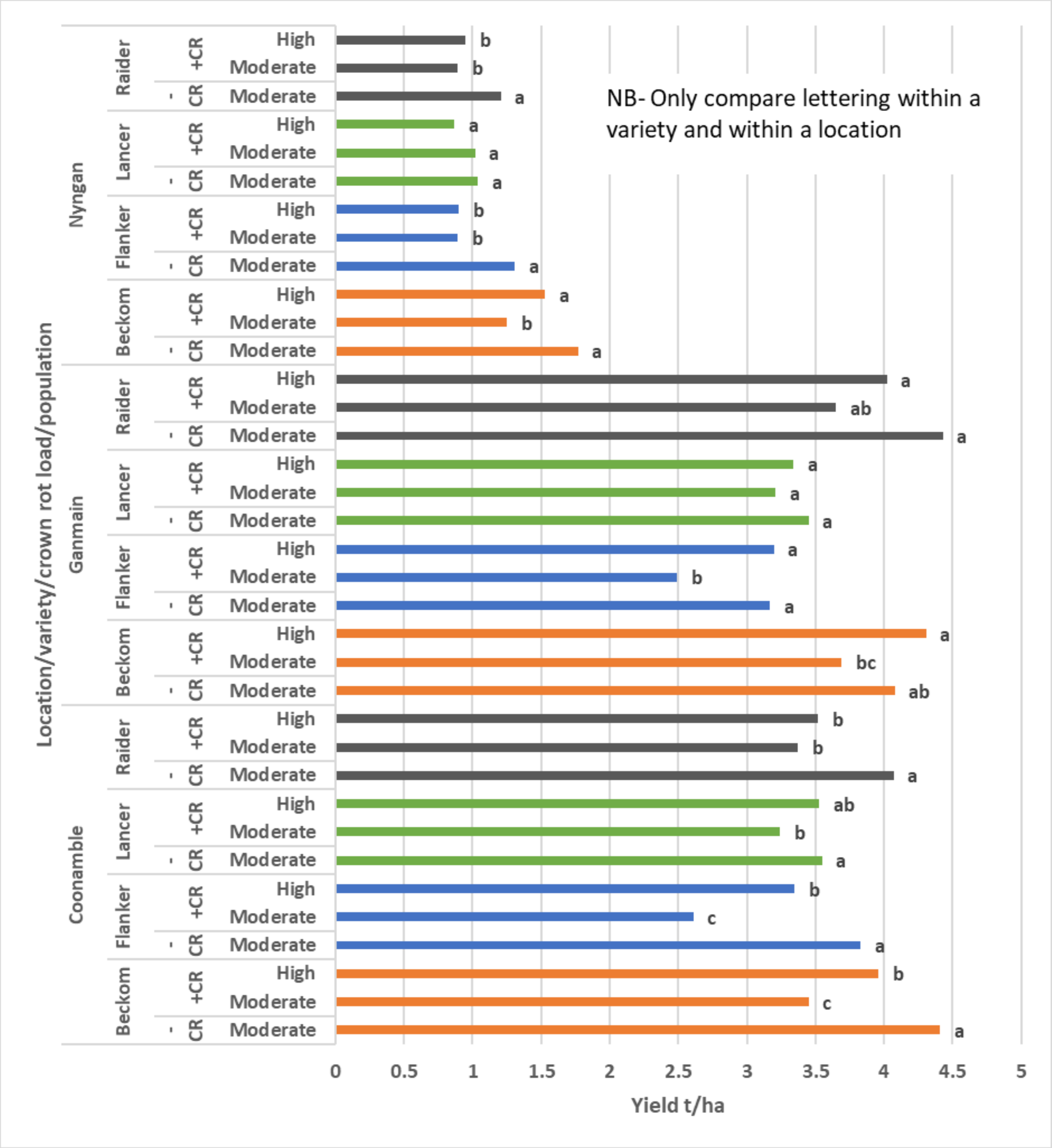
All the above results are intertwined with variety. At all sites Beckomⓓ was a top performer compared to the other varieties and both it and LRPB Flankerⓓ were affected the most by +FCR. Interestingly, even with the impacts of FCR on these two varieties, they often outperformed the other ‘more tolerant’ LRPB Lancerⓓ and LRPB Raiderⓓ, even in the absence of FCR (-FCR).

The effects of increasing plant population were often positive for yield and screenings. This benefit was greatest at the higher yielding sites at Coonamble and Ganmain. For both locations there was no negative impacts on yield but increases of up to 29% or 0.75 t/ha with the higher plant population.

At Coonamble, there was either no effect or a decrease on screenings with higher plant populations. For most treatments at Ganmain there was no impact of population on screenings, except in a few cases where a slight increase (<1.3%) was recorded.

Nyngan was less responsive to increasing plant populations, most treatments having no response. The few cases that did respond were mostly positive with yield gains of up to 0.30 t/h or 24% with the higher plant population treatment. Only one comparison out of 16 pairs resulted in a yield decrease of 0.41 t/ha with the high plant population. In only 3 out of 16 comparisons, screenings increased with higher plant population and were >5%.

An interesting interaction of FCR and plant population is illustrated in Figure 2. As already discussed, at moderate plant population the introduction of FCR can reduced yield. If we consider many of the factors investigated in these trials, for the +FCR treatments, increasing plant population often increased yield but not to the same extent as where FCR was lower. This was most evident in the higher yielding sites of Coonamble and Ganmain and in the less tolerant varieties Beckom and LRPB Flanker. This could prove a useful tool for growers to combat the impacts of FCR in moderate risk situations. In the lower yielding Nyngan site, the benefits were less. The reasons for this positive response cannot be explained, however it was observed but not measured that crop maturity was earlier at high population. The high population crops escaped heat and moisture stress that the moderate populations experienced, resulting in improved yields. This may warrant further investigation.



NB- Only compare lettering within a variety and within a location

Figure 2. Impact of increased plant population at high and low FCR pressure, and high nitrogen on yield of various varieties at Nyngan, Coonamble and Ganmain, 2023.

Conclusions

Growers are being encouraged to increase crop competition through increasing plant populations to aid in weed control. These trials have shown concerns by advisors and growers of decreased yield and increased screenings, particularly in low yielding environments, may not be well founded.

The first year of these trials reiterates the significant effect that FCR can have on wheat in both low and moderate yielding situations. The negative impacts resulted in both yield reduction and reduced grain quality (increased screenings).

Manipulation of plant population is emerging as a possible tool to reduce the effects of FCR. There was little negative impact of increasing plant population and more positive effects which resulted in increased yield, and in some cases reduced screenings.

Variety choice had a large effect on yield in the presence of FCR. Beckomⓓ and LRPB Flankerⓓ had the greatest yield reductions from FCR compared to LRPB Lancerⓓ and LRPB Raiderⓓ, however in many cases Beckomⓓ and LRPB Flankerⓓ, under higher FCR pressure, still outyielded these more tolerant varieties. The performance of these more intolerant varieties could also be improved under higher FCR pressure by increasing plant population.

This initial research has demonstrated that increasing plant population did not negatively impact crop performance and consistently resulted in improved yield and grain quality. This did not account for the benefits that increased plant populations could offer in terms of weed control. These trials have potentially identified that growers could increase plant populations to limit potential negative impacts of FCR, which was the largest driver of yield reduction in these trials.

Reference

Forknall CR, Simpfendorfer S, Kelly AM (2019) Using yield response curves to measure variation in the tolerance and resistance of wheat cultivars to Fusarium crown rot. *Phytopathology* **109**: 932-941.

Acknowledgements

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

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Septoria tritici blotch- risk and management considerations for 2024

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Key words

correct diagnosis, leaf disease, STB, pycnidia, integrated disease management (IDM)

GRDC codes

DAN00213: Grains Agronomy & Pathology Partnership (GAPP) - A strategic partnership between GRDC and NSW DPI. Projects BLG208 and BLG207 (completed)
DPI2207-002RTX: Disease surveillance and related diagnostics for the Australian grains industry (NSW)
DAN1907: NVT Services Agreement 2019-2023

Take home message

- Favourable climatic conditions early in the growing season of 2023 resulted in the widespread and increased prevalence of Septoria tritici blotch (STB) in southern NSW (sNSW)
- With resultant high stubble loads from the 2021 – 2023 seasons, STB risk levels are likely to be elevated again in 2024
- STB infection and epidemic development is highly dependent on climatic conditions throughout the season. Climatic conditions in 2024 will dictate the severity of any STB epidemic.
- If optimal climatic conditions are experienced and early STB infection is evident, apply fungicide at GS31 to suppress the epidemic and enable flexibility with later fungicide applications
- Not all fungicide active ingredients are equal when it comes to controlling STB and fungicide choice is becoming increasingly important
- NSW DPI plant pathologists can assist with correct diagnosis and advice on appropriate integrated disease management (IDM) options.

Introduction

Septoria tritici blotch (STB) is a necrotrophic disease of bread wheat, durum wheat and triticale, caused by the pathogen *Zymoseptoria tritici* (*Z. tritici*). STB is considered the third most significant wheat disease globally, threatening large areas of wheat production. Studies at the Wagga Wagga Agricultural Institute (2020 to 2021) revealed that in regions with moderate to high rainfall, the disease could lead to a considerable reduction in crop yield, ranging from 19% to 49%.

STB has a fungal structure produced on wheat stubble (pseudothecia), which releases airborne spores (ascospores) under ideal environmental conditions. The ascospores produced can spread over long distances (kilometres) on the wind to infect susceptible crops. Following an infection event, lesions appear up to 28 days later and produce pycnidia (small black structures inside tan leaf lesions that give a speckled appearance). The pycnidia produce a different type of spore called conidia, which are then splash-dispersed by rainfall within the wheat canopy, causing new infections and further driving the STB epidemic.

Under the NSW DPI project DPI2207-002RTX with co-investment from GRDC, diagnostic and management advice services are offered at no cost to growers and advisors. STB, for the third year in a row, was the fourth most queried disease during 2023 (data not shown), further emphasising the importance of this disease in southern and central NSW.

Septoria epidemic during the 2022 and 2023 growing seasons

The start of the 2023 growing season for much of southern New South Wales (sNSW) was characterised by widespread STB infection in the lower canopy of susceptible wheat varieties. However, unlike 2022 this early infection did not generally progress to the upper canopy during grain filling nor result in significant yield loss. Several climatic and management differences during 2023, as opposed to 2022 can help explain this.

STB development is highly driven by climatic conditions and requires extended periods of leaf wetness (>24 hours) and optimal cycling temperatures for infection of 15-20°C. There was below-mean rainfall during winter and spring at Wagga Wagga in 2023 (Figure 1). The long-term cumulative historical mean annual rainfall for August, September and October at Wagga Wagga is 129.9 mm. During 2022, the rainfall received during that period was 335.2 mm compared with only 61.8 mm in 2023. These three months are crucial for the development of STB epidemics, as this is when STB moves from the lower to mid-canopy onto the upper leaves (Flag, Flag-1, Flag -2). This is important because the upper leaves contribute the most to yield accumulation. The 2023 spring rainfall during those critical months was less conducive to STB cycling than in 2022, resulting in reduced STB infection levels in the mid and upper canopy of wheat crops.

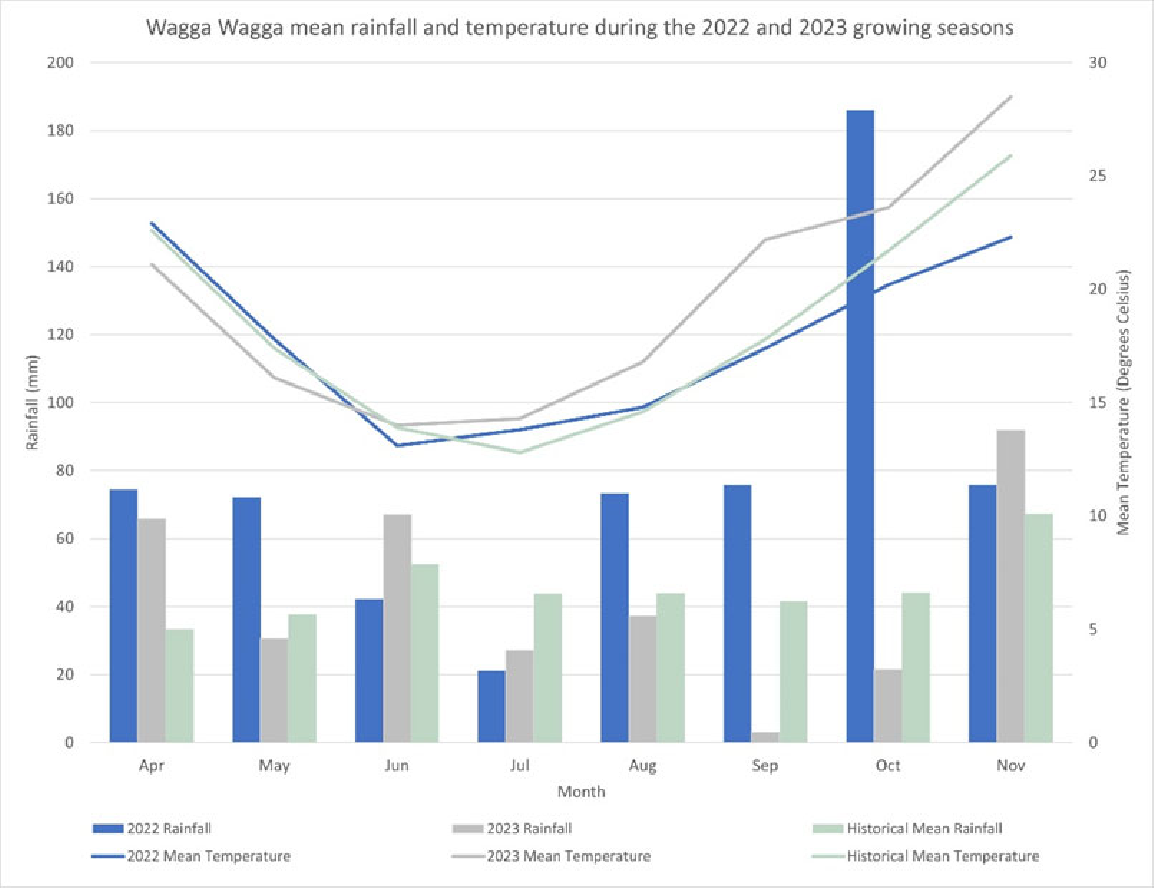


Figure 1. The growing season (April to November) rainfall and temperature during 2022 and 2023 as compared with the long-term mean monthly rainfall and temperature. The halt in STB infection levels during the second half of the 2023 growing season can be explained by the below mean rainfall and above mean temperatures during winter and spring months, particularly September and October (BOM, 2023).

The mean temperature during the spring months of 2023 was much higher than 2022 (Figure 1). The deviation from historical mean temperature for August, September and October during the 2022 and 2023 growing seasons are outlined in Table 1. In 2022, temperatures were much cooler, facilitating STB infection and cycling, whereas 2023 temperatures were outside the ideal cycling temperatures for STB development much earlier in the season and resulted in shortened leaf wetness duration. These factors reduced the number of cycles STB could undertake in 2023, helping to curb the levels of infection despite the extreme inoculum loads that had built up during the previous 2–3 years.

Table 1. Deviation from historical mean temperatures for August, September, and October 2022 and 2023

Month	Historical mean temperature (°C)	2022 deviation from historical mean temperature (°C)	2023 deviation from historical mean temperature (°C)
August	14.6	+0.2	+2.2
September	17.8	-0.4	+4.4
October	21.7	-1.5	+1.9

Temperature and rainfall are key factors that drive disease epidemics. However, for STB infection, leaf wetness and importantly the duration of leaf wetness also play a crucial role. The number of rainfall days and the consecutive number of rainfall days (greater than 2 days) during the growing seasons of 2022 and 2023 are outlined in Figure 2. A rainfall day is categorised as a fall of >5 mm in a 24-hour period and/or >5 mm falling during a single event over consecutive days (>2 days)

During the crucial three months for disease development – August, September and October – there is significantly less rain days along with less consecutive rainfall days in 2023 compared with 2022. For example, September 2022 had four rainfall events that lasted greater than two days, compared to zero during September 2023. October 2022 had four, and October 2023 had one rainfall day. This limitation in leaf wetness duration meant that the moisture requirement for STB to cycle was only partially met or not met at all, resulting in a net reduction in infection levels in 2023.

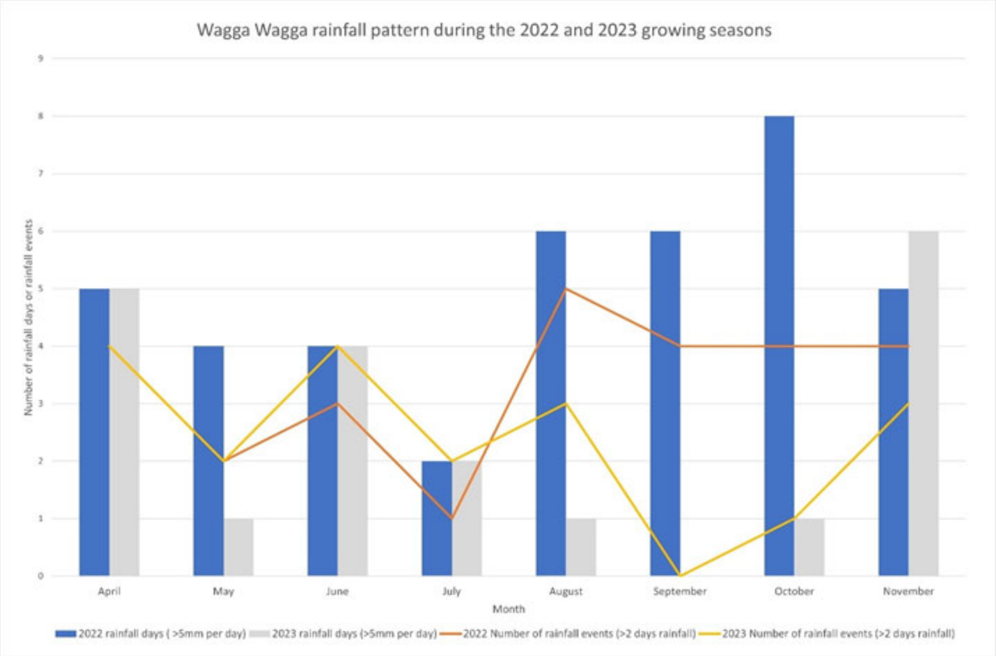


Figure 2. The growing season (April to November) number of rainfall days and number of consecutive rainfall days (>2 days) in 2022 and 2023 at Wagga.

Generally, the lack of rainfall, decrease in leaf wetness duration, higher-than-average temperatures and proactive fungicide use all contributed to STB staying in the lower to mid canopy of wheat crops in sNSW during the 2023 season. This was not the case for the entire cropping area of sNSW, particularly in the higher rainfall slopes regions, where STB continued to be a problem throughout the entirety of the 2023 season.

Septoria tritici blotch (STB) management considerations for 2024

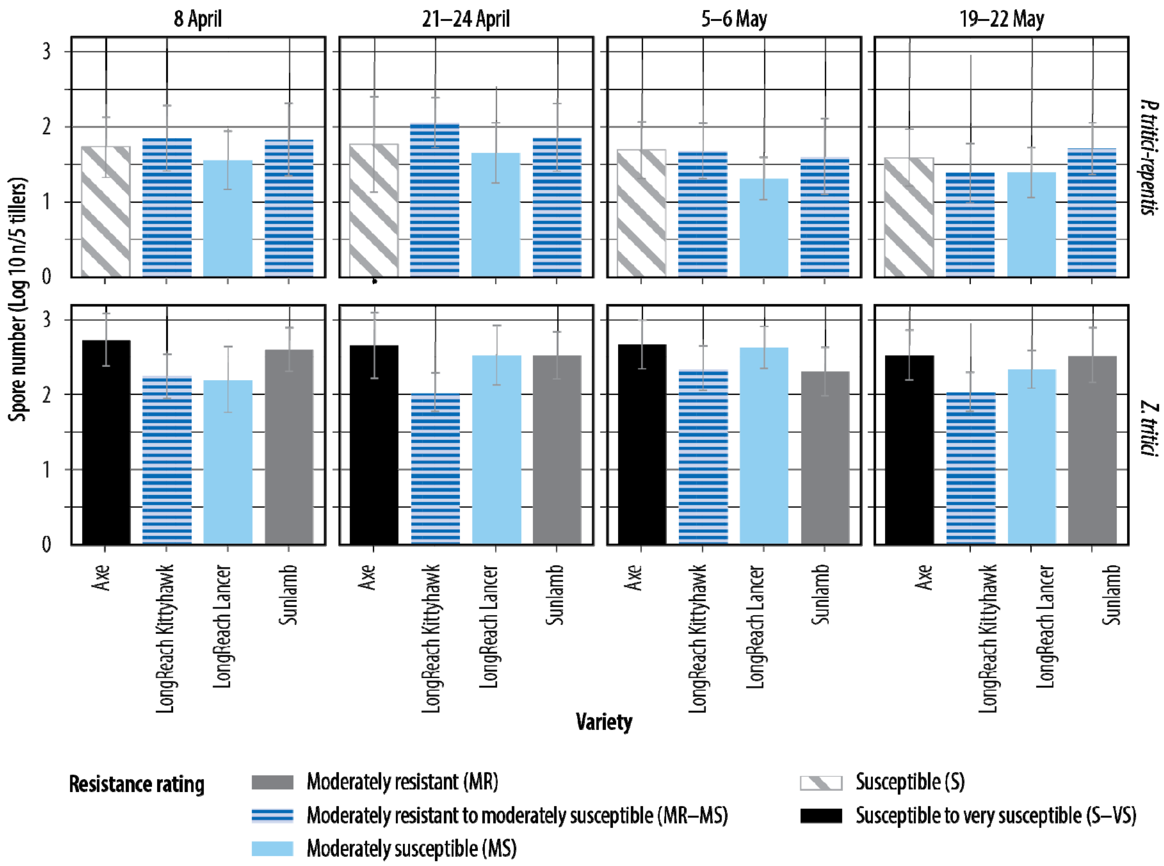
Even though STB did not pose a major threat in many regions in the latter half of 2023, the inherent risk moving forward is still elevated. An integrated disease management (IDM) system, comprised of the factors outlined below, should be implemented to reduce the risk of economic losses.

Stubble colonisation and associated management considerations

Stubble spore release experiments assessing plant resistance rating and time of sowing on ascospore release of pathogens *Z. tritici* (STB) and *Pyrenophora tritici-repentis* (Yellow leaf spot, YLS) were conducted at Wagga Wagga Agricultural Institute during 2020 and 2021 (Figure 3). Results have shown that the resistance rating of the wheat variety grown has little influence on the ability of these pathogens to colonise senescent stubble and inoculum levels produced off retained stubble, i.e., the number of spores released, in the following season.

There was no significant difference ($P = 0.05$) between the four sowing dates, or within a sowing date between varieties, in the number of *Z. tritici* and *P. tritici-repentis* ascospores released from stubble (Figure 3). In the case of STB, this means that a moderately resistant (MR) rated variety is statistically releasing the same number of ascospores in the following season as varieties rated moderately-resistant to moderately-susceptible (MR–MS), moderately susceptible (MS), susceptible (S) or susceptible to very-susceptible (S–VS). Essentially, the resistant rating of the plant does not carry over to ascospore release in the following season from the retained stubble. It is not known if the numerical differences in ascospore release numbers between variety resistance ratings, although not significant, have an influence on epidemic severity.

Therefore, any infected stubble from 2021–2023 must be considered a risk for the following wheat crop or crops nearby.

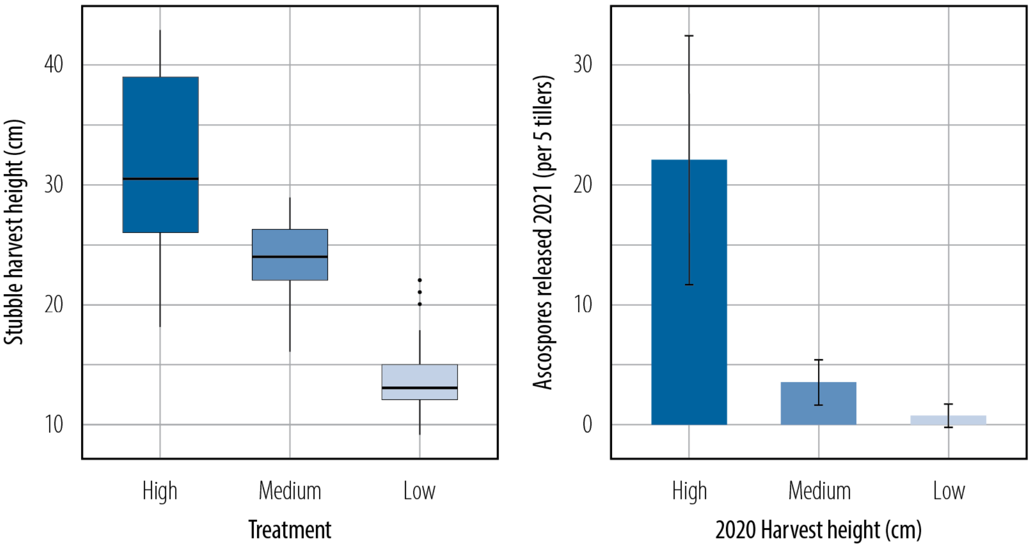


Note: The Log10 average combines all data from 2 years of spore release repetitions conducted in the laboratory.
There is no significant difference in the number of ascospores released between resistance ratings for both STB and YLS.
Log1 = 10 spores, Log 2 = 100 spores and Log 3 = 1000 spores.
Vertical bars represent 95% confidence intervals ($P = 0.05$).

Figure 3. The average number of *Zymoseptoria tritici* and *Pyrenophora tritici-repentis* ascospores (Log10) released from wheat stubble of four varieties with different resistance ratings to the diseases Septoria tritici blotch (STB) and yellow leaf spot (YLS). Varieties mentioned in the graphs above are protected under the Plant Breeders Rights Act 1994.

Furthermore, findings from other experiments (data not shown) indicated that stubble infected with the STB-causing pathogen *Z. tritici* can generate enough ascospores to initiate an epidemic two years after the wheat crop was grown, irrespective of the varietal resistance rating. This has important implications for crop sequences and stubble management. In sNSW, the cropping sequence is dominated by cereal–canola–cereal rotations. As infected stubble can produce ascospores at an epidemic-inducing level for up to 2 years, it suggests that a single break crop such as canola, might not be enough to reduce the risk of STB or YLS infection. If possible, avoid sowing wheat-on-wheat. If you are forced into a situation where this must happen, plan an IDM program to reduce the risk of yield loss.

Stubble management experiments have demonstrated that a net reduction in inoculum levels can be achieved by manipulating harvest cut height to reduce the standing stubble available for the STB pathogen to colonise (Figure 4). These experiments included three cut height treatments: 32 cm (high), 24 cm (medium), and 14 cm (low). Cut heights were selected to reduce stubble length by one node on the main stem. Using the 32 cm cut height as a baseline, lowering the cut height to 24 cm reduced the number of ascospores produced by 84%. When comparing the 32 cm cut height to the 14 cm cut height, there was a 97% reduction in the number of ascospores released from the stubble.



Vertical bars represent 95% confidence intervals ($P = 0.05$).

Note: average harvest cut heights for treatments: High – 32 cm, Medium – 24 cm and Low – 14 cm.

Figure 4. Left: Box plot showing the harvest cut height in centimetres (cm) of the high, medium, and low treatments for the 2020 STB stubble management experiment. Right: The number of *Zymoseptoria tritici* ascospore released from five tillers from the three stubble cut height treatments. This figure displays the reduction in ascospore numbers as the harvest cut height decreases.

The excess material must be removed from the paddock to result in a net reduction. Otherwise, the inoculum from the standing stubble is only relocated to the ground, which maintains the same inoculum levels within the paddock. Removal can be through baling or burning the stubble. However, the cost benefit risks of each method and other system impacts must be weighed before being undertaken.

Finally, the distinction needs to be made between managing disease in the current wheat crop to minimise yield loss and inoculum risk from the stubble in subsequent seasons. Even though the number of ascospores released from the senescent stubble does not significantly change with varietal resistance rating, variety choice remains critical to minimising losses from STB and other diseases within the growing season.

Variety selection

Research undertaken at Wagga Wagga Agricultural Institute confirms that a more resistant variety develops less disease compared with a more susceptible variety. In the absence of fungicide use, the difference in infection levels between a moderately susceptible (MS) variety and a susceptible to very susceptible (S-VS) variety with an early May sowing time can be as much as 30% less in the MS variety, resulting in a reduction of 10 – 15% in yield loss compared to the SVS variety (data not shown).

Choosing a wheat variety with a higher resistance level will protect yield in the presence of STB, while also reducing the number of fungicide applications required. This in turn decreases machinery, labour, and input costs. Minimising fungicide use also lowers the risk of fungicide resistance developing within both target and off-target fungal pathogen populations.

It is important to stay up to date with the latest variety resistance ratings as they can change from year to year. These ratings are developed through the National Variety Trial (NVT) pathology screening project and are released annually on the GRDC website (https://nvt.grdc.com.au/) and in state-based sowing guides such as the NSW DPI winter crop variety sowing guide (https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/nsw-winter-crop-variety-sowing-guide-2023).

Fungicide application

Not all fungicide active ingredients are equal when it comes to controlling STB, and fungicide choice is becoming increasingly important. The geographical spread of samples sent to Curtin University's Centre for Crop and Disease Management (CCDM) for fungicide resistance screening in 2022 is displayed in Figure 5. A further 22 samples were sent from NSW in 2023 which at the time of writing results were not available. Primarily, the 2022 results reveal that the G143A mutation, which confers resistance to Group 11 (QoI, strobilurin) fungicides such as azoxystrobin, was not detected in any of the samples submitted from NSW.

However, the G143A mutation was detected in an STB sample from Tasmania in 2022 (not shown), marking the first detection outside of South Australia. It is unclear if this is the result of gene flow (wind dispersion) or an independent mutation event. This detection should act as a warning for NSW growers to use fungicide resistance management strategies to prolong the effectiveness of Group 11 (QoI, strobilurin) chemistry against STB.

Unsurprisingly, mutations that confer reduced sensitivity to Group 3 fungicides (DMI, triazoles) were found in all the samples except one from NSW. Specifically, the mutation called Cyp51 G1 (formerly identified as Cyp51 Isoform 11) was present in most leaf samples. This mutation is particularly significant because it leads to elevated levels of reduced sensitivity to some Group 3 fungicides such as tebuconazole, flutriafol and propiconazole. It is not unexpected since Cyp51 G1 was the predominant mutation in the STB population from a previous NSW study conducted in 2016.

These results support our recommendation that Group 11 (QoI, strobilurin) fungicides are effective in preventing STB infection in NSW. We continue to advise that if your goal is to specifically target STB curatively with fungicides, it is best to avoid using cheaper Group 3 triazole actives like tebuconazole and propiconazole. Instead, opt for stronger Group 3 fungicides such as prothioconazole or epoxiconazole.

Decision support matrix and suggested fungicide regime for STB management if the 2024 season is conducive to infection and disease development is outlined in Table 2. The table also outlines the efficacy status of any fungicide application on stripe rust, as many fungicides registered for use on STB will also have efficacy on stripe rust. There is very little data showing a yield benefit from using fungicides prior to the commencement of stem elongation. That said, any sprays applied before the commencement of stem elongation will at best only have a suppressive effect on inoculum load, as none of the leaves that contribute significantly to grain yield emerge until after this growth stage. Therefore, crops which include a fungicide with the herbicide application during tillering (GS25) still require a dedicated fungicide spray at GS31-32 to protect the Flag-2 leaf. All applications may not be needed depending on seasonal conditions, growth stage, infection levels and economic considerations. Particularly if fungicide treatments are applied to seed and/or flutriafol is applied to the fertiliser to protect seedlings from early STB or stripe rust infection.

Table 2. Decision support matrix and suggested fungicide regime for STB management if the 2024 season is conducive to infection and disease development. The table also outlines the efficacy status of fungicide applications on stripe rust

Growth stage (GS)	STB present	Fungicide application required	Fungicide activity on stripe rust?
GS 25	Yes	No	Flutriafol activity if used
GS 31	Yes	Yes*	Yes
GS39	Yes	Yes/No*	Yes
GS50-59	Yes	Yes/No*	Yes

*All applications may not be needed pending seasonal conditions, growth stage, infection levels and economic considerations.

If the 2024 season is not conducive to STB development, and stripe rust is the primary foliar fungicide application target, consider products containing active ingredients such as tebuconazole or propiconazole to alleviate the selection pressure on prothioconazole and epoxiconazole after repeated use patterns during the 2021–2023 growing seasons. In dry conditions, fungicide applications may not be needed at all.

The 2022 results reiterate the need to protect fungicide modes of action when targeting all pathogens, but particularly those prone to developing resistance to diseases such as STB and wheat powdery mildew. To help prolong the life of fungicides, avoid susceptible varieties, implement crop rotation, consider non-chemical means of controlling inoculum sources, get a correct diagnosis if in doubt before applying a fungicide, rotate fungicide active ingredients and groups, adhere to label rates and use patterns. Further resistance management advice can be found at https://afren.com.au/.

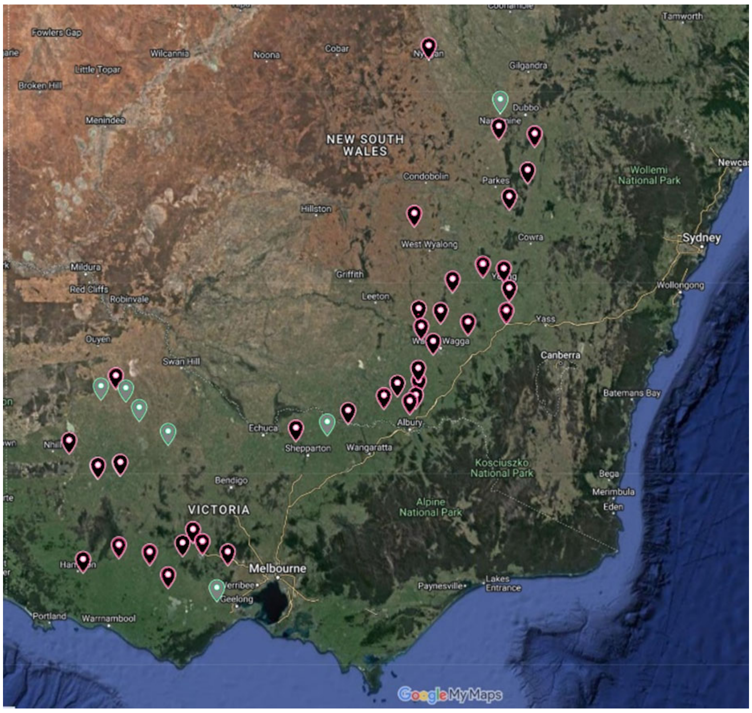


Figure 5. STB fungicide resistance screening results across NSW and Victoria in 2022. Note: Not all samples submitted appear on map, as some leaf samples did not recover DNA of high enough quality to be used for screening. Grey indicates the absence of Cyp51 G1 (Isoform 11). Black indicates the presence of Cyp51 G1 (Isoform 11) Group 3 (triazole) resistance. Courtesy of CCDM

Conclusions

With high wheat stubble loads from high yielding years from 2021 through to 2023, the STB inoculum risk for next season is elevated. However, incidence of STB is highly dependent on climatic conditions and 2024 growing season conditions will dictate the severity of any epidemic. To help counter these factors, components of the research outlined above can be implemented into an IDM plan to suppress and control STB. Acknowledging the risk and duration of the risk (i.e., >2 years) that any STB infected stubble can have on subsequent cereal crops can guide crop rotation decisions. If growing wheat on wheat, a plan can be implemented to appropriately manage the risk of STB, but it is best avoided. Cultural practices, such as variety selection, stubble cut height and stubble removal should be used in the first instance to reduce the resistance pressure on fungicides and prolong their effective lifespan.

NSW DPI is here to support growers with correct diagnosis and discussions of management options prior to sowing and as required throughout the season.

Acknowledgements

The research undertaken as part of these projects is made possible by the joint investment of NSW DPI and GRDC, and the significant contributions of growers and their advisers through both sample submission and engagement. The authors would like to thank them for their continued support. The authors would also like to express gratitude to cereal pathology staff members located at Wagga Wagga and Tamworth for their valued contributions to project work. Additionally, the authors acknowledge the ongoing support for cereal pathology capacity by NSW DPI.

References

BOM,2023. *Historical climate data*. http://www.bom.gov.au/climate/data/ Accessed 11/12/23.

Useful links

NSW DPI research result booklets: https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides

NSW DPI Sowing Guide: https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/nsw-winter-crop-variety-sowing-guide-2023

NVT Online: https://nvt.grdc.com.au/nvt-disease-ratings

Australian Cereal Rust Survey: https://www.sydney.edu.au/science/our-research/research-areas/life-and-environmental-sciences/cereal-rust-research/rust-reports.html

AFREN website: https://afren.com.au/

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Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Weed mapping using drones for targeted weed spraying

Ben Single & John Single, Single Agriculture

Key words

weed mapping, drones, spot spraying, weed management, chemical saving

Take home messages

- Weed maps are a significant tool in the fight against herbicide resistance, reducing the requirements for cultivation hence reducing farming carbon footprint
- Weed mapping using drones is now commercially available at significantly lower costs than conventional sprayer mounted optical spot sprayers
- Weed maps can be produced at rates of up to 250 ha/hr that can then be loaded into conventional sprayers to be used as spot sprayers
- Weed maps from drones allow for selecting weeds based on size as well as calculating the spray area prior to spraying which is the next step forward in selective spot spraying – know what to spray before you spray
- **Knowing what to spray before you spray allows for informed decisions maximising chemical efficacy and minimising spray costs resulting in cheaper, more effective weed control.**

Background

Drone-based weed mapping involves using a drone equipped with cameras or sensors to fly over a field and collect data on the location and size of weeds. The drone can be programmed to fly a predetermined flight pattern over the field, taking images at high frequency time intervals to ensure complete coverage and adequate resolution. The images and data are then processed to identify the location and size of the weeds in the mapped area, which is then converted, typically, into a prescription map. The map is then loaded into a spray rig display which turns on the individual spray sections to only spray the weeds in a spot spraying pattern across the field.

In this approach the mapping is completed prior to the critical spray timing windows and is not constrained by dust while stubble interference is minimal. The spray rigs can use standard spray nozzles (i.e. AI nozzles) to meet label requirements, can spray at full recommended speed and the capital outlay is lower than many fixed camera boom based spraying technologies. Drone-based weed mapping allows the location and size of the weeds to be identified and this enables the area to be sprayed to be calculated prior to spraying as well as options to filter based on weed size and spray area (radius) around the weeds. This is a very powerful tool and how this can be leveraged to optimise cost savings and maximise chemical efficacy will be explored in the rest of this paper. The technology described here does not distinguish weeds species from crop species unless there is a clear size difference where the weed is much larger than the crop, consequently the technology described here is mostly applied to fallow scenarios with some exceptions. The scenarios below are examples of completed weed maps and the advantages they offer in weed control.

Fallow situation with dual line spraying with one blanket spray line and one spot spray line

Situation

A winter fallow spray event in July 2022, near Coonamble NSW, with fresh weed germination (small weeds) after a rain event and advanced milk thistle (*Sonchus oleraceus*) that were randomly distributed across the paddock. Conventional spray application would require a blanket spray of glyphosate @ 2.2L/ha and mixing partner costing $42.40/ha which would be enough to target milk thistle as well as eliminate the smaller weeds, however if only the small germinating weeds were targeted, the chemical rates required to treat the weeds in the paddock would be significantly less. In this situation, this paddock would not be economically viable for conventional spot spraying (i.e., broom spray mounted camera with live weed recognition) due to the high density of small weeds that the conventional spot spraying systems would spray.

Drone weed mapping

The field was mapped using the Single Shot® drone weed mapping system with a coverage rate of 200ha/hr at a cost of $1.30/ha. The data was analysed using the inbuilt tools at various weed diameters to determine spot spray areas as per Figure 1.

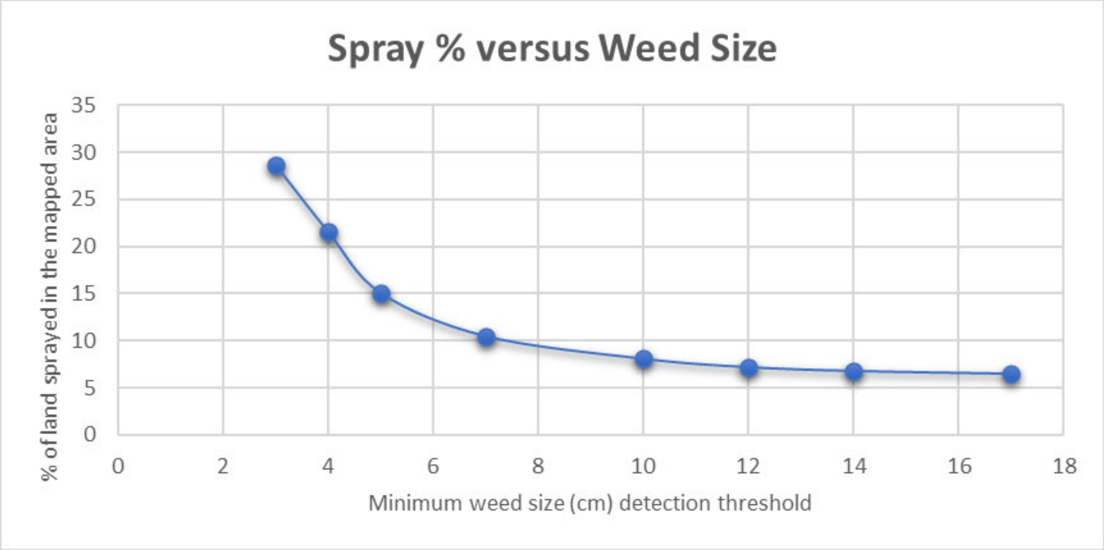

Figure 1. The estimated percent of land sprayed (y axis) in the mapped area as impacted by weed size (x axis). The smaller the weed size detection limit - the larger the land area that requires spraying.

The key observations from the graph are:

- Spot spraying milk thistle which had a diameter of 15cm or larger results in ~7% of the land area (done mapped area) being spot spray however;
- Reducing the minimum weed size threshold from 15 to 7cm results in the % of land sprayed in the mapped area increasing from 7 to 11%, meaning a greater number of weeds could be targeted with higher chemical usage without a dramatic cost increase,
- The drone mapping system has a minimum weed detection size of 3-4cm and size detection can be used to inform when it’s most appropriate to move to a blanket application. For example, where the weed size detection limit is change by 1 cm (e.g. from 4 down to 3 cm detection) and the % of land sprayed in the mapped area increases significantly (e.g. >5% per cm of weed), ground truthing with paddock inspection would be necessary to identify if blanket application was the best approach.

Solution

A blanket spray at 1.4L/ha glyphosate and mixing partner in spray line one, plus an additional spot spray in spray line 2 at 1.4L/ha glyphosate, and mixing partner as a spot spray rate on the weeds 7cm and greater. It should be noted that a higher chemical rate used on milk thistle did not significantly increase the overall cost, but the efficacy on milk thistle was significantly increased. This approach resulted in a saving of $13.40/ha as well as a much more successful control of milk thistle. This analysis and decision making was all made prior to any spraying and would not be possible without the ability to both calculate spray areas, spray volume as well as selectively targeting different sized weeds.

Green-on-green using size differences mapped by drone

Situation

Feathertop Rhodes grass (*Chloris virgata*) was growing in a wheat crop (Figure 2) after being unsuccessfully controlled prior to planting. There is no current in crop treatment available, with the typical treatment being an application of appropriate pre-emergent herbicides post-harvest as well as higher cost knock down herbicides applied during fallow periods.

Figure 2. feathertop Rhodes grass in wheat

Drone weed mapping

The field was mapped using the Single Shot® drone weed mapping system with a coverage rate of 200ha/hr at a cost of $1.30/ha. By using a minimum weed size detection diameter of 7cm, the wheat was removed from the weed map leaving just the feathertop Rhodes grass (FTR) displayed on the map. By itself, this isn't particularly useful as the FTR will have matured and seeded by the time of mapping. The advantage in this situation is that the software also includes the ability to set a radius around each plant as a target zone which is part of a necessary solution.

Solution

A radius around each FTR plant was estimated to cover the likely seed rain area around FTR plants. This assisted the targeting of a pre-emergent herbicide applied post-harvest to control seed banks in these limited areas, killing FTR seedlings as they emerged and significantly reducing chemical usage. This strategy also reduces the risk level associated with herbicide residue impacts on future crops. Maps can be kept and used in later years for additional targeted pre-emergent applications as well as a useful forensic tool to determine the effectiveness of the control methods used. Additionally, a knock down can be used to target the existing plants if a registered option is available.

Of note in this example, is that there was an ideal time for weed detection (early crop development) and an ideal time for weed treatment (post-harvest) and they were vastly different. This process can also be applied to weeds that do have selective herbicides available, for instance marshmallow in wheat. Detection can be at an early stage of the wheat development, (e.g. similar to Figure 2), and then treatment can be at a later date to comply with the label and minimise crop damage.

Combine drone weed maps with other spatial data

Situation

A field with areas of black and red soil was due to be sprayed in November prior to sorghum planting which contained low levels of windmill grass and fleabane amongst other more easily controlled weeds. When inspecting the paddock, it was noted that the windmill grass was almost exclusively present in the red soil areas of the field while fleabane and other weeds were distributed across the paddock (both soil colours). Typical application would be to either blanket or spot spray to control both the windmill grass, fleabane and other weeds throughout the whole paddock, with products and rates determined by the harder to control weeds.

Drone weed mapping

The field was mapped using the Single Shot® drone weed mapping system and processed using a minimum weed diameter of 7cm and the weed map was then loaded into Google Earth® (**Figure**). The different soil types can clearly be seen. The processing software was used to draw polygons to only output weed maps in the red soil area and calculate the spray area for the selected polygon. This feature is normally used to define fields (field boundaries) but can also be used to define other areas (see Figure 3 example).

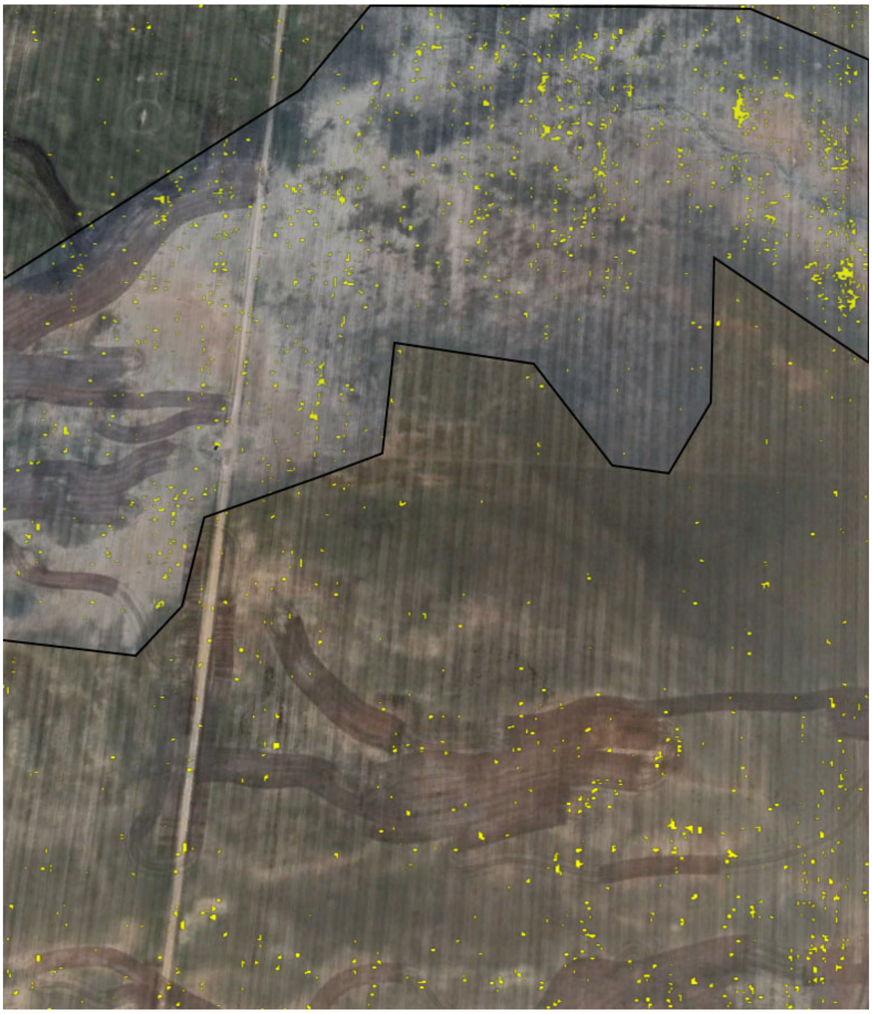

Figure 3. Google Earth® overlaid with weed locations (small yellow atches) and red soil area enclosed in the polygon. Windmill grass was confined to the red soil area. Other weeds were distributed across both soil types in the paddock.

Solution

The field was segmented as per Figure 3 with the polygon enclosed area (red soil) only sprayed with the herbicides needed to target the windmill grass. Then the entire field was spot sprayed in a second application with a broad-spectrum knockdown herbicide. Segmenting the field allowed for targeted chemistry to control the windmill grass which substantially reduced cost, as these higher cost herbicides were only applied to that portion of the field where windmill grass was a problem (polygon area).

Acknowledgements

Tony Single for his contributions in developing the technology and its application.

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Drone docking stations and weed detection

Tristan Steventon, StevTech

Key words

drone, weed detection, green-on-green, artificial intelligence

GRDC code

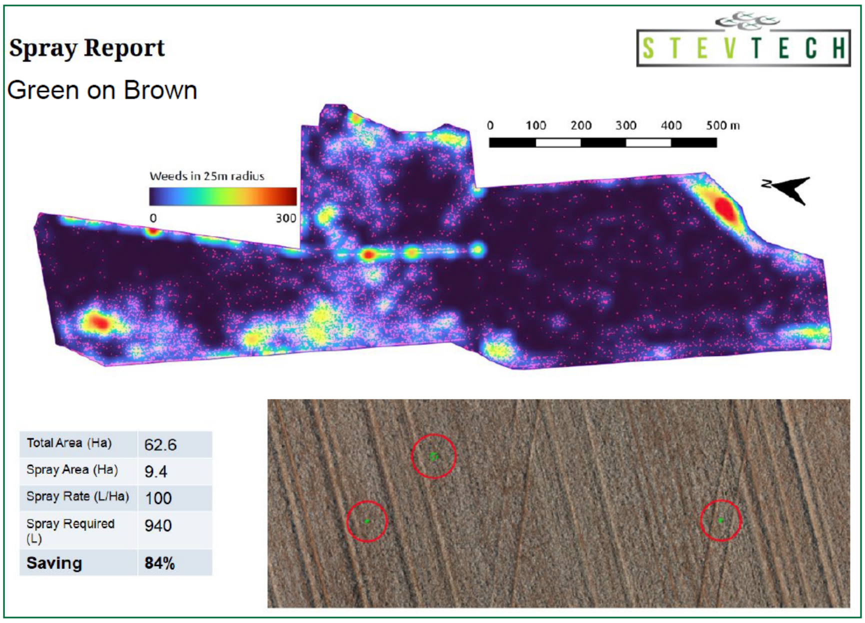
DFL2312-001RTX

Take home message

StevTech Pty Ltd has a fully autonomous drone docking station that can be deployed on farm for the duration of a growing season or for specific crop risk periods. The drone, which lives within the weatherproof dock and is controlled from an operations centre at StevTech HQ, deploys from the dock and collects ultra high-resolution imagery (+/- 1cm pixel). On return to the dock the data is transferred via satellite internet to the cloud where it is processed using StevTech machine learning techniques. In the case of weed detection data, it is then sent directly to the grower's spray rig for application. See below for some examples of previous green on green and green on brown weed detection work.

Why is this necessary

Farm size has almost doubled in the last 30 years. Individual agronomists are managing larger client bases and servicing very large areas, travelling vast distances. Increasing herbicide resistance, the price of chemical and the aforementioned increasing scale of Australian farms are fuelling innovation in sensors and technology to automate the detection and destruction of weeds. StevTech is part of this innovation drive, and this year will deploy a fully autonomous drone docking station with weed detection capabilities that can integrate directly with on-farm GPS guided spray equipment as part of a GRDC funded project. Weed detection is only one part of the solution which will also include early warning for pest, disease and nutrition issues without the need for a human crop scout.



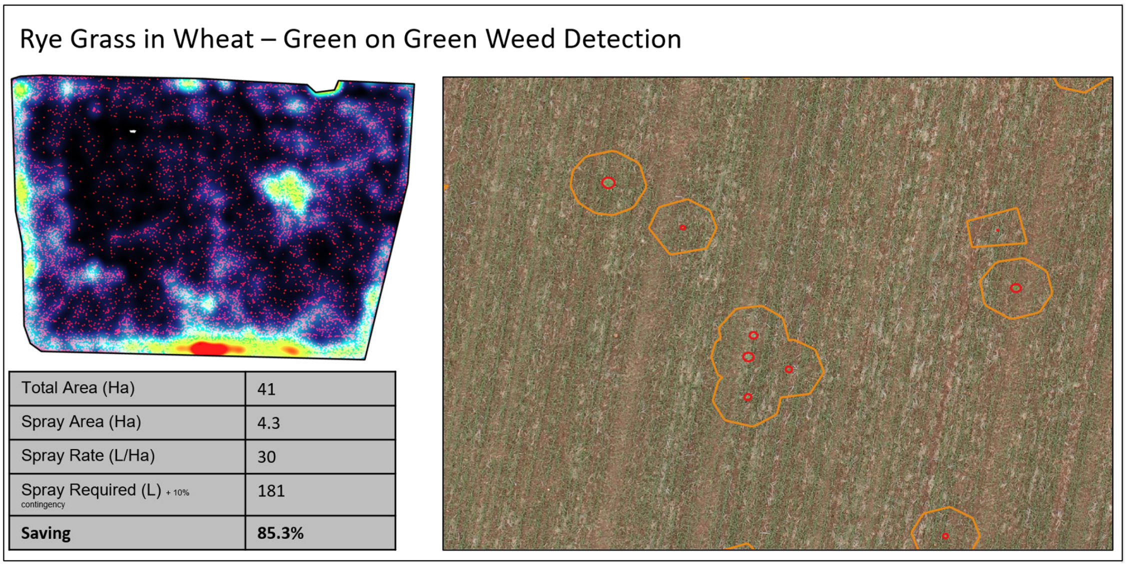
Total Area (Ha)	62.6
Spray Area (Ha)	9.4
Spray Rate (L/Ha)	100
Spray Required (L)	940
Saving	**84%**

Figure 1. Example of green on brown weed detections using a drone and integrated into a John Deere SP spray rig.

CALDWELL'S CLUB-RUSH IN RICE

- Total Area: 141.3 Ha
- Spray Area: 4.3 Ha
- Paddock Sprayed: 3%
- Chemical Used: 4L
- Chemical Saved: 87L
- Alternate Cost: $7,488
- Cost Saving: $3,088
- Drone Spray Drift: 5m

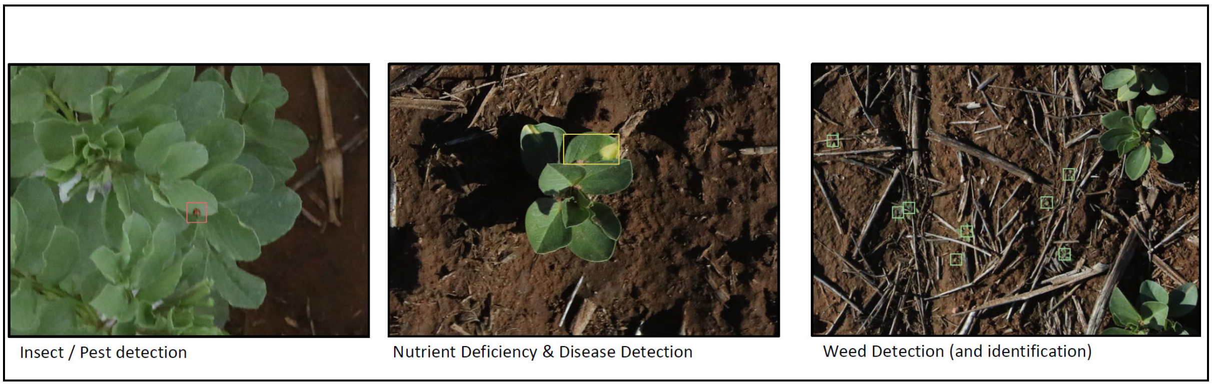
Figure 2. Green on green detection of a weed in rice and integrated into spray drones. Drift was measured to be less than 5m during application.



Rye Grass in Wheat – Green on Green Weed Detection

Total Area (Ha)	41
Spray Area (Ha)	4.3
Spray Rate (L/Ha)	30
Spray Required (L) + 10% contingency	181
Saving	**85.3%**

Figure 3. Green on green weed detection of rye grass in early wheat crop.



Insect / Pest detection

Nutrient Deficiency & Disease Detection

Weed Detection (and identification)

Figure 4. StevTech examples of early warning for pest, disease, nutrient deficiency and weeds using machine learning and image recognition techniques.

StevTech & Ripper Corp
Drone Docking Station and Remote Operations Centre

Figure 5. Top left: Remote operations centre. Top right: Inside the docking station.
Bottom: The docking station preparing for transportation.

Cost comparison vignette

A grower in Central West NSW requested StevTech identify fleabane within a 180 ha paddock late in fallow to allow for a high rate of chemical to be applied to these plants given their size. The plants had not been controlled by earlier sprays and required a double knock from two separate chemical mixes.

StevTech was able to map the paddock and the grower was able use the same map for both spray applications. Other growth had been controlled effectively during fallow. Cost analysis below:

Table 1. Cost benefit table of chemical costs using StevTech compared to blanket spraying

Task	StevTech cost based (per ha)	Chemical cost based on per ha rate
Blanket Spray 1 (without StevTech)	**$0**	**$15/ha ($2700)**
Blanket Spray 2 (without StevTech)	**$0**	**$12/ha ($2160)**
Total for blanket spray option		$4860
First spray using StevTech map	**$7/ha ($1260)**	**87% saving on chemical.** **Spray application for 13% of paddock (23.4ha) 23.4ha x $15 = $351**
Second spray using StevTech map	**$0**	**23.4ha x $10=$234**
Total cost for StevTech option		**$351 + $234 + $1260 = $1845**
Costs/benefit on 180ha paddock		**$3015 cheaper**
Cost benefit if conducted across 2000ha		**$54,000.00 vs $21,020.00**
		+$32,000 better off

GRDC autonomous agronomist project 2024

Grain Automate is a new initiative from GRDC within the scope of GRDC’s new 2023-2028 RD&E plan. Grain Automate will be a portfolio of new research, development, and extension (RD&E) investments aimed at delivering outcomes for Australian grain growers in machine autonomy and intelligent systems. It complements GRDC’s existing investment programs in precision agriculture, digital agronomy, and advanced analytics.

Data Farming Australia has received funding from GRDC to answer the question “Can we automate agronomy in a way that increases agronomic efficiency, enables better interaction and communication between farmers and agronomists, and supports more timely and precise field actions?”

For the project a 100ha field will be selected with the aim of providing all agronomic recommendations for a complete fallow and cropping cycle without the agronomist entering the paddock. This concept is similar to the ‘hands free hectare’ that was trailed in the UK, however in this case, the focus will remain on the agronomic management decisions and the interaction with technology including the communication between the grower and agronomist required to achieve this.

StevTech has been selected to deploy our ’drone in a box’ system for this project and it will be used to complete crop checking during the entire season. This piece of technology will be fundamental to the project as it provides extreme high-resolution images and video of weeds, pests, diseases, and nutritional disorders that the agronomist would normally be scouting for in the field. The potential future integration at this point is in machine vision integrations which automatically calculate severity levels of infestations and present recommendations.

Once the data has been collected and sent back to the ‘agronomy control room’, a trained agronomist will review the images and results from the inspection. The processed outputs of this data will then be sent to autonomous ground robots (SwarmFarm and similar) to complete in-field tasks such as weed spraying.

Legislation relating to Autonomous Drone Flight

StevTech is in the final stages of having approval for the use of a Drone in a Box that is controlled from a remote operations centre. This has been a lengthy process however one of the aims of the Autonomous Agronomist Project with GRDC is to demonstrate the ability, (or inability due to legislative boundaries) for this type of operation. It is hoped that this project will encourage CASA to consider the sensible application of drone legislative requirements within an industry that would benefit greatly from the increased and more streamlined use of drones and the high-quality data that they produce.

Conclusion

StevTech's drone docking station solution is built upon the last 6 years of StevTech weed detection R&D and commercial operations. The completely autonomous nature of the docking station takes away the hassles of having contractors coming on farm, or the time-consuming nature of collecting drone data yourself. It is present in your paddock like a weather station or soil probe and provides early warning and high value data sets on demand.

As farms get bigger, quality labour becomes increasingly scarce, and chemical prices rise, the StevTech docking station may be part of the on-farm solution to meet these challenges.

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Farming systems profit and risk over time: exploring the N legacy impacts on profit in different farming systems

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Key words

risk, water use efficiency, early sowing, nitrogen, diversity, legumes

GRDC codes

CFF00011, CSP2110-004RMX

Take home message

- A range of different systems were profitable and had similar average annual gross margin over 6 years, but differed significantly in variability and return on investment (ROI)
- Despite being the most profitable at only two of the four sites, Diverse systems involving grain legumes with a low N strategy had consistently higher ROI than Baseline cereal-canola systems
- Reduced N inputs to legumes and to cereal and canola crops following legumes were more important economically than yield benefits following the legumes, which were rare
- Fababean was more profitable than lupin and had a greater legacy on subsequent crops
- Issues related to nitrogen supply (costs and response) underpin most of the productivity and profitability differences observed between the systems.

The Southern Farming Systems Project – a brief description

The southern NSW farming systems project was established in 2017 after 12-month consultation period and extensive literature review demonstrated a significant gap in profitability and rainfall efficiency ($/ha/mm) of current cropping systems (i.e. actual *vs* potential) despite good agronomy of individual crops. The average annual gross margin of the best 3-4-year sequences was often ~$400/ha higher than the worst, and $150 to $250/ha higher than the common 'Baseline' sequences. Research sites and simulation studies were established to investigate strategies to increase the conversion of rainfall to profit across a crop sequence while managing weeds, diseases, soil fertility and risk.

Four sites covered soil and climate variability across southern NSW at Greenethorpe, Wagga Wagga and Condobolin (high, medium and low rainfall sites on red acidic loam soils), and a 4th site on a sodic clay vertosol at Urana. At each site, the 'Baseline' system (sequence of canola-wheat-wheat or canola-wheat-barley; timely sown in late April-early May; and with a conservative decile 2 N strategy) was compared with a range of other systems that varied in (i) crop diversity (inclusion of legumes), (ii) sowing time (early and timely) and (iii) N strategy (conservative decile 2 and optimistic decile 7) (Table 1). Management protocols for all other input and management decisions (e.g. tillage and stubble management; variety choice; herbicide, fungicide and pesticide applications) were agreed by the project team using a consensus approach of best practice that was continually reviewed.

Table 1. Selected systems common to most sites including different crop sequence, time of sowing and N strategies. Early-sown (March) treatments included winter grazed crops at Wagga and Greenethorpe. Diverse systems including a legume are shown in grey.

System	Crop sequence	Sowing time[1]	N strategy[2] (Decile 2 or 7)	Grazing
Baseline	Barley[3]-canola-wheat	Timely	2, 7	No
Intense Baseline	Canola-wheat	Early, Timely	2, 7	Yes
Diverse low value	(Faba/lupin)-canola-wheat	Timely	2, 7	No
Diverse high value	(Lentil/chickpea)-canola-wheat	Early, Timely	2	No
Diverse mix	Vetch-canola-wheat	Timely	2	No
Continuous wheat	Wheat-wheat-wheat	Timely	2, 7	No
Fallow	Fallow-canola-wheat	Early, Timely	7	No

[1] Early sowing= from March 1 if grazed, April 1 if un grazed; Timely sowing = late April to mid-May

[2] The N strategies (decile 2 or decile 7) apply top-dressed N each year in July to cereals and canola assuming the season will finish as either decile 2 (lower yield and less N) or decile 7 (higher yield so more N). N requirement is adjusted in each treatment to account for soil N measured pre-sowing, so carry-over 'legacy N' from previous seasons (fertiliser or legume N) means less N will be required for the current crop and so the value of legacy N from fertiliser or legumes is captured in the lower input costs.

[3] At Greenethorpe, a 2nd wheat crop replaced the barley

Seasonal conditions at the sites during the 2018-2023 seasons

The 2018 and 2019 seasons were dry (decile 1-2), the 2020 to 2022 were wet (decile 7-10) while the 2023 season was closer to long-term average (decile 5-6), except at Urana (decile 8) (Table 2).

Table 2. Rainfall (+irrigation) at the experiment sites from 2018 to 2022 and the long-term median (LTM) rainfall and the decile for that season (brackets).

Site	2018	2019	2020	2021	2022	2023	LTM
Greenethorpe	359 (2)	353 (2)	726 (10)	943 (10)	875 (10)	590 (5)	579
Wagga Wagga	403 (3)	320 (2)	557 (8)	757 (10)	886 (10)	559 (6)	526
Urana	276 (1)	222 (1)	488 (6)	564 (9)	968 (10)	552 (8)	449
Condobolin	218+120 (1)	162+118 (1)	685 (9)	806 (10)	958 (10)	474 (6)	434

Brief background to the outcomes so far

Phase 1 (2018-2020)

In Phase 1, the outcomes for the different systems were highly influenced by the two consecutive dry seasons (see Kirkegaard *et al.,* 2021). The key outcome for grain-only systems for phase 1 was that at all sites, the diverse systems that included a legume, and with a decile 2 N strategy were more profitable than the *Baseline* system, were less risky, had stable or declining weed and disease burdens, and lower average input costs. Simulation also predicted these results to be robust for a range of seasons modelled over the longer term. In mixed (grazing crop) systems, the most profitable systems involved early sown grazed crops (wheat-canola) with a higher N fertiliser strategy (decile 7).

Phase 2 (2021-2023)

The effect of the 3 consecutive wet seasons (2020 -2022) on these early results were considered in detail in (Kirkegaard *et al.*, 2022, 2023). The wet conditions provided opportunities to lift yield and profitability, capitalise on higher N strategies and earlier-sown crops, but also increased the risks of disease, lodging, grain quality reduction and reduced the timeliness of operations. Grain legumes can suffer significant yield losses to disease and lodging and/or significant costs for multiple fungicide applications. Consequently, during these wet seasons, the Baseline and Intense Baseline systems with more canola and higher N supply performed well in terms of profit but had lower return on investment, while some systems with legumes (e.g. chickpea) performed poorly.

As a consequence, after 5 years, the diverse systems with grain legumes and decile 2 N strategy remained the most profitable at two sites (Urana and Greenethorpe), while the *Baseline* and *Intense Baseline* were more profitable at Wagga and Condobolin, but with greater risk.

Profit and risk after 6 years (2018-2023)

Effect of diversity and N strategy in timely-sown grain-only crops

A summary of outcomes for selected timely-sown grain-only systems across all sites is provided in Table 3, with a focus on the effect of crop diversity, and nitrogen strategy. The systems are arranged in Table 3 for each site in order of increasing crop diversity (Continuous wheat = 100% cereal, Baseline systems = 66% cereal, Intense Baseline = 50% cereal, Diverse = 33% cereal). For the diverse systems, the most profitable of the legume sequences was used in each case.

Profitability is represented by average annual $GM (2018-2023), risk by both the variability (standard error) of annual $GM, and the profit/cost ratio (ROI). The average annual N applied as fertiliser (kg/ha/yr) is also shown in Table 3, as N fertiliser was a significant cost driver.

At the two sites (Wagga and Greenethorpe) where continuous wheat systems were included, they had significantly lower $GM than the Baseline systems although the variability in $GM was also relatively low (Table 3). The ROI was also relatively low compared to the Baseline at Wagga Wagga but similar at Greenethorpe, perhaps reflecting the lower level of N applied at Greenethorpe. At Wagga, the average $GM of continuous wheat system was responsive to higher N in the decile 7 treatment (extra 56 kg N/ha/yr), but this did not match the profitability or ROI of the more diverse systems with lower N.

Intensifying the Baseline systems by moving to Intense canola-wheat (C-W) systems reduced average $GM at Wagga Wagga and Urana while increasing the $GM at Greenethorpe and Condobolin. At all sites, the variability in $GM was increased, while ROI was either reduced (Wagga Wagga, Urana) or unchanged. Average N supply increased at all sites in the Intense Baseline system, most notably at Greenethorpe with minor increases at the other sites (Table 3). Increasing N supply to the Intense Baseline systems (average increase 40-60 kg/ha/yr) had most impact on $GM at Urana (+$164), smaller effects at Wagga Wagga and Greenethorpe (~+$50/ha) and a small reduction at Condobolin. The additional income barely covered the higher N costs, with ROI declining or remaining relatively unchanged and variability in $GM generally increasing.

The diverse system with low N was the most profitable system at Urana, matched the most profitable at Greenethorpe, but was less profitable than the Baseline at Wagga and Condobolin. However, the Diverse systems consistently had the highest ROI at all sites by a significant margin, This was partly related to the much lower average annual N required (40-50 kg/ha/yr less) in those systems. The variability in $GM was similar or lower than Baseline at Wagga and Condobolin but higher at Greenethorpe and Urana – possibly reflecting the variable performance of the legumes across the years with respect to yield and price compared to canola, wheat and barley.

Table 3. Average gross margins ($/ha/yr) and variation (standard error) in gross margin for timely-sown, grain-only systems at four experimental sites over 6 years (2018-2023). Profit/cost ratio ($GM/$Variable costs) are shown as a measure of return on investment and risk. The average annual N application as fertiliser (kg N/ha/yr) to each system is also shown. N2 and N7 refer to the decile 2 and decile 7 nitrogen strategies.

System	**Crop sequence**	**Average annual gross margin (GM) ($/ha/yr)**		**Variability in gross margin (Std. Err.) ($/ha/yr)**		**Profit/Cost ratio (ROI)**		**Average N applied (kg/ha/yr)**	
		N2	**N7**	**N2**	**N7**	**N2**	**N7**	**N2**	**N7**
Wagga Wagga									
Cont. wheat	W-W-W	652	732	86	129	0.94	0.91	77	133
Baseline	C-W-B	902	944	116	121	1.11	1.06	97	143
Int. Baseline	C-W	767	819	143	143	0.87	0.9	103	144
Diverse	Lu-C-W	802	-	97	-	**1.20**	-	54	-
Greenethorpe									
Cont. wheat	W-W-W	953	-	96	-	**1.47**	-	47	-
Baseline	C-W-W	1108	1130	131	159	1.42	1.32	77	119
Int. Baseline	C-W	1163	1219	198	222	1.37	1.33	88	135
Diverse	Fa-C-W	1179	-	172	-	**1.46**	-	40	-
Urana									
Baseline	C-W-B	816	-	109	-	1.12	-	72	-
Int. Baseline	C-W	682	847	115	163	0.91	0.98	78	137
Diverse	Fa-C-W	992	-	130	-	**1.38**	-	29	-
Condobolin									
Baseline	C-W-B	781	-	127	-	1.14	-	67	-
Int. Baseline	C-W	826	809	153	158	1.15	1.08	74	116
Diverse	Lu-C-W	730	-	127	-	**1.31**	-	42	-

In summary, while the most profitable diverse systems have matched the average profit of the Baseline and Intense Baseline systems at some but not all sites, the consistent benefit is the increased ROI of the Diverse systems at all sites, partly related to the reduced requirement for N fertiliser. Economic responses to increased N fertiliser were relatively small with lower ROI. There are a few exceptions to this. The N7 Int. Base at Urana was quite a bit more profitable ($165/ha) than the N2 and has a higher profit/cost ratio. This was also the case at Wagga Wagga, however not as pronounced.

The Diverse systems involving chickpea/lentil matched the profit of the system involving fababean at Urana, but were less profitable by $145/yr. at Condobolin (*cf* lupin), $90 at Greenethorpe (*cf* fababean), and $37/yr at Wagga (*cf* lupin). The chickpea was especially affected by waterlogging and cold conditions in 2022, and by the need for repeated fungicide sprays for Ascochyta in 2020 and 2021.

Effect of earlier sowing in grain-only crops

Recent research has demonstrated that earlier sown crops selected to flower within the optimum flowering window can have a grain yield and water-use efficiency advantage over timely-sown crops especially when stored subsoil water is available (Flohr *et al.,* 2020). They also provide grazing opportunities on mixed farms. However early sown crops may leave a legacy of drier and lower N subsoils which can reduce the growth of following crops in a sequence. Consequently, the effect of earlier sown crops on the profitability of the system was of interest in this project.

At 3 of the 4 sites (not at Greenethorpe), we could make direct comparisons of grain-only systems that differed only in the sowing time of the wheat and canola crops (Table 4).

The benefit of early-sown wheat and canola in the Diverse N2 system was significant at Condobolin where it added $139/yr to the average annual $GM and this was mostly driven by the higher yield of the earlier-sown wheat and canola. At Wagga, a smaller benefit was achieved by sowing early in the Diverse N2 system, but not in the N7 system, because the additional cost of the increased N applied was not recovered. At Urana in the Intense Baseline canola-wheat system there was only marginal benefit from sowing earlier in the N2 system and reduced profit at N7, similar to the Wagga observation.

In summary the value of earlier-sown crops is dependent on the site and the system (both crop sequence and N strategy) but can provide a significant boost to the profitability of the system in the medium term.

Table 4. Effect of wheat and canola sowing times in selected systems at three sites on the average annual gross margin from 2018-2023.

Site	**System**	**Average annual gross margin ($/ha/yr)**		
		Timely sown	**Early sown**	**Difference**
Condobolin	Diverse N2 (Le/Ch-C-W)	585	724	+139
Wagga	Diverse N2 (Le/Ch-C-W)	765	786	+21
	Diverse N7 (Le/Ch-C-W)	748	609	-139
Urana	Int. Baseline N2 (C-W)	682	695	+13
	Int. Baseline N7 (C-W)	847	775	-72

N legacy impacts on profit

The effect of N legacies at the experimental sites have been reported at previous Updates by Swan *et al.,* (2022) and Dunn *et al.*, (2023). In exploring the value of N legacies from legumes on following crops and on the profit and risk of the systems there are several questions that can be considered.

1) Is there a legacy of higher soil mineral N in the soil after legumes compared to non-legumes?
2) How much less fertiliser was applied to the system as a result?
3) Was there a yield increase in following crops?
4) Did (1)-(3) contribute to increased profit and reduced risk?

In answer to (1) Table 5 summarises the soil mineral N in the soil prior to the canola crops following wheat or barley crops in the Baseline systems and following legumes (lupin or fababean) in the Diverse systems (as previously shown in Table 3). Except in the flood year at Condobolin (2022), a legacy of higher mineral N following the legumes was observed at all sites and in all seasons, with an additional average pre-sowing mineral N of 26, 98, 48 and 42 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively. This would have reduced the N applied to reach the target yield in the canola crops within those systems each year. In addition to the higher N in the soil prior to the canola, there was also higher N in the soil prior to the subsequent wheat crops which averaged +27, +50, +16 kg N/ha at Wagga, Greenethorpe and Urana while there was 10 kg N/ha less prior to wheat at Condobolin (data not shown). Though it is difficult to attribute this legacy specifically to the legume due to the differences in top-dressed N and N removal by the canola crops, the overall effect was to reduce the average annual application of N fertiliser to the Diverse system by 43, 37, 43, and 25 kg N/ha/yr (as shown previously in Table 3).

Table 5. Mineral N in the soil prior to sowing canola following barley or wheat in the Baseline systems and following fababean or lupin in the Diverse systems at the four sites. Note all crops in 2018 (Yr 1) followed wheat so no legacy effects existed in that year.

System	Crop sequence	Mineral nitrogen in soil prior to canola (kg N/ha)					
		2019	2020	2021	2022	2023	Mean
Wagga Wagga							
Baseline	B-**C**-W	47	81	91	91	47	**71**
Diverse	Lu-**C**-W	78	67	114	128	154	**97**
Greenethorpe							
Baseline	W-**C**-W	217	180	109	127	58	**136**
Diverse	Fa-**C**-W	260	264	339	233	133	**234**
Urana							
Baseline	B-**C**-W	45	84	66	47	45	**57**
Diverse	Fa-**C**-W	101	106	123	112	133	**105**
Condobolin							
Baseline	B-**C**-W	53	64	15	11	132	**52**
Diverse	Lu-**C**-W	133	146	48	2	190	**94**

With respect to (3), any yield benefit following the legumes in the subsequent canola crop cannot necessarily be attributed to the extra N measured pre-sowing, because the canola crops were top-dressed to a decile 2 yield target according to the N available at sowing. Indeed, the N applied to the canola crops was reduced on average by 18, 58, 41 and 27 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively following the legumes in the Diverse systems. This represented a cost saving, but had an equalising effect on N supply, although additional N may have mineralised after sowing following the legumes, to provide an additional N benefit for the following crop. As the higher soil N legacy persisted to the subsequent wheat crops, there was also around 20 kg N/ha less N applied to the wheat crops on average in the Diverse systems. These N savings were significant but were small compared to the reductions in N applied to the legume crops themselves (<5 kg N/ha applied) compared to barley or wheat (50 to 100 kg N/ha applied) which were 86, 47, 62 and 50 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively.

There was little overall yield benefit measured in the canola crops following the legumes in the Diverse systems at the 4 sites (+0.3 t/ha at Urana only) or in the subsequent wheat crops (+0.3 t/ha at Greenethorpe only) (data not shown). Consequently, except for these two cases, little of the economic benefits within the Diverse systems have arisen from higher yields and income in the canola or wheat crops following the legumes in the Diverse systems.

In assessing the impact of legacy N on profit and risk, it is useful to examine the overall performance of the different crops in the sequence across the 6 years in light of the impacts on N inputs (Table 6). At Wagga, despite the N legacy effects of the lupin reducing the overall N inputs, the lower profitability of the lupin itself (average yield 3.1 t/ha) compared with the barley (average yield 6.0 t/ha) in the system was the major driver of the lower $GM of the Diverse system (Table 6). A somewhat similar outcome occurred at Condobolin, although the boost in canola $GM offset the lower profitability of the lupin compared with the barley. The fababean in the Diverse system at Greenethorpe (average yield 4.4 t/ha) and Urana (average yield 4.7 t/ha) were as profitable or significantly more profitable than the wheat (average yield 5.4 t/ha) or barley (average yield 6.2 t/ha) in the Baseline systems at those sites, and there were also higher $GM in the following canola and wheat crops following the fababean.

In summary, the reduced N fertiliser input costs in the Diverse systems due to low N applied to the legume crops and reduced N applied to subsequent canola and wheat crops due to legacy N has contributed to the $GM of the Diverse systems much more than increased yield of subsequent crops following the legumes. Urana is the exception to this. The increased yield and profit ($257/ha for canola) following fababeans have been quite pronounced. However the lower profitability of lupin compared to barley has eroded that economic advantage at Wagga and Condobolin, while the higher profitability of fababean has added to the economic advantage at Greenethorpe, and especially at Urana.

Table 6. Average annual 6-yr gross margins for individual crops in the grain-only Baseline N2 (barley-canola-wheat) and Diverse N2 (legume-canola-wheat) systems from 2018 to 2023.

System	**Crop sequence**	**Average annual $GM ($/ha/yr) 2018-2023**			
		Cereal/Legume	**Canola**	**Wheat**	**Mean**
Wagga Wagga					
Baseline	B-C-W	1103	838	764	901
Diverse	Lu-C-W	800	812	794	802
Greenethorpe					
Baseline	W-C-W	1094	1034	1195	1107
Diverse	Fa-C-W	1058	1228	1252	1179
Urana					
Baseline	B-C-W	1089	475	884	816
Diverse	Fa-C-W	1301	732	942	992
Condobolin					
Baseline	B-C-W	818	771	752	780
Diverse	Lu-C-W	604	834	752	730

Do legacies occur with higher fertiliser strategies?

At two sites (Wagga and Greenethorpe) Baseline systems were included with both decile 2 and decile 7 strategies (see Table 3). The question arises as to whether there is evidence that the higher N applied each season to the N7 treatment that is not used by the crop, carries over to subsequent crops in the same way that legume N carries over.

At Wagga there was an average of +17, +32 and +27 extra kg N/ha/yr measured pre-sowing in the N7 compared to the N2 prior to the canola, wheat and barley respectively, an average of +25 kg N/ha for the system. This compares with an extra 50 kg N/ha/yr applied to the N7 treatment (Table 3). At Greenethorpe there was an average of +37, +102 and +6 extra kg N/ha/yr measured pre-sowing in N7 compared to N2 prior to the canola, wheat 1 and wheat 2 crops respectively. This compares with an extra 41 kg N/ha/yr applied in the N7 treatment (Table 3). This suggests that a significant portion of the increased N applied that may not be utilised by the crops can carry over as legacy N within the system, although in this case it has only generated a small increase in $GM but a lower ROI within the systems (Table 3). A more complete N balance will be carried out to provide more detail on the fate of the applied N in terms of offtake, changes in soil organic matter or N losses.

Whole-farm and business considerations

The results at the four sites demonstrate that a range of different systems with relatively small differences in average annual gross margin over 6 years can be quite profitable but may differ in performance in different seasons (wet, dry) and have different risk profiles. This reminds us that different systems may suit specific businesses depending on a range of factors other than the agronomic management - many of which cannot be measured in these small-scale experiments but must be considered when making decisions to integrate grain legumes into the business. For example, it is likely that to ensure the best outcome from grain legumes that some storage capacity may be required on farm, the capacity to handle the inoculation process in a timely and effective manner, and careful and timely application of fungicides in wetter seasons. These will generate labour peaks and demand on machinery that must be considered. Enterprises with significant areas of legume-based pastures may find that these can perform much the same function of organic N supply, disease and weed management as that played by grain legumes in the systems reported here and are suited to phased rotation with more intensive cereal-canola systems. The choice of legume is also clearly important based on those best adapted to specific paddocks.

Never-the-less, the emerging data from these systems experiments demonstrate the importance of fully assessing the value of grain legumes in different systems beyond their performance in individual years, as much of the benefit derives from legacy effects, input savings and more even performance across seasons. These are difficult to assess without longer-term side-by-side comparisons and supporting data to understand the mechanisms behind the responses.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC and NSW DPI, the author would like to thank them for their continued support. The authors would like to especially thank Warakirri Cropping “Karoola Park” and Rod and Nick Kershaw “Iandra Pastoral” for their support and co-operation in hosting the Urana and Greenethorpe field experimental sites. The authors would also like to acknowledge the contributions of Graeme Sandral for his role as site leader during the first two and a half seasons of the project. We also thank Chris Baker (Baker Ag Advantage), Tim Condon (Delta Agribusiness), Greg Condon (Grassroots Agronomy), Heidi Gooden (Delta Agribusiness), Peter Watts (Elders), Rod and Nick Kershaw (Iandra), John Stevenson (Warakirri Cropping) and John Francis (Agrista) for the many useful discussions in their role on the project advisory committee.

References

Kirkegaard J, Dunn M, Swan T, Whish J, Pumpa R, Fiske K (2023) Farming systems profit and risk over time: the impact of three wet consecutive seasons. GRDC Updates Wagga Wagga 2023. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/farming-systems-profit-and-risk-over-time-the-impact-of-three-wet-consecutive-seasons

Dunn M, Kirkegaard J, Swan T, Whish J, Pumpa R, Fiske K (2023) Legacy effects and the value of legumes in the farming system after three consecutive wet seasons. GRDC Updates Wagga Wagga 2023. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/legacy-effects-and-the-value-of-legumes-in-the-farming-system-after-three-consecutive-wet-seasons

Kirkegaard J, Swan T, Dunn M, Sandral G, Whish J, Berary M, Reardon D, Woodsford-Smith A, Friske K, Pumpa R (2022) Farming systems performance at a ‘macro’ scale: effects of management strategies on productivity, profit, risk, WUE GRDC Update Wagga Wagga 2022. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/farming-systems-performance-at-a-macro-scale-effects-of-management-strategies-on-productivity,-profit,-risk,-wue

Swan T, Dunn M, Kirkegaard J, Goward L, Leighton E, Sandral G, Hunt J, Bullock M, Pumpa R, Fiske K, Woodford-Smith A, Reardon D, Barry M, Burns H (2022). What is the N legacy following pulses for subsequent crops and what management options are important to optimise N fixation? GRDC update, Wagga Wagga 2022. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/what-is-the-n-legacy-following-pulses-for-subsequent-crops-and-what-management-options-are-important-to-optimise-n-fixation2

Kirkegaard J, Swan T, Dunn M, Sandral G, Whish J, Leighton E, Reardon D, Bullock M, Friske K, Pumpa R (2021) Managing water and N across years and crop sequences to drive profit. GRDC Updates Wagga Wagga 2021. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/02/managing-water-and-n-across-years-and-crop-sequences-to-drive-profit

Flohr BM et al., (2020) Deep Soil Water-Use Determines the Yield Benefit of Long-Cycle Wheat. *Frontiers in Plant Science* 11, 548 doi: 10.3389/fpls.2020.00548.

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Practicalities and economics of integrating dual purpose crops into the whole of farming operation in the medium rainfall zone

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Key words

dual-purpose crops, grazing crops, whole farm profitability

GRDC code

CFF00011

Take home message

- There is no one size fits all approach to the integration of dual-purpose crops into a farming system. The value of the integration will depend on several factors including the existing system and the existing skill base. Following are some tips that may assist in successful implementation to ensure that dual purpose crops are an enduring part of the farming system
- Extracting value from dual purpose crops at a whole farm level requires optimising not only the grazing crop but also the other parts of the farming system
- Don't underestimate the investment in skills required to make some of the changes. Start small to build confidence as this will minimise risk and build skill over time
- Whole farm feed budgeting prior to making systems changes will assist in understanding the extent of the capital requirements for the additional livestock and the stocking rates necessary to deliver profitability improvements
- If feed budgeting skills can be learned and perfected through exposure to dual purpose crops and then applied to other parts of the farm, then there is the potential for improvement in whole farm profit.

Introduction

The GRDC farming systems project has compared the performance of crop sequences over the 2018 to 2020 growing seasons to account for legacy effects of one crop to the next. This has helped to move thinking beyond individual crop performance within any year to rotation performance across years. Further insights will be delivered with GRDC's investment into the second three-year phase which will run from 2021 to 2023.

The introduction of dual-purpose crops has the potential to increase whole farm profitability where the per hectare returns exceed those of the existing enterprises and their introduction doesn't erode the profits of the existing system. The aim of this paper is to demonstrate some of the factors that will influence the financial performance of dual-purpose crops. Dual purpose crops will have a greater chance of being an enduring part of the system if there is general understanding of the success factors prior to implementing change.

This paper will take a theoretical approach and combine it with case studies to demonstrate some of the practical issues associated with integrating dual purpose crops into the whole farm system. The value created, or destroyed, as a result of the integration of dual-purpose crops into the system is dependent on a range of factors including skills, management, the existing system and the extent to which it is already optimised.

This paper will also address the methodology for assigning a value to the grazing component of dual-purpose crops and consider some of the issues associated when scaling up from experimental components to an integrated whole farm system.

Play to your strengths

Decisions around farming systems changes should have some element of weighting on financial performance however there are a range of other factors that are also important. The financial performance resulting from production delivered in farming systems experiments is highly dependent on the management applied to the plots. This is entirely appropriate as the aim of these experiments is to measure the effect of an experimental treatment or test a hypothesis which is usually easier if all other management factors are optimised.

Not all farm business managers have the same level of skill across their enterprise mix. Farm performance analysis often shows that in mixed enterprise farms some business operators consistently perform better in one enterprise than another irrespective of commodity price differences. There is little data showing why this occurs, but the speculation is that passion or natural preference for one enterprise over another plays a role in this outcome. This passion leads to a greater skill development in the preferred enterprise at the cost of skill development in another enterprise and that just exacerbates the relative difference in performance.

A case in point is a producer in a 600-millimetre mixed farming area of southern NSW with 15 years of farm production and financial performance data. The highest return and best use for their farmland is dryland cropping with livestock enterprise returns being the next most appropriate use based on the resource base. Despite this, the farm manager has exceptional livestock performance due the skills built in this enterprise, the desire to manage livestock and his implementation of a livestock system that matches feed supply with feed demand and the timing of offtake of trading livestock coinciding with the decline in feed quality.

For this particular producer, over the last 15 years the per hectare financial returns of dual-purpose crops, inclusive of the value of grazing income, have rarely exceeded those of the chosen livestock enterprise. While farm performance data suggests this is not reflective of similar farms in the area, it reflects the management and skill sets of this individual manager. Despite these results, the manager was an early adopter of dual-purpose crops and continues to grow them for the role they play in reducing the weed seedbank prior to sowing long term perennial pasture.

For every manager with strengths in livestock management skills and weaknesses in crop management skills there will be another with strengths in crop management skills and weaknesses in livestock management skills. There is real value in identifying the weakness and establishing the cost of that weakness prior to executing a change in system, as the investment in a system change requires appropriate skill sets. Capital investment without the necessary skill sets is likely to be insufficient.

The key point here is that some farm managers have strengths and skills that need consideration when deciding about which farming system to implement. The financial performance delivered in a research trial may never be achieved on some farms because the effort and discipline required to build the management skills to deliver the same results exceeds the marginal reward when compared to the alternative.

What do you give up and what do you gain?

Studies of human behaviour, psychology and mental processes have shown that we value a loss and a gain of the same magnitude differently. The value that we place on loss is far higher and has a far greater impact than the value we place on gain. In fact, some studies have shown that we fear loss nearly twice as much as we value gain. Given this, it is important to quantify the value of any potential downside as well as the frequency of occurrence of that downside.

The vast weight of research data involving dual purpose crops suggest that, provided a few simple grazing rules are followed, there is no marginal cost of foregone grain yield of moving from a grain only system to a dual-purpose cropping system. In other words, yields of grazed crops are not significantly dissimilar to yields of ungrazed or grain only crops. This suggests that there is little risk from the grain income side of introducing a dual purpose crop, but there may be perceived risk on the grazing side.

The risks in introducing a grazing enterprise to a system where there was previously no livestock include:

1. Biosecurity risk. The introduction of weed seeds in the livestock themselves.
2. Labour risk. The time taken to manage the grazing livestock erodes some value elsewhere on the farm.
3. Management risk. The skills haven’t been developed so there are unknown elements that could induce cost.
4. Capital risk. There is more capital required for the outlay of the livestock however this needs to be tempered with the extremely low probability that it would be completely lost.
5. Production and price risk due to a lack of skill. The combination of these doesn’t combine to deliver the outcome necessary to generate an adequate return.

These risks need to be considered against the reward which is the additional income that can be generated from the grazing. It is also worth noting that many of these risks can be dealt with by taking a pro-active management approach to minimise their impact.

What base are you coming from?

An important step in establishing the value of any systems change is to first consider the status quo or base case. This is important because the value of a change in system depends in part on the existing system and its performance. When assessing the integration of dual-purpose crops into an existing farming system, there will be several factors that require consideration which are outside of the production and financial performance demonstrated in research trials.

These include, but are not limited to:

- Skills
- Human resources
- Capital requirements
- Land class suitability.

The extent of the change in technical skills, labour requirements and capital investment when integrating dual purpose crops into a farming system, previously devoid of this enterprise will differ depending on the existing enterprise mix. Table 1 shows that a mixed grain and livestock business will experience only small changes in skills, labour and capital investment when integrating dual purpose crops into the system. By comparison, the changes are large if moving from a livestock or grain only enterprise mix.

Table 1. The extent of the change in skills, labour and capital investment to integrate grazing of dual-purpose crops will differ depending on the existing enterprise mix.

Current enterprise	Change in skills, labour & capital investment
Mixed grain and livestock enterprise	Small
Livestock only enterprise	Large
Grain only enterprise	Large

Allocating grazing value to crops

The allocation of the value of grazing to a dual-purpose crop is necessary to account for the multiple streams of income (grain and grazing) that can be provided by the crop. There can be complexity associated with the allocation of the net value of grazing to dual purpose crops. Simplification sometimes results in miscalculation of the true value of the grazing resulting in erroneous values that can influence decision making. This can have major consequences where implementation is heavily dependent on financial performance.

Market value of feed

To assess performance at an enterprise level it is necessary to place a market value on the production generated by the dual-purpose crop. The market value of the grain is easily estimated as it is a simple calculation of yield by price. There is more complexity associated with the calculation of the value of grazing biomass because the value differs depending on how that biomass is used. The biomass can be used for trading livestock, creating value internally through utilisation in existing livestock enterprises or by agisting external livestock.

The value of a livestock trade allocated to a dual-purpose crop can be calculated as the net value or proportion of net value created by the trade. This is calculated as sales less purchases less all associated enterprise costs. If the trade occurs over a period which is longer than the dual-purpose crop grazing period, then the appropriate proportion of net earnings generated by the crop should be allocated.

The value of external agistment allocated to a dual-purpose crop is dictated by the price paid by the market. When feed is abundant the value may be low and when feed is in short supply the value increases. The range is usually around $0.50 cents to $2.00 per DSE per week.

The value to existing livestock enterprises of using a dual-purpose crop can be allocated in one of two ways. The first is to assign the market value of agistment as if the feed were to be sold as external agistment. The second is to establish the value generated from the use of the feed internally. The latter is far more difficult to calculate because splitting the costs and benefits of different components of a breeding unit is not straightforward.

In any livestock breeding enterprise, there are usually several income streams. These include trading livestock sales, cull and surplus female sales, bull, ram or wether sales and wool sales. The largest of the livestock income streams is usually the livestock trading component typically made up of young livestock such as lambs, hoggets, steers or heifers. In a breeding enterprise, the production of these trading livestock is dependent on a female breeding animal. This breeding animal incurs most of the enterprise cost and consumes around 75 percent of the total feed of the breeding and trading unit combined. Allocation of the trading income to the dual-purpose crop without either attribution of the cost of carrying the breeder or allocation of a purchase price of the lamb therefore results in unrealistically high values accrued against the dual-purpose crop.

Allocating a livestock trading enterprise value to a grazing crop

Where feed utilisation levels of fifty percent or above are achieved on pastures in the farming system then the inclusion of a livestock trading enterprise can be an effective means of utilising the additional feed supplied by the dual-purpose crop. To achieve feed utilisation levels of fifty percent or above, it is necessary to manage a livestock system that matches feed supply with demand. Typically, in a breeding operation, this means timing operational activities with high energy demand such as lambing, calving to coincide with the highest energy supply and ensuring trading livestock are sold as energy supply declines rapidly.

Where a trading enterprise is introduced for the sole purpose of generating revenue from the grazing crop, then the allocation of trading enterprise net earnings to the crop is relatively straight forward. The net earnings, or margin on the trade consists of sales less purchases less operational costs. It is generally not necessary to allocate any overhead costs to this trade unless it consumes a large proportion of the total labour use on farm. If a portion of the time spent by the trading livestock occurs off the crop, then the net earnings can be allocated on a pro-rata basis.

It appears to be a reasonably common industry practice to allocate the income of a livestock trading enterprise to the dual-purpose crop irrespective of the way the crop feed is utilised. This can be problematic as it may result in skewed results that aren’t truly reflective of the value at a whole farm level.

Industry practice appears to involve an estimation of grazing income, based on the estimation or measurement of weight gained on the crop by livestock, multiplied by a sales value per unit of weight gained. Some potential issues associated with the use of this methodology follow.

1. If the business is a breeding business and doesn’t have a trading enterprise, then it is possible that this method will overestimate the value of income.
2. There is no allocation of the value of any enterprise costs associated with the trade. If the trade was conducted purely for the consumption of the crop-supplied feed then the costs will include freight to farm, induction costs (animal health treatments including drench and vaccine), shearing and crutching costs and transaction costs including commissions, transaction levies and freight costs.
3. There is no allocation of the financial impact of mortality rate on income. At a financial level, mortality is accrued as foregone income by multiplying only those livestock sold by the value per head. Per hectare calculations derived from per head performance multiplied by stocking rate will need to account for mortality. This means that some per hectare calculations will be based on the number of livestock purchased and some on the number of livestock sold with the difference between the two being mortality.
4. Trading gains or trading losses are not allocated where income is calculated as sales value per unit of weight multiplied by weight gained.

Two components to a livestock trade

There are two components in a livestock trade that contribute to the margin net of costs. An explanation of these components follows.

1. The trading margin – calculated as the difference between buy and sell price.
2. The weight gain margin. The value of every unit of liveweight gain multiplied by the price per unit of liveweight gain at the point of sale. This must account for mortality as dead livestock tend not to put on a lot of weight.

The trading margin (difference in the buy and sell price) only applies to the weight purchased. When there is a positive price differential between the sell and buy price (i.e., the sell price exceeds the buy price) every kilogram purchased makes money. When there is a negative differential between the sell and buy price (i.e., the sell price is lower than the buy price) every kilogram purchased loses money. The weight gain margin is the value of every kilogram added after purchase.

It is the sum of the two that matters (i.e., makes the net income) – not one or the other in isolation. Some high-profile livestock producers have self-promoted their grazing and trading results on social media showing only the value of total weight at sale. In a livestock trading enterprise this gives an incomplete picture as it doesn't declare the value at purchase or the enterprise cost.

Many livestock trading enterprise managers conduct their risk analysis and trade margin calculations based on there being an adequate margin over the volume traded rather than ensuring the buy and sell price being the same. That is, they tend to accept that the sell price might be lower than the buy price because they think that the value of the weight that they gain at a lower price (than the buy price) will more than compensate for the lower price at sale. This mentality is not captured where trading income is calculated as sales price by weight gained.

The assignment to grazing crops of the value of livestock weight gain multiplied by the sales value per kilogram is only appropriate if the buy and sell price in a trade is exactly the same and mortality rate equates to zero. This however only accounts for the income in the trade and without the cost associated with the trade it overestimates the net margin associated with crop grazing.

Tables 2 and 3 provide examples of the calculations that are used to estimate grazing income on dual purpose crop. The methodology used in Table 1 potentially overestimates the value of the grazing contribution as it doesn't account for costs or trading gains or losses. The methodology in Table 3 more accurately values the grazing contribution to the crop as it accounts not only for the value of the weight gain but also for trading gains or losses, mortality and operating costs. The examples apply to a lamb trade however the principles apply equally to any livestock enterprise.

Table 2. Weight gain margin approach to valuation – does not account for costs or trading gain/loss

Biomass available for grazing (kg DM/ha)	3,800
Utilisation	75%
Feed conversion efficiency (kg DM/kg lwt)	8.3
Yield (cwt:lwt)	50%
Sale price ($/kg cwt)	$6.25
Carcase weight gained (kg cwt/ha)	171
Gross value of weight gain ($/ha)	$1,069

Table 3. Net margin approach to valuation – accounts for costs trading gain/loss and mortality

Buy to sell price disparity	**0%**
Gross value of weight gain ($/ha)	$1,069
Mortality adjusted value of weight gain ($/ha)	$1,035
Trading gain/loss ($/ha)	$0
Enterprise & transaction costs ($/ha)	$436
Net margin on trade ($/ha)	$599
Bottom line relative to headline	56%

Table 4 shows the assumptions that drive the outputs shown in Tables 2 and 3.

Table 4. Assumptions driving production and financial outputs.

Assumption	Metric
Mortality rate for period	1%
Induction & enterprise costs ($/head)	$8
Sales costs (commissions/fees/freight)	7%
Buy to sell disparity	0%
Yield (lwt to cwt)	50%
Sale price ($/kg cwt)	$6.25
Feed conversion efficiency	8.3
Crop area	250
Target sale weight (kg cwt/head)	22

Figure 1 shows that the weight gain margin method for valuing grazing to crops is insensitive to price disparity. This results in over estimations of net grazing value except where sell to buy price disparity exceeds 10 percent. The magnitude of the outcome of this analysis differs based on the selling price which in this example is $6.25 per kilogram carcase weight (lamb).

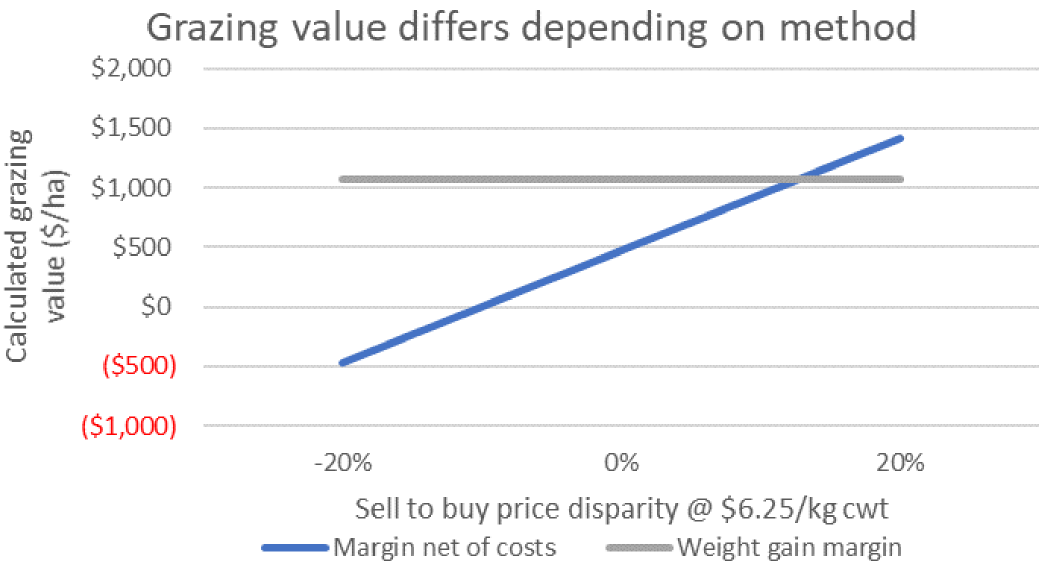

Figure 1. The weight gain margin method of grazing valuation is insensitive to trading gains or losses and ignores costs.

Shuffling the deck chairs or capturing the value? A case study demonstrating the difference

Farming systems trials have shown that dual purpose crop profits are highest where grain yield is optimised and vegetative crop biomass is well-utilised. Several research studies have concluded that the additional value generated through the inclusion of dual-purpose crops to the farming system adds considerably to whole farm profitability.

While farm benchmarking data shows that there are individuals who are able to capture the benefits of including dual purpose crops into their systems there are as many who generate no additional value. Individual farm benchmarking data sets have been examined to explore these issues and gain some understanding of why the additional return from dual purpose crop inclusion is not being delivered across the farm.

Table 5 shows two farming systems. The first three columns represent a livestock only system while the next three represent a system with 80% of the total farm area as pasture with the remaining 20 percent as dual-purpose crop (DP crop). The type of livestock enterprise, the time of lambing and calving and the time of turnoff of trading livestock are all important but they are not drivers of the outcome in the context of this analysis.

Table 5. Biomass production calculations for two systems – one livestock only, the other includes 20 percent dual purpose crop

	Livestock 100% Dual purpose crop 0%			**Livestock 80% Dual purpose crop 20%**		
	Pasture	**DP crop**	**Total**	**Pasture**	**DP crop**	**Total**
Enterprise (% total area)	100%	0%		80%	20%	
Area (ha)	1000	0	1,000	800	200	1,000
Biomass grown (kg DM/ha)	7,366	0	7,366	7,366	3,980	6,689

Figure 2 shows the stocking rate by systems component of the two farming systems. The grey line represents the monthly stocking rate, expressed in DSE per hectare, on pasture of the livestock only system. The dark blue bars represent the monthly stocking rate on the 80-pasture area while the light blue bars represent the monthly stocking rate on the 20 percent dual purpose crop area.

Figure 2 Shows the value of dual purpose crops is short duration grazing during Autumn and mid winter.

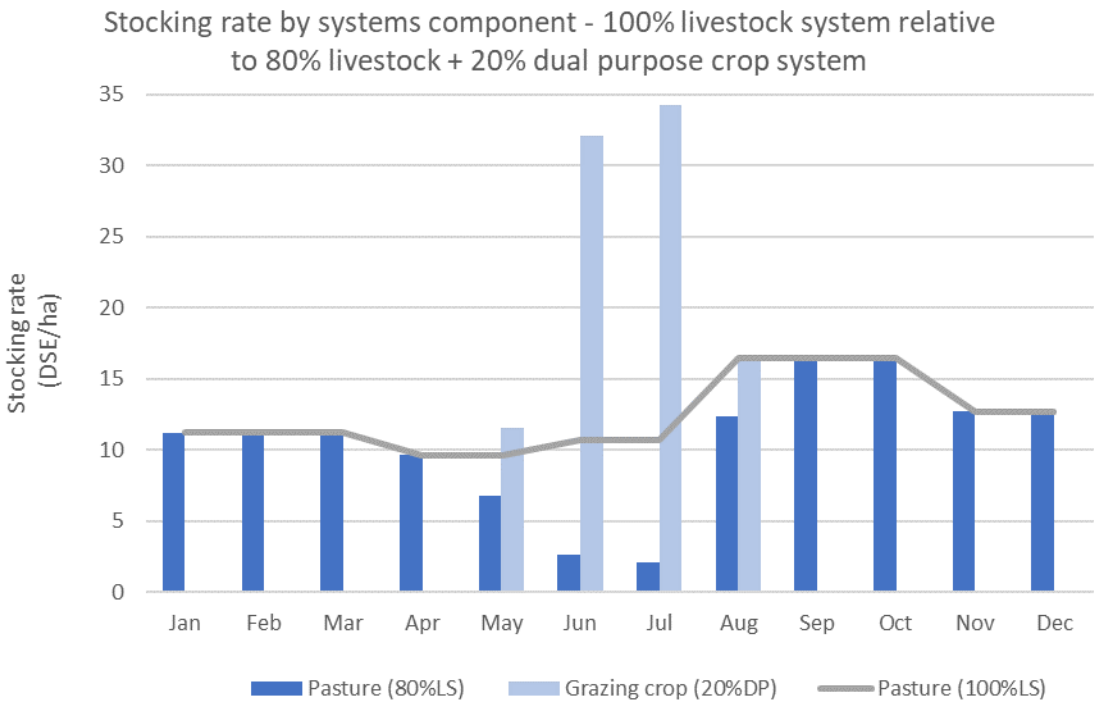

Figure 2. Stocking rate by month for a 100% livestock system vs an 80% livestock + 20% dual purpose crop system.

Table 6 shows stocking rate per hectare by component (pasture and crop) and by farming system. It also shows opening and closing annual biomass per hectare as well as feed utilisation levels. Feed utilisation is calculated as intake divided by feed grown. The closing crop biomass and the utilisation levels in the crop demonstrate that the additional feed supplied by the dual-purpose crop has been very well utilised. The issue however is that the lower mid-winter stocking rate in the pasture, shown as the dark blue bars in Figure 2, has reduced the average annual stocking rate on the pasture.

This reduction in average annual pasture stocking rate in the mixed livestock crop system has led to a reduction in feed utilisation demonstrated by the utilisation rate and the lower average annual stocking rate when compared with the livestock only system. If the pasture system was achieving a stocking rate of 12.5 DSE per hectare prior to introducing dual purpose crop it should be achieving the same stocking rate afterwards. Instead, the stocking rate on pasture declined.

At a whole farm level this means that the 9,980 DSE managed in the pasture and dual-purpose crop system represent 80 percent of the 12,430 DSE managed in the livestock only system. Given the pasture area in the pasture crop system represents 80% of the pasture area in the livestock only system this stocking rate should have been achieved in the absence of the dual-purpose crop and the 1,580 DSE in the dual-purpose crop should have been additional livestock. In other words, the grazing crop has added no marginal grazing value at a whole farm level.

This doesn't mean that the dual-purpose crop hasn't paid for itself, but it does mean that there is no additional grazing value added as a result of dual-purpose crop inclusion. The contribution of grain typically dwarfs the contribution of grazing to dual purpose crop income so there may still be value in adding dual purpose crops to the enterprise mix but their value isn't optimised. This is covered in more detail in Table 6.

Why is it so? For those that don't keep good livestock production records or differentiate pasture stocking rates from crop or whole farm stocking rates then it is possible that this issue isn't even known. It is plausible that the extremely high stocking rates on the crop, where the majority of livestock graze during a period that is conventionally difficult to manage and which accounts only for the minority of total grazed area, are causing misjudgements about the whole farm stocking rate. This is why recording stocking rate by area grazed is particularly important.

Dual purpose crops can provide potential benefits beyond production and its value. In cases where dual purpose crops are grazed with trading livestock, producers have been forced to become more skilled at feed budgeting. Many managers, because of growing dual purpose crops, are very attuned to crop growth rates, wastage rates, livestock intake and the factors that influence these.

In some cases, these feed budgeting skills have delivered improvements in feed utilisation in pasture systems as these managers become more confident in their ability to manage the livestock pasture interface. In some cases, the value of the improvements to the other parts of the farming system, depending on its scale may be greater than the value of the introduction of the dual-purpose crops to the system.

Table 6. Stocking rate per hectare by component (pasture and crop) and by farming system and opening and closing annual biomass per hectare as well as feed utilisation levels for 100% livestock system vs. an 80% livestock and 20% dual-purpose crop system. Dual purpose crop biomass is well utilised but pasture utilisation decreases.

	Livestock 100% Dual purpose crop 0%			**Livestock 80% Dual purpose crop 20%**		
	Pasture	**DP crop**	**Total**	**Pasture**	**DP crop**	**Total**
Opening biomass (kg DM/ha)	2,500			2,500	1,230	
Closing biomass (kg DM/ha)	2,526			2,884	508	
Average annual stocking rate	12.43		12.43	10.5	7.9	10.0
Utilisation rate	49%			42%	58%	
Farm stocking rate DSE	12,430		12,430	8,400	1,580	9,980

The impact on financial performance of two systems and three scenarios is presented in Table 7. The first column represents an efficient livestock only business (LS OPT). The next three columns represent the enterprise components of an 80% pasture base and 20% dual purpose crop system (LSC SUB) with pasture utilisation compromised or sub optimally stocked. The rightmost three) columns represent the enterprise components of an 80% pasture base and 20% dual purpose crop system (LSC OPT) with pasture utilisation and stocking rate optimised.

The value of the biomass in a dual-purpose crop represents only a small proportion of the total value of the crop. The majority of the total enterprise earnings are in grain production.

Table 7, which is an extension of Table 6, shows the difference in financial performance between enterprise components and between systems with sub optimal and optimal feed utilisation. In the system with sub optimal pasture utilisation the livestock (August lambing wool flock) are agisted onto the crop at a value of $1 per DSE per week. This is shown as crop grazing income at a gross level or Agistment/grazing margin at a per hectare level. This equates to $68 per hectare.

This agistment income is then seen as an expense in the livestock enterprise. When spread over all the livestock it equates to approximately $1.40 per DSE. The gross overhead costs allocated to the livestock enterprise decline from $310,000 to $250,000 but this equates to no net change on a per DSE basis. This is demonstrated in the cost per DSE which is $25 for the LS OPT and LSC SUB systems. Profits per DSE decline from $45 per DSE in the LS OPT system to $44 per DSE in the LSC SUB system due to the additional cost of the agistment onto the crop.

In the system with optimal pasture utilisation (LSC OPT), crop biomass is utilised with a livestock trade rather than the existing wool flock. The average annual stocking rate on the crop equates to 7.9 DSE per hectare but unlike the pasture, which is grazed year-round, it has been derived from short duration high intensity grazing for only a proportion of the year.

The number of livestock grazed on pasture increases relative to the LSC SUB system to reflect the per hectare stocking rate of the LS OPT system. This equates to 9,980 DSE. All of the expenses associated with the trade have been deducted so the net earnings of the trade are what is shown as the grazing margin. This means that there is no cost to be accrued against the existing livestock enterprise. The overhead cost base of the existing livestock enterprise is maintained at $25 per DSE which delivers the same profit per DSE.

The assumptions for the trade are shown in Table 8. The margin for the livestock trade ($308 per hectare) compared with the agistment income reflects the higher risk in this enterprise.

The grain income is assumed to be $1,238 per hectare which is higher than the average of the three-year grain income in the farming systems trial to attempt to reflect less volatility. The outcome of the analysis is highly sensitive to the value of the grain income per hectare. This reinforces the message around the importance of skills. Croppers know how much timeliness and management skill contributes to attaining the production while others may be less aware.

Per hectare comparisons

Livestock/pasture enterprise returns

The LS OPT system delivers operating profit or EBIT of $560 per hectare. The LSC SUB system delivers EBIT of $544 per hectare from the livestock due to additional agistment costs associated with grazing the dual-purpose crop. The LSC SUB system has maintained the 12.4 DSE per hectare stocking rate on the pasture by agisting on the crop which adds no value at a whole farm level.

The LSC OPT system generates the same return as the LS OPT system per hectare as the stocking rate per hectare on pasture has remained the same, but the additional feed produced by the crop is consumed using a livestock trading enterprise. At a gross level, profits have declined but only by the proportion of area sown to crop.

This means that there is no marginal cost associated with the crop as it has been grazed with trading livestock.

Crop enterprise returns

The LSC SUB system generates operating profit or EBIT of $555 per hectare in profit primarily due to low agistment income of only $68 per hectare when compared to the LSC OPT system. The LSC OPT system has higher grazing income because the net returns of trading (after costs) in this example are higher than the value attributed to agistment. The LSC OPT system generates $796 in EBIT per hectare which weights the whole farm EBIT per hectare up. This demonstrates that the value of the dual-purpose crop comes from creating additional value from the crop grazing.

Bottom line

The bottom line (EBIT) is demonstrated by the column titled ‘Whole farm.’ This is the aggregation of the enterprise contribution of income, expenses and profits within each system and scenario. The LSC SUB system generates less return to the whole business relative to the LS OPT system not because the grazing crop didn’t deliver solid production and financial performance but because that performance came at the cost of optimising the performance in the livestock system.

The LSC OPT system generated more profit across the whole farm because the stocking rate in the pasture system was maintained and the crop profits were higher than the livestock only system.

The returns of both the LS SUB system and the LS OPT system are highly sensitive to grain production, pasture feed utilisation (stocking rate) and agistment or grazing returns.

In this case study the livestock system generates the majority of the whole farm profit so it is critical that per hectare performance is maintained in this enterprise to ensure that whole farm profit isn’t eroded with the inclusion of a dual purpose cropping system.

The key message associated with this whole farm analysis is that without good records it is difficult to establish the value contributed by dual purpose crops at a whole farm level. Without recording whole farm stocking rate and taking it further to understand stocking rate per pasture and crop hectare it is impossible to establish the contribution of different enterprises to the whole farm performance. A good starting point for those looking to compare the value of dual purpose crops with alternative enterprises is to have good farm records to allow for the analyses to be conducted.

Table 7. Where whole farm grazing is optimised there is a greater business case to introduce dual purpose grazing crops. The difference in financial performance between enterprise components and between systems with sub optimal and optimal feed utilisation

System	**LS OPT Livestock Optimal SR**	**LSC SUB Internal agistment onto crop Sub optimal pasture stocking rate**			**LSC OPT Trade livestock onto crop Optimal pasture stocking rate**		
	Pasture	**Pasture**	**Crop**	**Whole farm**	**Pasture**	**Crop**	**Whole farm**
Stocking rate (AADSE)	12,425	8,400	1,580	9,980	9,980	1,580	11,560
Area (ha)	1,000	800	200	1,000	800	200	1,000
Gross profit ($/DSE)	$95	$95			$95		
Enterprise expenses ($/DSE)	$25	$25			$25		
Agistment expenses ($/DSE)		$1					
Overhead expenses ($/DSE)	$25	$25			$25		
EBIT ($/DSE)	**$45**	**$44**			**$45**		
Gross profit grain ($/ha)			$1,238			$1,238	
Agistment/grazing margin ($/ha)			$68			$308	
Gross profit ($/ha)	$1,180	$1,185	$1,305	$948	$1,185	$1,546	$1,257
Enterprise expenses ($/ha)	$311	$329	$450	$340	$312	$450	$340
Overhead expenses ($/ha)	$311	$312	$300	$310	$312	$300	$310
EBIT ($/HA)	**$559**	**$544**	**$555**	**$547**	**$561**	**$796**	**$608**
Gross profit livestock ($)	$1,180,419	$948,100		$948,100	$948,100		$948,100
Gross profit grain ($)			$247,500	$247,000		$247,500	$247,500
Crop grazing income ($)			$13,543	$13,543		$61,650	$61,650
Component gross profit ($)	**$1,180,419**	**$948,100**	**$261,043**	**$1,209,143**	**$948,100**	**$309,150**	**$1,257,250**
Enterprise expenses ($)	$310,637	$249,500	$90,000	$339,500	$249,500	$90,000	$339,500
Agistment grazing expense ($)		$13,543		$13,543			
Overhead expenses (4)	$310,637	$249,500	$60,000	$309,500	$249,500	$60,000	$309,500
Total operating costs ($)	**$621,273**	**$512,543**	**$150,000**	**$662,543**	**$499,000**	**$150,000**	**$649,000**
EBIT ($)	**$559,146**	**$435,557**	**$111,043**	**$546,600**	**$449,100**	**$159,150**	**$608,250**

It is possible to calculate the minimum per hectare profits from the dual-purpose crop enterprise required to break even with the LS OPT system. Deduct the whole farm livestock enterprise EBIT in the LSC SUB and LSC OPT systems from the LS OPT system and dividing that figure by the crop area.

For example, the LSC SUB system compared to the LS OPT system: $559,146-$435,557 = $123,589 ÷ 200 = $617 per hectare.

For example, the LSC OPT system compared to the LS OPT system: $559,146-$449 100 = $110,046 ÷ 200 = $550 per hectare.

This approach can be used in forecast budgets to assist in decisions.

Table 8. Livestock (lamb) trading assumptions

Livestock trade assumptions	
Weight gain (kg/head/day)	0.275
Yield (cwt to lwt %)	46%
Feed adjustment period (days)	10
Sale weight (kg cwt/head)	21
Sale weight (kg lwt/head)	45.7
Purchase weight (kg lwt/head)	29.2
Price in ($/kg cwt)	$8.00
Price in ($/head)	$107.28
Price out ($/kg cwt)	$8.50
Price out ($/head)	$178.50
Sales cost ($/head)	$12.50
Enterprise costs ($/head)	$8.00
Total cost ($/head)	$20.50
Net margin ($/head)	$50.73
Net margin ($/ha)	$398
Net margin ($ gross)	$61,650

What this means to you

There is no one size fits all approach to the integration of dual-purpose crops into a farming system. The value of the integration will depend on several factors including the existing system and the existing skill base. Following are some tips that may assist in successful implementation to ensure that dual purpose crops are an enduring part of the farming system.

1. Extracting value from dual purpose crops at a whole farm level requires optimising not only of the grazing crop but also the other parts of the farming system.
2. Don't underestimate the investment in skills required to make some of the changes. Start small to build confidence as this will minimise risk and build skill over time.
3. Whole farm feed budgeting prior to making systems changes will assist in understanding the extent of the capital requirements for the additional livestock and the stocking rates necessary to deliver profitability improvements.
4. Where there is opportunity for feed budgeting skills learned as a result of exposure to dual purpose crops to be implemented to other parts of the farm there is massive opportunity for improvements in whole farm profitability.

Acknowledgement

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

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