Final Technical Results Report

2024 Minimising frost risk and damage on the Eyre Peninsula

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Does the report have any of the following sensitivities?

Intended for journal publication	YES ☐ NO ☒
Results are incomplete	YES ☐ NO ☒
Commercial/IP concerns	YES ☐ NO ☒
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ABSTRACT

Following a series of years where large areas of Eyre Peninsula were badly affected by frost (2017-2021) in 2022 and 2023 a number of strategies were evaluated looking to minimise frost damage.

Strategies included varietal phenology and sowing time, growing mixtures of varieties with differing maturity, the use of nutritional and ice-nucleating bacteria products, zoning and role of soil amelioration.

The project found that high risk areas can have over 30 frost events from June to October and avoiding frost through the selection of variety maturity and time of sowing is difficult. It was able to demonstrate there is value in being able to identify areas of high frost risk and potentially manage them differently.

The project was also able to demonstrate that canopy temperatures were warmer during frost events in sandy soils that had been ameliorated.

The project was provided direction by a group of trusted local advisors, who also helped disseminate information generated by the project.

EXECUTIVE SUMMARY

Aiming to identify and demonstrate the most valuable and relevant frost mitigation tactics on the Eyre Peninsula, a GRDC-funded project was conducted during the 2022 and 2023 growing seasons. To address regional knowledge gaps and assist in disseminating information, a steering committee was formed, comprising advisors working with growers in frost-affected areas and local researchers.

Field trials were conducted from 2022 to 2023, encompassing strategies that were either commonly used in the area, showed promise in frost research from other regions, or were of interest to growers despite limited supporting literature. A summary of the frost tactics demonstrated to growers is provided below.

Varietal Phenology: This trial showcased various sowing time and variety combinations available to growers to avoid frost exposure. Extending this work over two contrasting growing seasons highlighted the complexity of making these decisions without reliable frost and rainfall forecasts. Multiple frost events, both early and late in the season, made it challenging to consistently choose a wheat variety and sowing time strategy that reduced frost risk without the benefit of hindsight. Barley consistently achieved higher yields across several phenology and sowing time combinations than wheat in frosty environments.

Crop Type: In 2022, a trial of different crop types demonstrated the varied reactions of crops like canola, beans, lentils, and vetch to frosty environments. Growers and advisors sought to understand the relative frost damage risk across a range of break crops, especially given the growing importance of these crops in the farming system and the decline in livestock production. The recent expansion of lentil cultivation across central and upper Eyre Peninsula necessitated more knowledge about frost impacts on lentils and the suitability of alternative break crops such as faba beans. The work conducted in 2022 found that lentils experienced more frost damage than faba beans.

Nutritional Amendments and Ice-Nucleating Bacteria Control Products: This trial aimed to assess the value of various products purported to improve crop resilience to frost damage. Claimed mechanisms included foliar transpiration inhibition, nutrition-based sugar enhancement, plant health enhancement, floret sterility reduction, and antibacterial properties. Over two years in high frost incidence environments, none of the products demonstrated a yield benefit beyond correcting well-documented nutritional deficiencies, such as low potassium levels in sandy soils.

Zoning: Frost damage consistently affects certain landscape areas due to topography and air movement. Consequently, some paddock areas incur significant frost damage, while nearby areas remain unaffected. With advancements in precision farming equipment, growers can now manage high frost risk areas differently. To evaluate the benefits of such management, phenology, crop type, and nutritional amendment trials were mirrored in both high and moderate frost risk zones within the same paddock. Data showed that high-risk zones experienced more severe frost damage, and strategies like sowing longer-season wheat varieties (winter varieties) and various barley varieties had higher value in high-risk zones. This demonstrated the value of managing zones differently. Collecting data over additional seasons will be crucial for modelling yields and frost damage accurately, aiding growers and advisors in making informed management decisions based on frost risk.

Soil Amelioration: Anecdotal evidence from growers and previous research in Western Australia suggested a potential relationship between soil amelioration on sandy soils and frost mitigation. Data and observations from eight sites over 2022 and 2023 allowed direct comparisons between ameliorated and original soil compositions. Six of the eight site comparisons found that soil amelioration occasionally reduced daily canopy temperature fluctuations, with temperature differences increasing as conditions became more extreme. Some events were up to a few degrees warmer during the coldest overnight periods. Instances where amelioration did not result in warmer temperatures were found on heavier textured soils. Understanding the underlying mechanisms may help quantify the soil-temperature interaction level needed to reduce frost damage.

BACKGROUND

Extensive crop damage and financial losses were driven by frost events occurring across large areas of Central and Eastern Eyre Peninsula over the four years leading up to 2022. This GRDC-funded project aimed to enhance the knowledge and confidence of growers in the Eyre Peninsula's frost-prone areas, enabling them to adopt and implement practices that minimise the impact of frost on their profitability.

While growers understand that a complete solution to avoiding damage from frost is not currently possible, several strategies were identified by local advisors and growers for their potential to reduce frost damage. These strategies were evaluated to develop localised information on their optimal implementation.

The strategies evaluated included:

- Determining whether longer-maturing varieties should be planted to avoid frost damage and whether fast-maturing varieties can be planted early to mature before frost events occur.
- Assessing the potential advantage of planting mixtures of varieties with differing maturity times. This approach could mitigate the impact of a frost event on one variety by having another variety with a different maturity time continue to grow unaffected.
- Investigating reports of certain nutrients and products that can be applied to crops to either enhance plant resilience against frost or reduce the levels of ice-nucleating bacteria.
- Exploring anecdotal evidence suggesting that soil amelioration practices on sandy soils might reduce frost damage.

These strategies were identified by a project steering committee, consisting of five experienced local consultants, in consultation with Mick Faulkner, a consultant from Mid-North South Australia with considerable experience in frost research, as well as frost researchers from Western Australia.

PROJECT OBJECTIVES

The goal of this project is to evaluate the performance of current frost mitigation tactics on the Eyre Peninsula, providing growers with confidence in their local practices and offering insights for other regions to investigate suitable strategies.

Objectives:

To develop localised information enabling growers and their advisors in the Eyre Peninsula's frost-prone areas to evaluate the effectiveness of various strategies in reducing frost damage. Additionally, to generate data that will assist growers in determining when implementing a frost mitigation strategy is warranted.

The range of strategies evaluated includes:

- Identifying areas with a higher risk of frost damage and exploring potential management differences for these areas.
- Assessing crop choices and varietal maturity to determine their impact on frost resilience.
- Evaluating the effectiveness of mixtures of varieties with differing maturity times.
- Investigating products that may enhance a plant's resilience to frost damage or reduce the level of ice-nucleating bacteria.
- Examining the impact of soil amelioration practices on reducing frost damage.
- Use a network of trusted and experienced advisors in the design of the project activities and utilise their skills and client base to help disseminate information generated by the project through field days, as well as one on one and group discussions.

METHODOLOGY

The work conducted as part of this investment occurred over three tiers:

1. Small plots – located in a high risk frost location, with a moderately risky frost trial site located nearby all situated in a central location so that a range of frost mitigation strategies could be evaluated and viewed by growers in one location.
2. Demonstration paddocks – located in three strategic locations across the frost prone region of Eyre Peninsula. To evaluate the large-scale efficacy of practices such as soil amelioration at a range of locations to help create localised discussion points.
3. Extension and implementation of frost mitigation strategies – five experienced and trusted advisors located on Eyre Peninsula (Ed Hunt, George Pedler, Josh Hollitt, Andy Bates and Michael Hind) convened as a steering committee for the project in collaboration with Mick Faulkner, experienced frost researcher and advisor from the Mid-North. The advisors took responsibility for presenting frost research to field days and amongst their client bases.

Small plot trials

In each growing season of both 2022 and 2023, two field trials were established in close proximity at Tooligie, Central Eyre Peninsula. One site was located in an area with a high risk of frost damage, while the other site (only a few hundred metres away) had a more moderate frost risk.

The trials were designed as complete randomised blocks with three replications. For trials where time of sowing was a factor, each time of sowing served as the main plot in a split-plot design. The trials were sown with no gaps between plots, maintaining a constant 25 cm row spacing across each site. Additionally, the pathways and areas surrounding the trials had crops growing throughout the season to mimic paddock conditions and prevent extra gaps for air movement.

At each site, a number of individual trials were conducted:

Phenology: Across two times of sowing (around 25 April and mid-May), a range of wheat and barley varieties (seven wheat in 2022, eight wheat in 2023, and three barley in both years) were grown, selected for their different flowering and maturity times.

Objective: To evaluate if faster or slower maturing varieties, or different crop types (wheat vs. barley), could reduce exposure to frost damage.

Measurements: Soil testing, canopy and Stevenson screen temperature, weekly phenology scores, harvest index cuts, grain yield, and grain quality.

Variety Mixtures: Across two times of sowing (around 25 April and mid-May), mixtures of two to three wheat or barley varieties were grown, primarily based on their differing flowering and maturity times.

Objective: To determine if growing a mixture of varieties with different maturity times could prevent total crop failure by having at least one variety escape frost damage.

Measurements: Soil testing, canopy and Stevenson screen temperature, harvest index cuts, grain yield, and grain quality.

Note: Phenology scores were challenging to obtain due to the large variation across the different varieties.

Nutritional Amendments and Ice-Nucleating Bacteria Control Products: In both 2022 and 2023, a range of nutritional amendments and products aiming to reduce the effect of ice-nucleating bacteria were investigated (18 treatments in 2022, 10 treatments in 2023, plus an additional eight-treatment intensive Cu x K trial in 2023).

Objective: To assess the efficacy of products such as foliar transpiration inhibitors, nutrition-based sugar enhancers, plant health enhancers, floret sterility reductants, and antibacterial agents.

Measurements: Soil testing, plant tissue testing, canopy and Stevenson screen temperature, phenology, harvest index cuts, grain yield, and grain quality.

Crop Type: In 2022, a range of break crops were trialled.

Objective: To determine which crops performed better relative to others in the presence of frost.

Crops evaluated: Lentil, woolly pod vetch, common vetch, faba bean, linseed, safflower, canola, and a mixture of lentil and faba beans.

Measurements: Soil testing, canopy and Stevenson screen temperature, phenology, harvest index cuts, and grain yield.

Note: this was not continued in 2023 due to complex management of the range of break crops evaluated and fear that improper management may bias results.

Picture 1: Cereal Phenology trial at Tooligie in 2022 *Photo credit Rhaquelle Meiklejohn*

Zoning - With improvements in equipment and their ability to deliver precision prescriptions, growers can now manage areas of high frost risk differently. To help determine when value exists in managing areas of frost risk differently the phenology, crop type and nutritional amendment trials described above were mirrored in both a high and moderate frost risk zone of the same paddock to try and capture the opportunity cost of a given management decision between each zone.

Soil amelioration investigation – Anecdotal evidence provided by growers through the formative stages of this project and previous research done in Western Australia, suggested there was merit in investigating a relationship between soil amelioration on sandy soils and frost. In 2022 and 2023 data and observations were collected on eight sites, where direct comparison could be made between ameliorated treatments imposed on a sandy soil and the original soil composition.

All field scale trials included the following measurements:

- Preliminary soil characterisation
- Soil nutrition analysis
- Moisture samples

- Penetrometer readings
- Qualitative frost assessment
- Weekly growth score measurements during the frost prone period
- Harvest index
- Yield

In 2023 the amelioration demonstration work was extended further to capture the role of soil moisture in frost damage. Soil moisture cores were taken withing 24 hrs of the three major frost events to compare the ameliorated and control treatments.

LOCATION

Site #	Nearest town
Trial Site #1 phenology 2022 & 2023	Tooligie
Trial Site #2 Crop type 2022	Tooligie
Trial Site #3 nutrition 2022	Tooligie
Demo site #1 2022	Tooligie
Demo site #2 2022	Warramboo
Demo site #3 2022	Moody
Demo site #4 2022	Mangalo
Demo site # 5 2023	Tooligie
Demo site #6 2023	Mt Bosanquet
Demo site #7 2023	Moody
Demo site # 8	Wharminda

If the research results are applicable to a specific GRDC region/s (e.g. North/South/West) or GRDC agro-ecological zone/s, indicate which in the table below:

Research	Benefiting GRDC region (select up to three)	Benefitting GRDC agro-ecological zone	
All trials in project	Southern Region Choose an item. Choose an item.	☐ Qld Central ☐ NSW NE/Qld SE ☐ NSW Vic Slopes ☐ Tas Grain ☒ SA Midnorth-Lower Yorke Eyre ☐ WA Northern ☐ WA Eastern ☐ WA Mallee	☐ NSW Central ☐ NSW NW/Qld SW ☐ Vic High Rainfall ☒ SA Vic Mallee ☐ SA Vic Bordertown-Wimmera ☐ WA Central ☐ WA Sandplain

RESULTS

PART 1: SMALL PLOT TRIALS

Season overview.

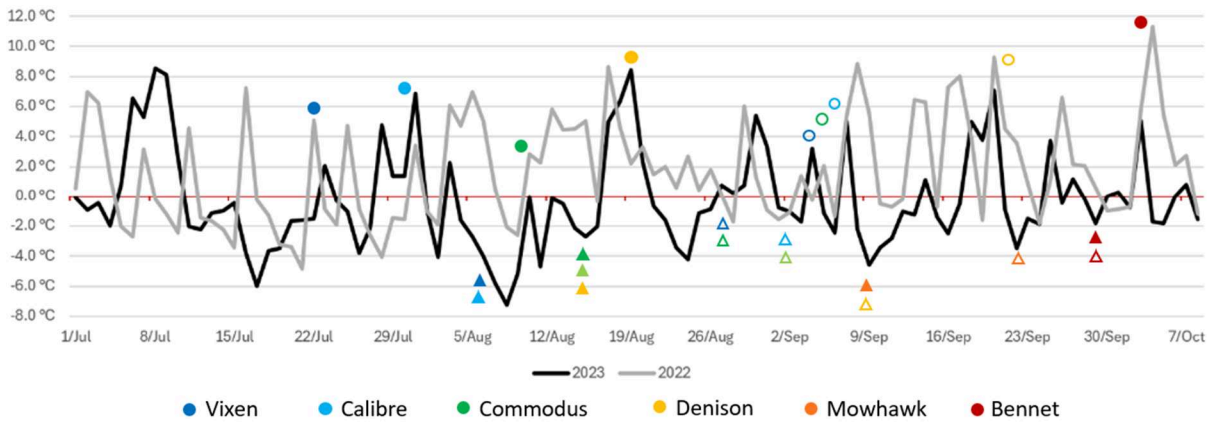

Figure 1: *Daily minimum temperatures across the months cereals are most susceptible to frost. Date of head emergence for each variety 2022 in circles and 2023 in triangles (TOS 1 in full and TOS2 outlined).*

2022 was characterised by a decile 8 year for rainfall, beginning the season with a full soil water profile and finishing with a slow wet spring. This made favourable conditions for early sown, slow maturing wheats to maximise on the long growing season. The Tooligie high risk site reached a minimum of -2.7℃ and experienced 26 events below 0℃, which for the purpose of the report will be referred to as a frost event.

2023 began with a relatively full soil profile, with a season break around ANZAC day. The season dried up around mid-July with a dry spring until October. The high-risk site experienced 43 frost events reaching a minimum of -7.2℃. Events extended through till October and would often occur over consecutive nights that consisted of up to 7 consecutive frost events. This combination of late frost and early water stress, managed to pinch both ends of the optimal flowering period. Rather than looking for maximised yields, this year highlighted the importance of avoiding risky combinations like spring wheats sown early.

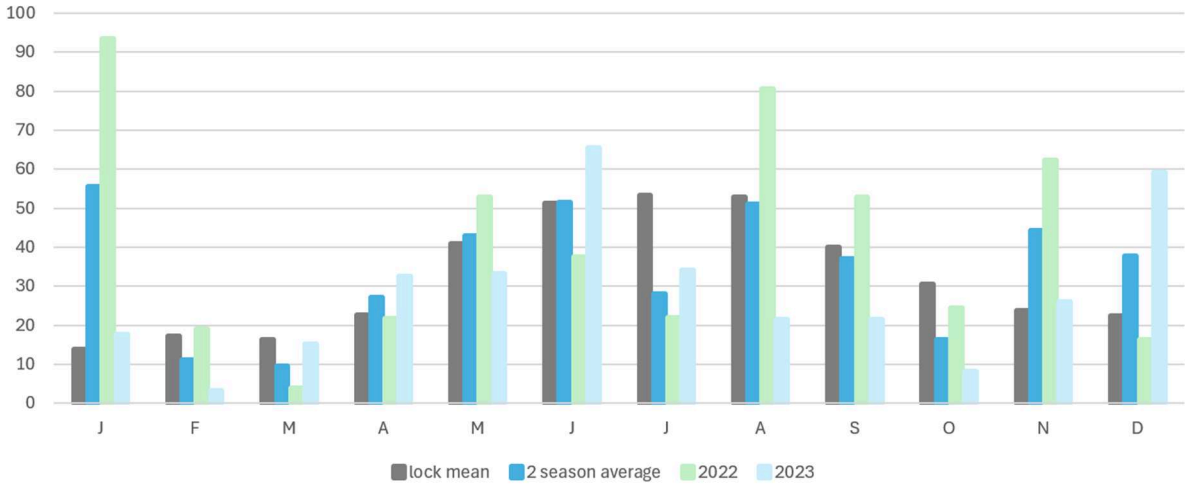

Figure 2: *Monthly rainfall (mm) recorded at Lock BOM station (closest to site). Showing Lock long term mean, two season average and monthly rainfall for 2022 and 2023.*

Table 1: Phenology Trial yield results (t/ha) for selected varieties in high and moderate frost risk zones in 2022 and 2023.

	2022 Yield (t/ha)				2023 Yield (t/ha)			
	High Risk		Mod Risk		High Risk		Mod Risk	
Variety	**TOS 1**	**TOS 2**	**TOS 1**	**TOS 2**	TOS 1	TOS 2	TOS 1	TOS 2
Vixen	0.24	0.20	5.21	5.77	0.32	1.79	2.18	3.09
Calibre	0.87	0.34	5.15	5.25	0.58	2.44	2.55	3.58
Rockstar ('22)/ Matador ('23)	0.77	0.35	5.97	5.37	0.34	1.38	2.92	3.37
Denison	1.05	3.05	5.49	4.94	0.34	2.25	2.76	3.47
Longsword('22)/ Mowhawk ('23)	1.08	3.29	6.02	5.56	2.39	2.13	3.17	3.54
Bennett	5.40	-	5.50	-	1.34	1.00	1.69	1.86
Commodus	5.12	4.32	5.80	5.24	1.92	1.64	1.92	3.48
lsd	0.85		0.94		0.87		0.86	
P	<0.001		0.15		<0.001		<0.001	

1. Phenology

The fastest maturing wheat experienced the most frost damage and yielded the least in both seasons. A winter type wheat yielded the highest across the two seasons, either quick or slow depending on the season finish. Despite having a similar phenology to a Fast-Mid Spring wheat, barley was the highest yielding cereal option for a frost prone paddock.

2. Time of sowing

The early (around ANZAC day time of sowing), generally saw large yield reductions in many of the commonly grown fast to mid length growing season wheat varieties in the high-risk trial compared to the moderate risk trial. However, when sown later (mid-May) the slower developing spring wheats were given a chance to dodge frost by flowering later and able to yield higher, however frost events into October in both 2022 and 2023 made the success of

this practice very difficult to predict. In both years winter wheats (Bennett, Longsword, Mowhawk) were able to demonstrate some potential, although advisors wanted more data before they were confident to adopt as a practice.

3. Mixtures

One way to address the question of which variety to sow in such unpredictable flowering conditions, is to sow a mixture of varieties. In this trial, the yield of a given mixture would mostly equate to the sum of its parts. This meant when weighing up the value of sowing a mixture, it was usually better to have simply sown the highest performing variety alone. With out a direct yield advantage, mixtures seemed to be more of a personal decision about how a grower may prefer to spread their risk.

Table 2: Cereal variety mixture trial yield results (t/ha) for selected varieties in high and moderate frost risk zones in 2022.

	High Risk (t/ha)		Mod Risk (t/ha)	
Variety Mixture	TOS 1	TOS 2	TOS 1	TOS 2
Vixen/ Calibre	1.05	0.79	4.48	5.64
Vixen/ Rockstar	1.08	0.84	6.15	5.70
Denison/Vixen	1.22	1.40	5.48	5.48
Denison/Calibre/Vixen	1.11	1.42	4.27	5.39
Denison/Calibre	1.27	1.55	4.13	5.51
Denison/Rockstar	1.62	1.53	5.53	4.94
Vixen/ Calibre	1.05	0.79	4.48	5.64
Vixen/ Rockstar	1.08	0.84	6.15	5.70
lsd	0.79		1.45	
P	<0.001		0.18	

Table 3: Cereal variety mixture trial yield results (t/ha) for selected varieties in high and moderate frost risk zones in 2023:

	High Risk (t/ha)		Mod Risk (t/ha)	
Variety Mixture	TOS 1	TOS 2	TOS 1	TOS 2
Denison+Vixen	0.34	2.06	3.04	3.48
Denison+Vixen+Scepter	0.25	2.34	3.17	3.36
Denison+Scepter	0.39	2.19	2.72	3.61
Mowhawk+Vixen	0.78	1.44	2.83	3.51
Mowhawk+Vixen+Scepter	0.77	1.77	2.77	3.25
Mowhawk+Scepter	0.99	1.71	2.73	2.66
lsd	0.87		0.86	
P	<0.001		<0.001	

4. Crop type

Barley is often grown in place of wheat to avoid frost damage because its physiology is more resilient to frost stress. This was demonstrated in the 2022 phenology trial where TOS1 Commodus yielded 4 times greater than Calibre and Denison, despite being exposed to a relatively similar level of frost. In 2023 barley also yielded higher than similar maturing wheat lines, however not to the same extent as in 2022 (Table 1).

5. Zoning

Table 4: Site mean yields (t/ha) of cereal phenology trials for high and moderate frost risk zones in 2022 and 2023.

	High Risk		Mod Risk	
	TOS 1	**TOS 2**	**TOS 1**	**TOS 2**
2022 Site mean yield	2.53	2.20	5.38	5.32
2023 Site mean yield	0.96	1.88	2.70	3.21

Being able to identify the areas of paddocks that are of higher risk to frost damage demonstrated large differences in yield potential. In both 2022 and 2023, yield in the moderate risk sites was double that of the high-risk sites. This demonstrates the value of being able to identify the areas that are more likely to experience frost damage and potentially manage them in a different manner, either by reducing costs, or planting a different crop on them.

6. Nutritional Amendments and Ice-Nucleating Bacteria Control Products

Table 5: Nutritional amendments and ice nucleating bacteria control products trial wheat yield (t/ha) results in 2022.

	Yield (t/ha)	
Treatment	High Risk	Mod. Risk
Antibacterial - seaweed	2.15	6.55
Antibacterial - smoke	1.82	6.50
Antitransparent	2.28	5.54
Copper	2.20	5.83
Defoliation	1.75	4.84
K foliar	1.78	6.24
Kestral Cu	2.35	5.62
Nil	1.96	5.89
Nitrogen	2.53	6.56
Plant stress product	1.96	5.73
Potash	2.74	6.24
Potash + Cu	2.78	6.26
Seaweed concentrates	1.85	6.09
Sugar foliar	2.03	5.63
Sugar seed	2.21	5.98
Trace triple	2.60	5.97
Y Polyglutamaic acid	2.58	5.91
Zn + Cu	2.64	6.04
Site mean yield	2.23	5.97
lsd	ns	ns

Table 6: Nutritional amendments and ice nucleating bacteria control products trial wheat yield (t/ha) results in 2023.

Potassium + Copper	High Risk (t/ha)		Moderate Risk (t/ha)
No additional K or Cu	2.28	a	3.09
0K + Cu	2.51	abc	3.21
25K	2.29	c	2.98
25K + Cu	2.46	ab	3.24
50K	2.57	bc	3.07
50K + Cu	2.85	bc	3.14
100K	2.68	bc	3.02
100K + Cu	2.62	bc	3.03
lsd			ns
Product ***	**High Risk (t/ha)**		**Moderate Risk (t/ha)**
[redacted]	2.62	b	2.86
Control	2.59	ab	2.87
[redacted]	2.54	ab	2.94
[redacted]	2.59	ab	2.86
[redacted]	2.39	a	2.90
[redacted]	2.55	ab	2.97
[redacted]	2.43	ab	3.09
[redacted]	2.43	ab	3.02
[redacted]	2.46	ab	2.93
[redacted]	2.50	ab	2.41
lsd			ns

**** product names are confidential to this report and have not been circulated*

- Details of soil and plant tissue tests can be found in Appendices.
- No significant yield responses were recorded to any of the products evaluated, beyond those applied where recognised nutritional deficiencies were found.
- Samples sent to WA for Ice Nucleating Bacteria assessments came back inconclusive of the treatment and needs further investigation.

7. Break crop type

In 2022 a trial was included to assess the value of different broad-leaved crops in frost prone areas.

Table 7: Break crop grain yields (t/ha), biomass yields (t/ha) and harvest index of a selection of break crops grown in high and moderate frost risk zones in 2022.

	Grian Yield (t/ha)		Final Biomass (t/ha)		Harvest Index	
Crop/ Variety	**Moderate Risk**	**High Risk**	**Moderate Risk**	**High Risk**	**Moderate Risk**	**High Risk**
Bendoc/ Beans	4.93	3.95	10.2	8.7	0.48	0.45
Highland/ Lentil	1.88	1.06	3.9	5.8	0.48	0.18
Hurricane/ Lentil	3.09	1.18	10.4	5.3	0.30	0.22
Hylola Enforcer/ Canola	2.09	2.57	6.0	7.0	0.35	0.37
lentil & bean/ Mixture	5.27	1.87	10.1	5.8	0.52	0.32
Studenica/ Vetch	5.45	2.12	13.2	9.2	0.41	0.23

The difference in yields and harvest index between the moderate and high-risk zones demonstrates that lentils are more prone to yield loss from frost events than faba beans or canola. The common vetch (Studenica) experienced damage from frost somewhere in between lentil and faba bean. The lentil/ faba bean mixture demonstrated some promise but advisor feedback was growers were less likely to adopt due to difficulty in managing both crops both during the season and at harvest. These data suggest the lentils were the most susceptible crop to frost damage, followed by vetch, faba beans and canola.

PART 2: SOIL AMELIORATION DEMONSTRATIONS

Growers across the southern region had been observing reduced frost damage after having used some form of mechanical amelioration to alleviate soil constraints. Despite the repeated anecdotes, the exact mechanism behind why this was happening remains unclear. Efforts from the University of Adelaide and WA DPIRD hypothesised two main thinkings around this phenomenon:

1. The amelioration improves soil conditions enabling a healthier plant in general with greater resilience to stressors such as frost.

2. The amelioration changes the soil's physical properties in a way that maintains warmer canopy temperatures during a frost event.

Figure 3: An EP grower reported a 2 t/ha yield increase when harvesting the ameliorated area of frosted paddock. Photo credit Niel Cummins, Lock, 2021. 1.8-2.2 t/ha in frosted area and 4 t/ha where ripping had been implemented.

The following work aimed to gather any in-field empirical data that may help tease apart these two hypotheses. This involved comparing ameliorated and control strips in frost prone areas with the following parameters:

1. Improved soil conditions	2. Warmer canopy temperatures
Soil characterisations	Soil characterisations (e.g. Texture, SEM)
Tissue testing	Soils moistures aligned with frost events
Penetrometer reading	Ground &canopy temperature 8 amelioration sites: - Minimum temperatures - No of frost events - Degree hours <0
In season moisture	
Biomass/yield	
Ice nucleating bacteria samples	

Eight amelioration sites were selected across the most frost affected areas of the Eyre Peninsula. It was important they were growing wheat in a high frost risk zone and maintained a control strip for comparison.

1. Tooligie high risk zone 2022: Here a Bednar demonstration strip had been run perpendicular to the plot trial.
2. Tooligie moderate risk zone 2022: The moderate risk zone was also monitored to show a comparison using the same machinery and frost exposure, with a slightly heavier soil type.
3. Warramboo 2022: A sandy site in dune swale country where ripping down to a metre had doubled yields in some parts of the landscape.
4. Mangalo 2022: large tine ripper.
5. Moody 2022: This site had been showing yield increases with ripping even 5 years after ripping treatment.
6. Moody 2023: The same Moody site was monitored again in 2023, with barley planted over the site.
7. Wharminda 2023: sandy soil, ripping to 40 cm had bought clay to surface.
8. Mt Bosanquet 2023: delved sandy site that had bought clay to the surface.
9. Tooligie high risk zone 2023: replicating results over different frost seasons (planted to canola in 2023).
10. Tooligie moderate risk zone 2023: replicating results over different frost seasons (planted to canola in 2023).

Figure 4: Pictures of soil profile following amelioration with a Bednar Terraland ripper at Tooligie in 2022. Photo credit Rhaquelle Meiklejohn, May 2022.

Maintaining an appropriate control strip was a common problem during site selection. Sites were selected opportunely meaning control strips were found in places where a grower had finished using an implement and for many cases, this was because of a change in soil type.

As the season progressed it became more apparent that the location of the 'control' tiny tags at Mangalo and Bosanquet, were placed too far away from the ripped treatment to make a fair comparison.

For most of the sites, amelioration improved crop yields, however the effect on frost damage was not so certain. Harvest index was used as a key indicator for frost damage and only very mild differences were found between treatments.

Table 8: Yield (t/ha) and harvest index for 10 demonstration sites monitored to compare the effects of amelioration.

	Yield (t/ha)		Harvest Index	
	Control	Ameliorated	Control	Ameliorated
2023 Moody (barley)	1.31	2.34	0.34	0.38
2023 Wharminda	0.08	0.36	0.02	0.10
2023 Mt Bosanquet	1.59	0.6	0.33	0.18
2023 High risk Tooligie (canola)	1.00	0.70	0.20	0.10
2023 Mod risk Tooligie (canola)	1.30	1.40	0.30	0.30
2022 Moody (wheat)	4.67	6.07	0.32	0.38
2022 Mangalo	3.73	3.42	0.41	0.50
2022 Warramboo	2.07	2.59	0.41	0.39
2022 Tooligie High Risk (wheat)	0.81	4.62	0.16	0.40
2022 Tooligie Mod Risk (wheat)	5.43	5.70	0.33	0.36

Warmer canopy temperatures:

Six of the eight demonstration sites over two years found results that demonstrated canopy temperatures were warmer during frost events in areas where the soil had been ameliorated compared to un-ameliorated. Most ameliorated treatments experienced fewer, shorter and warmer frost events. This kind of temp x time severity can be described as "degree hours below 0".

Table 9: Canopy temperatures at eight EP demonstration sites where ameliorated and un-ameliorated strips were located in frost prone areas.

		Minimum	Events <0						Deg Hrs <0	Deg Hrs <-2
Location	**Treatment**	**Season Min:**	**Season Tot:**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Season Tot:**	**Season Tot:**
Tooligie Moderate Risk 2022	Control	-1.6	4	1	15	3	0	1	-9.34	0
	Ameliorated	-1.9	5	1	11	3	1	1	-15.85	0
Tooligie High Risk 2022	Control	-2.6	26	2	20	7	11	8	-89.57	-19.4
	Ameliorated	-2.7	17	1	17	4	5	8	-63.65	-32.95
Warramboo 2022	Control	-2.2	10	-	-	5	5	0	-20.05	-2.64
	Ameliorated	-0.6	3	-	-	2	1	0	-1.28	0
Moody 2022	Control	-2.9	22	-	-	9	8	5	-65.70	-13.35
	Ameliorated	-1.3	11	-	-	5	3	3	-6.91	0
Tooligie High risk 2023	Control	-7.2	43	2	19	18	19	6	-521.6	-325.7
	Ameliorated 2023	-5.2	30	1	11	11	14	5	-202.3	-96.9
	Ameliorated 2022	-5.8	31	1	13	12	14	5	-250.7	-121.0
Tooligie Moderate Risk 2023	Control	-3.1	13	0	8	8	5	0	-56.6	-16.0
	Ameliorated in 2023	-4.7	22	0	13	12	9	1	-164.0	-65.1
	Ameliorated in 2022	-3.2	12	0	10	8	4	0	-67.3	-16.4
Moody 2023	Control	-6.7	43	0	2	16	16	11	-488.4	-393.5
	Ameliorated	-4.7	30	0	1	13	10	7	-215.4	-123.9
Wharminda 2023	Control	-7.1	38	0	2	17	15	6	-403.8	-309.7
	Ameliorated	-6.1	27	0	1	15	9	3	-294.8	-212.7

The mechanism behind this warming trend is not entirely clear. The greatest difference was found in 2023 where the Bednar strip at the Tooligie high risk zone reduced the seasonal frost severity by -319 degree hrs. In the same year at the same site, the moderate risk zone experienced the opposite or no effect. The most notable difference between the two is the heavier soil type at the moderate risk zone. These kind of observations around interactions between frost damage and soil type may help strengthen our knowledge around where amelioration may be an appropriate frost tactic.

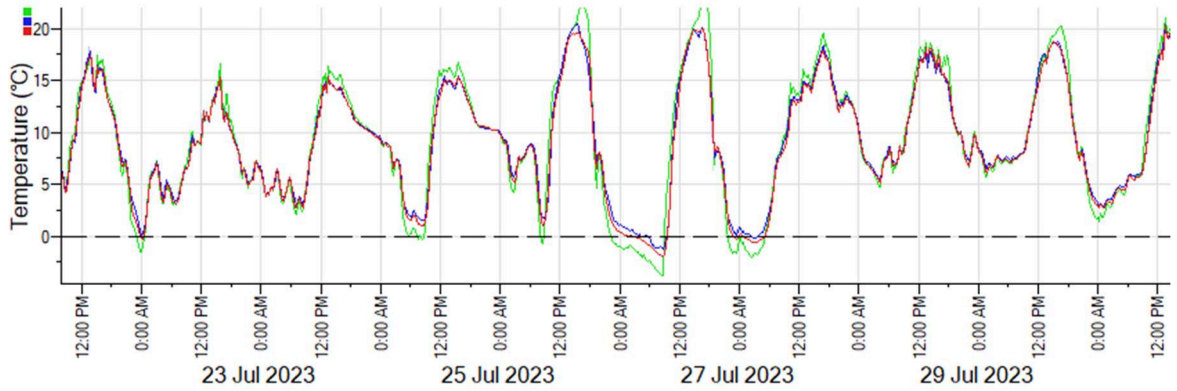

Figure 5: Snapshot of a week at the Tooligie high risk site in 2023 including a frost event. Green for unripped, blue and red for ripped.

When zooming in on a given frost event, we found that the ameliorated treatments were only experiencing warmer temperatures at night and were actually cooler during the day (Figure 5). This reduction in 'diurnal temperature fluctuations' is like the kind of temperature buffering you would observe when comparing clay to sand. Clay has a higher specific heat capacity then sand, meaning it takes more heat to warm up to a given temperature and in turn releases more heat as it cools down to a given temperature. However, Betti *et al*[1] found that claying alone did not create this effect, it was only with incorporation by spader or even spading alone that the temperature buffering effect was observed. We observed this trend over a variation of soil types and machinery that had been implemented anywhere from five years previous to or the same season as when measurements were recorded.

One explanation for this temperature buffering suggests amelioration may be reducing soil water repellency or increasing soil water content. These kind of changes in soil water relations may also increase its specific heat capacity. In 2023 we focused our efforts on understanding soil water relations by measuring soil water content following 4 major frost events (Table 10). Small but consistent differences in soil moisture validate this repellence/water content-based explanation.

Table 10: Gravimetric water content measurements taken 0-10 cm alongside four of the 2023 frost events.

		2-Aug	22-Aug	1-Sept	11-Sept
Moody	Control	9%	9%	6%	6%
	Ameliorated	10%	10%	8%	10%
Wharminda	Control	2%	3%	3%	2%
	Ameliorated	4%	5%	4%	3%
Tooligie	Control	5%	3%	4%	3%
	Ameliorated 2023	7%	4%	6%	3%
	Ameliorated 2022	5%	4%	6%	3%

PART 3: EXTENSION

The project convened a steering committee, consisting of trusted and experienced Eyre Peninsula advisors (Ed Hunt, George Pedler, Josh Hollitt, Andy Bates and Micheal Hind) as well as Mick Faulkner, Mid-North Advisor and experienced frost researcher.

The steering committee performed three roles:

1. To provide direction and input on where local knowledge gaps exist, and where to locate trials and demonstration strips.
2. Assist in discussing the research and its implications at field days and discussion groups.
3. To take the information generated by the project to their clients to discuss the ramifications for each business and how they might adjust their management strategies to help reduce damage from frost.

The steering committee met formally at the start of each season, to review results and plan activities for the coming season. The majority of communications were via phone or email as required throughout the season. Steering committee members and research staff also provided updates for the AIR EP RD&E Committee meetings.

Field days in spring were conducted in each year, with high levels of attendance, and results were presented at AIR EP Lower EP Ag Expo and written up for publication on the AIR EP website https://airep.com.au/research/tactics-to-minimise-frost-damage-on-the-eyre-peninsula/

Frost Field Day at Tooligie Hill, Wednesday 14 September 2022. Approximately 50 people attended. Steering Committee members each led discussions on different aspects of frost management.

Presentation by Andrew Ware, EPAG Research, summarising the results of the 2022 trials and local research at the AIR EP **Lower EP Ag Expo on 16 February 2023**, which included the results of the GRDC Frost Tactics trials. 52 people attended the event. An overall event satisfaction survey was conducted at the conclusion of the event, with high levels (4.7 out of 5) of event satisfaction, 4.4 'I have a greater understanding of current research occurring on lower Eyre Peninsula', and one participant recording 'Frost data was particularly interesting' when asked an open question about what was good about the event.

The **2023 Frost field day was held at Tooligie Hill on 21 September**. Around 58 people attended. Frost field day speakers: Andrew Ware EPAG Research and Frost Steering Committee members and local advisors, Ed Hunt, George Pedler, Andy Bates, Michael Hind, Josh Hollitt.

Topics suggested for further frost RD&E:

- Stubble loads x rotation
- Amelioration – what are the effecting factor/s, what helps?
- Mixtures in amber zones
- Canola following a legume is good – low stubble load
- INB?
- Comment: I won't be growing wheat.
- Easier to manage disease than frost
- Mixtures
- Beans a viable option, vetch, canola
- Modelling different rotations $
- Don't end up with big stubble loads on red zones
- Drone to move air during frost event??
- Height of cereals and canola
- Mapping air flow in paddocks
- Barley phenology is too even eg maximus vs commodus
- Additives to herbicides
- Antifreeze green blueprint Bill and Wayne Smith

Presentation by Andrew Ware EPAG Research, summarising the results of the 2023 trials and local research at the **AIR EP Lower EP Ag Expo held at Cummins on 27 February 2024**. A total of 47 individuals attended. Overall satisfaction with the event was rated 4.25 out of 5, learn something new / gained new insights rated 4.25, and 64% were planning to take action following the event. Frost mitigation, soil amelioration, nitrogen banking and risk management were key topics of interest based on themes identified from written feedback received.

Social media was also utilised to advertise coming events and provide brief updates on activities at trial sites during the season. This project has also been highly engaged with the MSF Frost extension project, via social media, newsletter and podcast activities.

The project also contributed to a Ground Cover article in 2022.

Various event evaluations were conducted throughout the project, with increased self-evaluated knowledge gained around management practices including soil amelioration, mixing varieties, zoning paddocks, and using different varieties through different zone sowing. There is still more knowledge to be gained.

DISCUSSION OF RESULTS

Varietal Phenology: This trial showcased various sowing time and variety combinations available to growers to avoid frost exposure. Extending this work over two contrasting growing seasons highlighted the complexity of making these decisions without reliable frost and rainfall forecasts. Multiple frost events, both early and late in the season, made it challenging to consistently choose a wheat variety and sowing time strategy that reduced frost risk without the benefit of hindsight. Barley consistently achieved higher yields across several phenology and sowing time combinations than wheat in frosty environments.

Crop Type: In 2022, a trial of different crop types demonstrated the varied reactions of crops like canola, beans, lentils, and vetch to frosty environments. Growers and advisors sought to understand the relative frost damage risk across a range of break crops, especially given the growing importance of these crops in the farming system and the decline in livestock production. The recent expansion of lentil cultivation across central and upper Eyre Peninsula necessitated more knowledge about frost impacts on lentils and the suitability of alternative break crops such as faba beans.

Nutritional Amendments and Ice-Nucleating Bacteria Control Products: This trial aimed to assess the value of various products purported to improve crop resilience to frost damage. Claimed mechanisms included foliar transpiration inhibition, nutrition-based sugar enhancement, plant health enhancement, floret sterility reduction, and antibacterial properties. Over two years in high frost incidence environments, none of the products demonstrated a yield benefit beyond correcting well-documented nutritional deficiencies, such as low potassium levels in sandy soils.

Zoning: Frost damage consistently affects certain landscape areas due to topography and air movement. Consequently, some paddock areas incur significant frost damage, while nearby areas remain unaffected. With advancements in precision farming equipment, growers can now manage high frost risk areas differently. To evaluate the benefits of such management, phenology, crop type, and nutritional amendment trials were mirrored in both high and moderate frost risk zones within the same paddock. Data showed that high-risk zones experienced more severe frost damage, and strategies like sowing longer-season wheat varieties (winter varieties) and various barley varieties had higher value in high-risk zones. This demonstrated the value of managing zones differently. Collecting data over additional seasons will be crucial for modelling yields and frost damage accurately, aiding growers and advisors in making informed management decisions based on frost risk.

Soil Amelioration: Anecdotal evidence from growers and previous research in Western Australia suggested a potential relationship between soil amelioration on sandy soils and frost mitigation. Data and observations from eight sites over 2022 and 2023 allowed direct comparisons between ameliorated and original soil compositions. Six of the eight site comparisons found that soil amelioration occasionally reduced daily canopy temperature fluctuations, with temperature differences increasing as conditions became more extreme. Some events were up to a few degrees warmer during the coldest overnight periods. Instances where amelioration did not result in warmer temperatures were found on heavier textured soils. Understanding the underlying mechanisms may help quantify the soil-temperature interaction level needed to reduce frost damage.

CONCLUSION

This project concluded that:

- With frost events occurring from June to October, finding a variety with the ability to dodge frost events by either flowering earlier or later is incredibly difficult. However, some promise with quick winter varieties such as Mowhawk was demonstrated.
- Barley proved much more able to return higher yields than wheat when planted in high frost risk areas.
- Growing mixtures of varieties with differing maturity couldn't demonstrate an advantage over growing just the best adapted variety.
- None of the nutritional or ice nucleating products evaluated were able to produce a yield response beyond the correction of established nutritional deficiencies.
- Soil amelioration on sandy soils was able to demonstrate warmer canopy temperatures, reducing the risk of frost.
- The project was able to demonstrate the value of understanding areas where high frost risk regularly occurs, so that differing management strategies can be implemented in those areas to either reduce costs or yield loss.

IMPLICATIONS

Since 2017 frost has had a major impact in many areas of central and eastern Eyre Peninsula, with growers reporting production reduced by well over half in years where frost is prevalent.

While this project hasn't found a solution to frost, it has been able to parameterise damage, so that alternative management strategies can be fully evaluated.

RECOMMENDATIONS

- This project found value in bringing together a steering committee of trusted advisors to help provide direction for the project and to disseminate information. This format for project management can be successful and highly impactful if used on the right issues.
- Because frost has had such a large impact on many growers across eastern and central EP this project achieved high levels of local recognition, with growers ready to engage with the project and adopt it's outcomes.
- Further work is needed so that frost damage functions across the region can be better understood, with this knowledge used in whole farm modelling/ budgeting to work through how best to deploy frost management strategies.

APPENDIX A: Trial result articles

Tactics to minimise frost damage on the Eyre Peninsula (GRDC AIP2203-001SAX)

2022 EP Frost Project Results

Frost events causing extensive crop damage and financial loss were experienced in large areas of Central and Eastern Eyre Peninsula in the four years to 2022. Anecdotal evidence indicated that even late in the growing season crops on Eyre Peninsula could suffer damage from frost events which reduced yields. As a result, growing longer season varieties that flower later to avoid frost can't always be relied on as an effective management strategy to mitigate frost risk. This project aimed to;

1. Demonstrate the effectiveness of a range of frost management strategies to mitigate yield penalties due to frost damage on representative frost prone site on Eyre Peninsula.

2. Help improve the understanding of Eyre Peninsula growers of the causes of frost damage in the region and strategies to mitigate this risk.

Selection of demonstration site and establishment of groups.

In consultation with the project steering committee a demonstration site where relatively consistent frost damage had been observed in crops in the five years to 2022 was selected on Tim Zacher's property east of Tooligie (Figure 1).

Historical production records were used identify two areas of different frost risk (high and moderate) within the paddock to demonstrate how effective different frost management strategies. The rest of the paddock was sown with wheat in 2021 and barley in 2022.

Several discussion groups (made up of growers that have been severely affected by frost in multiple seasons) were established to review the results from the demonstration site and landholder observations on their own properties.

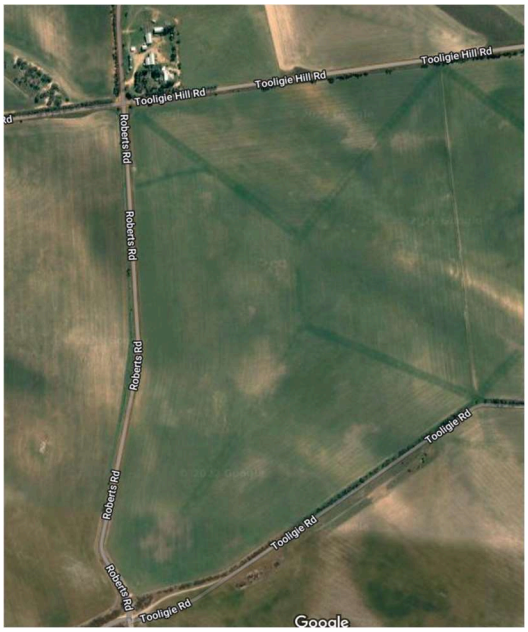

Figure 1. Main trial site paddock at Tim Zacher's, Tooligie Hill Road.

Site Establishment

Several demonstration trials were established in early 2022 which included;

- Trial 1: Phenology
- Trial 2: Mixtures
- Trial 3: Nutrition

- Demonstration: Bednar Ripper

Each of these trials were established as paired demonstrations sited in both a low and high frost risk zone within the paddock (Figure 2).

Additionally, a soil amelioration strip using a Bednar ripper was implemented which ran across the two frost risk zones (Figures 2 and 3). This soil amelioration treatment aimed to determine if soil modification practices such as ripping and topsoil mixing, using implements such as a Bednar ripper, can influence mitigating frost damage.

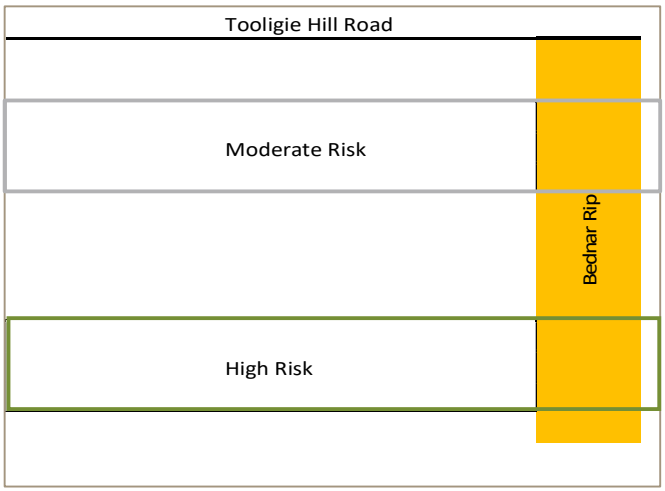

Figure 2. Site layout within the paddock.

Figure 3. Ripping with Bednar machine at Tim Zacher's, main trial site Tooligie, Autumn 2022.

Canopy Temperatures

Temperature sensors were placed at crop canopy height within both the ripped and unripped areas on each frost risk zone to record frost events as they occurred (Figures 4 and 5). Results showed that during critical frost risk window (GS31 at 12 August 2022) to 30 September 2022, no temperatures below 0°C were recorded in the moderate risk zone (either on the ripped or unripped areas) whilst below 0°C temperatures were recorded in the high-risk zone on several occasions.

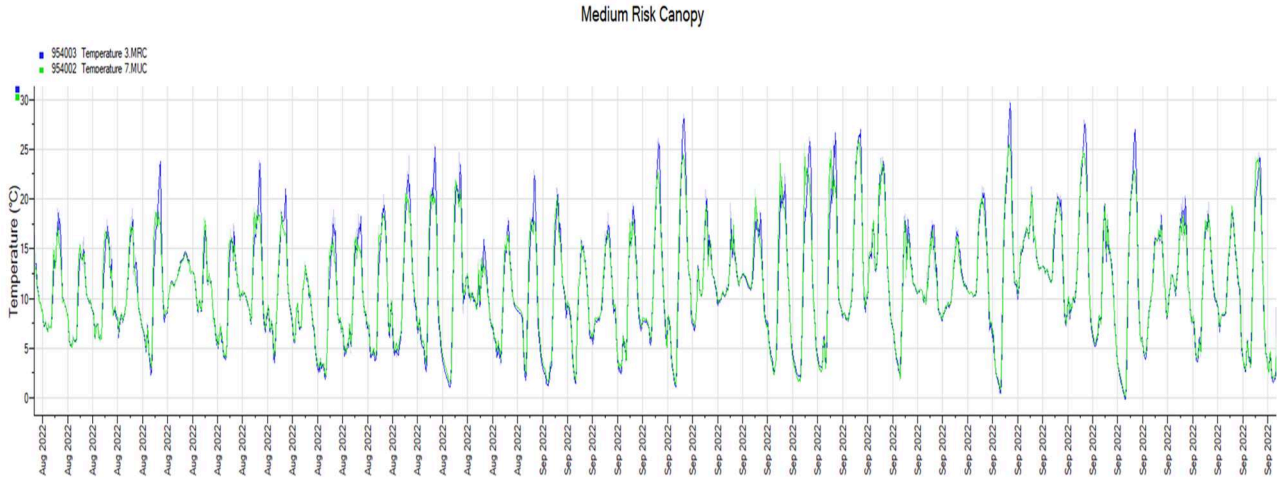

Figure 4. In canopy temperatures in ripped (MRC) and unripped (MUC) areas of the medium frost risk zone, Tooligie 2022.

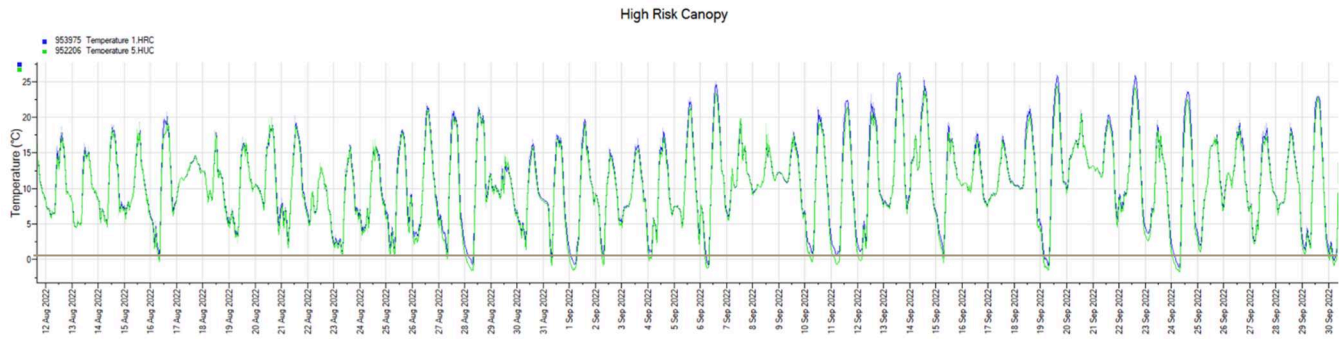

Figure 4. In canopy temperatures in ripped (MRC) and unripped (MUC) areas of the high frost risk zone, Tooligie 2022.

Pre-season soil Test

Preseason soil test revealed a sandy topsoil over a gradational loam on the moderate risk zone (Table 1). Boron and salinity levels increase with increasing depths from 60 cm. The high-risk site had significantly higher surface water repellence (M.E.D 2.0) with elevated salt and boron (18 mg/kg) starting at 40 cm below the soil surface. Nutrition levels were generally high with high amounts of available phosphorus.

Table 1. Preseason soil analysis to 1 m.

SampleName	Sample Depth	pH 1:5 water	pH CaCl2	Organic Carbon (W&B)	Colour	MIR - Aus Soil Texture	Nitrate - N (2M KCl)	Ammonium - N (2M KCl)	Colwell Phosphorus	PBI + Col P	DGT-P	MED	KCl Sulfur (S)	Salinity EC 1:5	Ece	Boron	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	TDS	MIR - Clay	MIR - Sand	MIR - Silt
		pH units	pH units	% (40°C)			mg/kg	mg/kg	mg/kg		µg/L		mg/kg	dS/m	dS/m	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/L	%	%	%
Medium Risk	0-10	7.35	6.91	1.47	brown	Sand	1.3	4	68	42	174	0.0	5.3	0.18	4.1	0.54	62	17	0.37	4	110	4.6	90.1	5.3
Medium Risk	10-20	7.97	7.47			loam	2.3	<1						0.23	1.9	2					150	25.9	62.1	12
Medium Risk	20-40	8.49	7.86			loam	2.5	<1						0.2	1.8	3.2					130	31.5	50.2	18.3
Medium Risk	40-60	9.37	8.27			loam	1.5	<1						0.34	2.9	5.1					220	29.7	50.1	20.2
Medium Risk	60-80	9.73	8.66			loam	3.5	<1						0.66	5.7	14					420	35.6	45	19.4
Medium Risk	80-100	9.7	8.7			loam	3.6	<1						0.98	8.4	17					630	31.4	50.8	17.8
High Risk	0-10	6.03	5.22	0.94	brown	Sand	17	46	67	22	694	2.0	15	0.1	2.3	0.55	35	6.7	0.33	2.7	65	5.3	90.6	4.1
High Risk	10-20	6.43	5.62			loam	3.2	19						0.049	0.69	0.32					32	8.7	90.6	<1
High Risk	20-40	8.96	8.16			loam	4	2.3						0.38	5.4	5.9					250	20.4	69.7	9.9
High Risk	40-60	9.25	8.48			Clay	3.2	1.9						0.95	5.5	18					610	36.6	45.3	18.2
High Risk	60-80	9.27	8.49			loam	48	2.8						1.3	11	13					830	32.3	54.4	13.3
High Risk	80-100	9.38	8.54			loam	3	1.3						1.1	9.1	12					670	26.7	63.9	9.5

Trial 1: Crop Phenology

Aim: to determine if time of sowing coupled with plant phenology can help mitigate frost damage.

Historically, it was considered that planting later or using longer season varieties could help mitigate the impact of frosts on crop yields. However, damaging frosts close to crop maturity have been experienced regularly in recent years reducing the effectiveness of this 'avoidance' method. The trial used different crop types and varieties with different phenology (development) speed (Table 2) and two different sowing times (TOS1: 19 April, TOS2: 18 May) to try and mitigate the damage from these late frosts.

Results show that on the moderate frost risk zone (which did not record temperatures below 0°C), in most cases the yield difference between sowing times was less than 15% (around 0.5 t/ha), with early sowing (TOS1) benefitting the quicker maturing varieties but penalising the slower maturing varieties. In 2022 yields on the high frost risk zone were significantly less than those in the zone which did not get frosted, ranging from 12 to 100% reduction in yield. The best strategy in the high-risk zone in 2022 was early sown barley yielding 75% to 88% of that achieved in the moderate risk zones. In the high-risk zone long season wheats sown late (TOS2) yielded better than TOS (and yielded 54 to 62% of the relative yield from the moderate risk zone), presumably missing the frost at critical development times. The yield of quicker maturing wheats in this zone was severely reduced regardless of sowing time.

Table 2. Varieties trialled, relative development speed and flowering date at Tooligie site in 2022.

			Flowering Date			
			TOS1		TOS2	
Crop	Variety	Phenology	Moderate Risk	High risk	Moderate risk	High Risk
Wheat	Vixen	V. Fast	7-Aug	8-Aug	18-Sep	18-Sep
	Calibre	Fast	23-Aug	25-Aug	21-Sep	24-Sep
	Scepter	Fast-Medium	23-Aug	-	23-Sep	25-Sep
	Rockstar	Medium	23-Aug	26-Aug	26-Sep	26-Sep
	Denison	Slow	10-Sep	10-Sep	29-Sep	29-Sep
	Longsword	Fast Winter	23-Sep	26-Sep	4-Oct	4-Oct
	Bennett	Long winter	14-Oct	14-Oct	-	-
Barley	Commodus	Fast	25-Aug	23-Aug	10-Sep	10-Sep
	Spartacus	V. Fast	8-Aug	8-Aug	15-Sep	17-Sep
	Planet	Fast-Medium	-	21-Aug	23-Sep	-

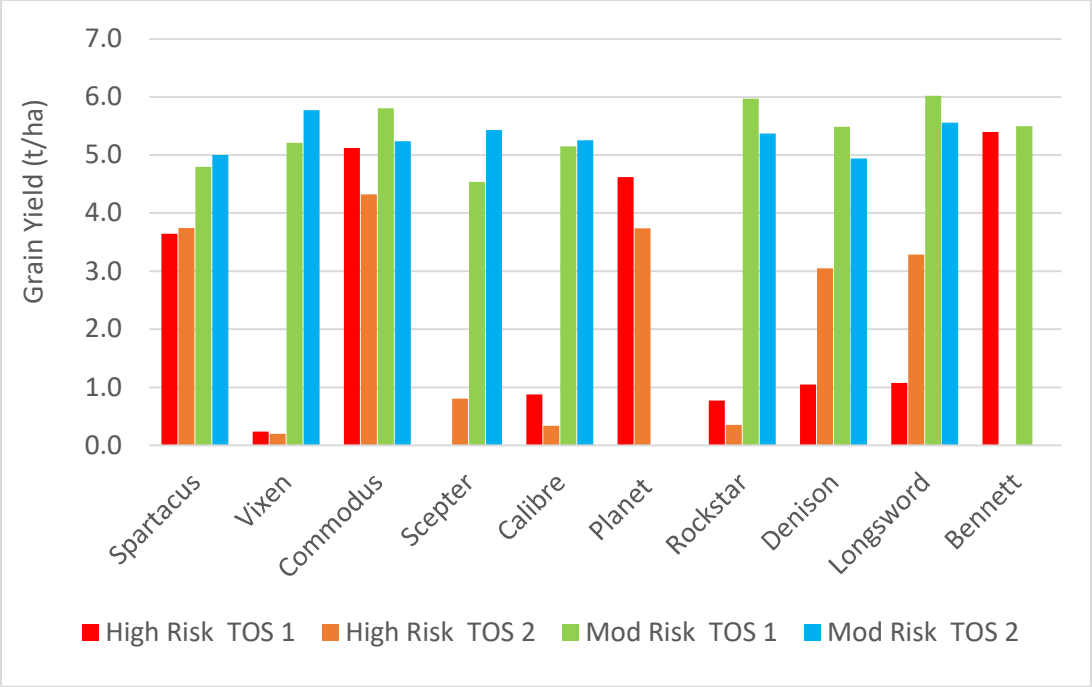

Figure 5 Grain yield of different wheat and barley varieties sown at Tooligie in 2022

Key Results

- The high-risk zone experienced frost damage in most of the wheat varieties at both times of sowing leading to very low yields.
- Winter wheat Bennett didn't appear to suffer any yield loss due to frost.
- Barley varieties: Spartacus, Commodus and Planet experienced less frost damage in the high-risk zone compared to the wheat varieties and yielded higher.

Trial 2: Varietal Mixtures

Aim: To determine if mixing varieties with different development times has the potential to reduce risk of frost damage.

Several treatments of different cereal varieties were trialled both for wheat and barley (Table 3). Thought was given to choosing varieties which fall within the same quality classification to facilitate delivery at harvest.

Table 3. Cereal mixtures trialled.

Wheat Mixtures	Denison/Vixen
	Denison/Calibre
	Denison/Rockstar
	Vixen/Calibre
	Vixen/Rockstar
	Dension/Calibre/Vixen
Barley Mixtures	Spartacus/Commodus
	Spartacus/Planet

Results reflected those from the variety/phenology trial with severely reduced wheat yields on the high-risk zone (for both TOS) compared to the moderate frost risk zone. The yields of barley mixtures were much less impacted by frost in this zone (Figure 6).

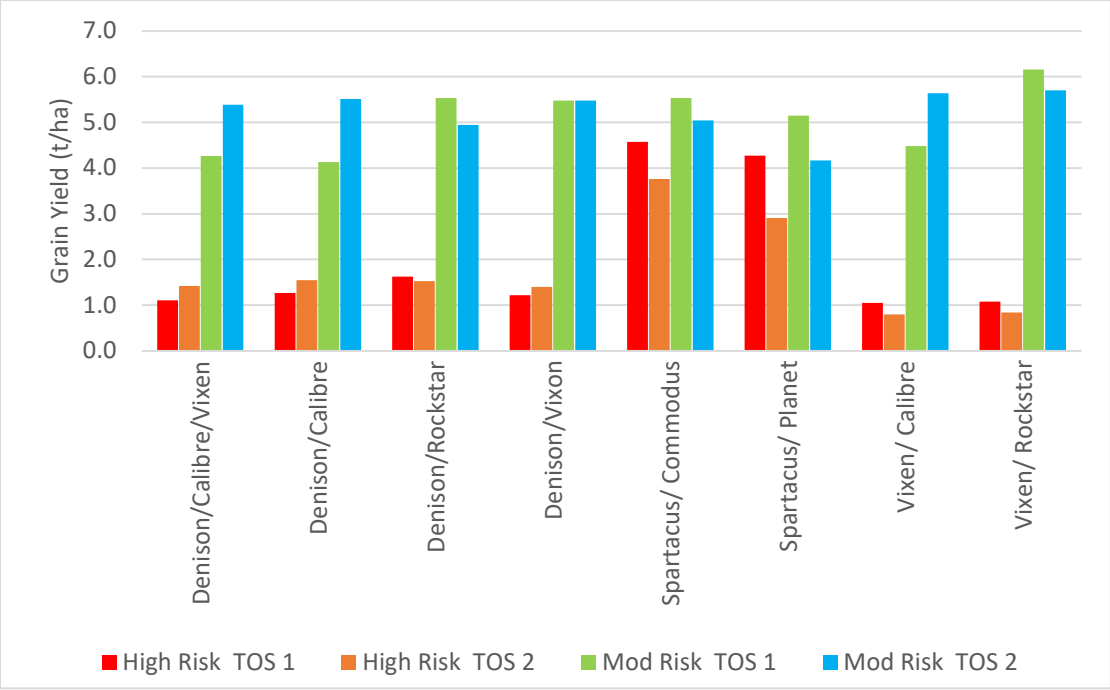

Figure 6. Grain yield of different wheat and barley variety mixtures sown at Tooligie in 2022

Key Results:

- Similarly, to the phenology experiment most of the wheat variety mixtures yielded poorly in the high-risk zone. However, when sown alone in TOS 1 of the phenology trial Vixen only yielded 0.24t/ha, but when included as part of a mixture in this experiment the treatment yielded just over 1t/ha.
- Mixtures containing barley yielded higher than mixtures containing wheat.

Trials 3 Crop Nutrition and manipulation

Trial 3. Crop Nutrition - aimed to determine if the application of nutrition treatments/ antibacterial treatments has any beneficial response to reducing frost damage and improving wheat yield, it also contained treatments aimed to manipulate crop development through the application of plant hormones or taking out the growing tip of plants.

Recent work in Western Australia suggests applications of potassium (K) and/ or copper (Cu) can help reduce the impact of frost. However, this typically this occurs where these elements are deficient. Soil test data prior to the season suggests that copper levels were adequate. Several different formulations of copper and potassium, as well as nitrogen (N) and zinc (Zn) and other trace element (TE) products were trialled at the site (Table 4). Additionally, there was some interest in trialling novel products which might be effective in mitigating frost risk and/or crop damage. Such products included a range of anti-bacterial products designed to disrupt ice nucleating bacteria as well as several growth stimulants/protectants.

Table 4. Nutrient, antibacterial, and other growth treatments applied on site in 2022.

Mineral Nutrients	Antibacterial	Other Growth stimulants/protectants
• Copper (Cu) • Foliar Potassium (K) • Chelated Cu (Kestrel) • Nitrogen (N) • Potash (K) • Potash K+ Cu • Triple trace (Cu, Zn, Mn) • Zn + Cu	• Antibacterial - Seaweed • Antibacterial - Smoke	• Plant stress product • Seaweed concentrate • TE to increase plant sugars applied as foliar. • TE to increase plant sugars applied on seed. • Y-Polyglutamaic acid * NB. Treatments also incorporated a defoliation treatment to manipulate crop maturity (Trial 4).

Treatments were applied GS 43 and 59. On the moderate risk zone (which did not record a frost in the critical growth period) grain yields ranged from 4.84 t/ha on the treatment which was manually defoliated during the season to 6.56 t/ha on the nitrogen treatment (and the nil control yielding 5.89 t/ha) (Table 5). However, the differences between treatments were not significant. On the high-risk frost zone grain yields were severely reduced (with the nil control yielding 1.96 t/ha) compared to the moderate risk zone, highlighting the frost impact in this zone, but again the differences between treatments were not significant.

Table 5. Grain yield of nutrient trial on unmodified strips at Tooligie, 2022.

	Yield (t/ha)	
Treatment	High Risk	Mod. Risk
Antibacterial - seaweed	2.15	6.55
Antibacterial - smoke	1.82	6.50
Antitransparent	2.28	5.54
Copper	2.20	5.83
Defoliation	1.75	4.84
K foliar	1.78	6.24
Kestral Cu	2.35	5.62
Nil	1.96	5.89
Nitrogen	2.53	6.56
Plant stress product	1.96	5.73
Potash	2.74	6.24
Potash + Cu	2.78	6.26
Seaweed concentrate	1.85	6.09
Sugar foliar	2.03	5.63
Sugar seed	2.21	5.98
Trace triple	2.60	5.97
Y Polyglutamaic acid	2.58	5.91
Zn + Cu	2.64	6.04
Site mean yield	2.23	5.97
lsd	ns	ns

Several of these products were also applied across the Bednar 'soil amelioration' strip adjacent to the main site. In the high-risk zone data loggers at crop canopy height recorded temperatures in the order of 0.56 to 1.38°C higher on the ameliorated soil compared to the unripped zones (Table 6).

Table 6. Minimum temperatures in high-risk zone 12/08/23 to 30/09/23

	Minimum temperate (°C)		Difference in temperature Ripped vs Unripped
Date	**Unripped Control**	**Ripped zone**	**(°C)**
28/08	-1.69	-0.72	0.97
31/08	-1.01	0.08	1.09
1/09	-1.6	-0.89	0.71
2/09	-1.11	0.15	1.26
4/09	-0.23	0.87	1.1
6/09	-1.33	-0.76	0.57
10/09	-0.53	0.73	1.26
11/09	-0.75	0.63	1.38
12/09	-0.19	1.09	1.28
15/09	-0.79	0.51	1.3
19/09	-1.62	-1.06	0.56
24/09	-1.83	-1.17	0.66
30/09	-0.99	-0.29	0.7

There was no significant difference between the grain yield of the ameliorated strip compared to paired unripped strip in the moderate risk zone (Table 7), but yields were significantly higher on the ameliorated strips in the high-risk zone compared to unripped controls (with the ripped nil product treatment yielding 4.56 t/ha).

Table 7. *Grain yield of nutrient and growth manipulation treatments on modified strips at Tooligie, 2022*

	Yield (t/ha)	
Treatment	High Risk	Mod. Risk
Antibacterial - seaweed	4.26	5.90
Copper	4.12	5.43
Nil	4.56	6.16
Potash + Cu	5.20	5.36
Sugar foliar	4.91	5.72
Trace Triple	4.53	5.83
Site mean yield	4.60	5.73
lsd	0.42	ns

Key Results.

- Moderate risk zone had warmer temperatures than the high-risk zone at night.
- On the Bednar ripped strips temperatures were warmer resulting in less frost events and less time below zero.
- As a result of this the most severe frost damage occurred on the unripped part of the high-risk zone with the least frost damage on ripped areas in the moderate frost risk area
- No significant yield improvement was achieved through the addition of any of the products applied.
- Treatments where potassium was applied had higher overall yields which warrants further investigation.

- Grain yields in the high-risk zone were higher where the soil was ripped compared to un-ripped (4.6t/ha compared to 0.8 t/ha, but similar in the moderate risk zone 5.7 t/ha compared to 5.4 t/ha).

Acknowledgements

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Investigating tactics to minimise frost damage at Tooligie in 2023

Brett Masters[1], Andrew Ware[1] and Jacob Giles[1]

[1]EPAG Research

Key Messages

- ***Mowhawk might provide a potential option in areas where there is some frost risk.***
- ***Barley appears to still be the best cereal option in areas with higher frost risk.***
- ***There was no clear crop yield response from sowing wheat mixtures in the high-risk zone.***
- ***There appeared to be a response to higher rates of K in the high-risk zone but there did not appear to be any positive grain yield response from applying any of the other products at this site in 2023.***

Why do the trial?

Frost events causing extensive crop damage and financial loss were experienced in large areas of Central and Eastern Eyre Peninsula in the four years to 2022. Anecdotal evidence suggested that crops on Eyre Peninsula (EP) could suffer damage from frost events which reduced yields even late in the growing season. As a result, growing longer season varieties that flower later can't always be relied to effectively mitigate frost risk. This AIR EP project funded by the GRDC aims to increase the knowledge and confidence of growers in EP's frost prone areas to adopt and implement practices which minimise the impact of frost on their profitability. The 2023 frost risk trial sites were established within a dune-swale landscape to the southeast of Tooligie Hill. Frost tends to settle in the lower parts of the landscape at this location. The 2023 trials followed on from work conducted in 2022, with treatments aimed to determine if mixing crop varieties with different development times, or applying extra nutrition or other novel products had the potential to reduce the risk and severity of frost damage.

How was it done?

The 2023 paired sites were sited in two distinct parts of the landscape representing a moderate frost-risk zone (MRZ) on the mid-slope of a broad dune), and a high-risk zone (HRZ) in the swale of the adjacent paddock. Several sub trials were replicated at both sites (Table 1).

Table 1. Description of Tooligie frost sub-trials (replicated at both the moderate and high-risk sites)

Trial ID	Treatment Aims and Description
a) **Crop phenology**	Manipulation of crop maturity to minimise crop vulnerability during times of peak frost risk by; - Sowing different cereal species (wheat vs barley) and varieties (and mixtures of varieties) with different maturity characteristics. - Varying time of sowing (TOS) - each variety/mixture was sown at two separate times. TOS1 was sown on 24 April with TOS2 on 18 May.
b) **Crop nutrition**	Application of copper and potassium to improve crop health and protect against damage.
c) **Novel products**.	Application of novel products designed to protect crops from the damaging effect of frost events

The soil type at both sites was a sand over clay which had been clay delved in 2020. Pre-sowing soil tests indicated good Colwell potassium (K) (160mg/kg) in the moderate risk site and low to adequate K (94 mg/kg) at the high-risk site. Plant tissue samples taken from wheat controls (TOS2 at flag leaf emergence), indicated adequate crop uptake of nutrition at both sites.

Temperature sensors were placed within a Stevenson Screen at 1.2 m and at ground level at both sites to record frost events as they occurred. Crop measurements were taken for: growth stage, head density, harvest index, grain yield, grain protein, screenings, and test weight. Only a selection of these measurements are reported here. The site was harvested on 29 November 2023. Results were analysed using Genstat®.

What happened?

Air Temperature

Results showed that during the period 4 July to 31 October 2023 air temperatures at 1.2 m above ground level fell below 0°C on 7 occasions in the MRZ and 17 occasions on the HRZ, with highest intensity of frost events at the high-risk site in August (Table 2). The HRZ also recorded several frost events in September and October. The temperature loggers show that during frost events the HRZ was colder on average than the MRZ.

Table 2. Sum of frost events for MRZ and HRZ at Tooligie – July to October 2023.

Monthly Summary	Moderate Risk zone (MRZ) # events <0°C	High Risk zone (HRZ) # events <0°C	Average difference in temperature (°C) between MRZ and HRZ	Average difference time (hours <0°C) per frost event between MRZ and HRZ
July	1	3	-1.75	2.58
August	4	8	-1.72	4.25
September	1	4	-2.30	3.88
October	1	2	-1.30	-0.13

When comparing the risk of frost with the potential to result in crop damage which might impact final crop yields, it is important to not just note the number of frost event, but also the length of time that temperatures remained below 0°C. The data showed that temperatures at the HRZ site during frost events were both colder and remained below 0°C for a longer period (Table 2 and 3). The HRZ also recorded more severe frost (<1°C) events during this period (Table 3). Several of these events reached minimum temperatures below 2°C, and remained below 0°C for up to 10 hours, whilst temperatures on the MRZ were some 1-2°C higher, with much shorter periods below 0°C.

Table 3. Minimum temperatures and duration of severe (<1°C) frost events

Date of frost event	Minimum temperature (°C)	Hours below 0°C	Minimum temperature (°C)	Hours below 0°C	Temperature difference between moderate and high-risk zone (°C)	Time difference (hours <0°C) between moderate and high-risk zones.
17/07/2023	-1.3	3.50	-2.5	9.50	-1.1	6.00
18/07/2023	0.9	4.50	-1.2	4.25	-2.1	-0.25
7/08/2023	-1.1	6.75	-3.1	10.00	-2.0	3.25
8/08/2023	-0.3	1.50	-2.5	9.50	-2.2	8.00
11/08/2023	-0.1	0.75	-1.2	5.00	-1.1	4.25
15/08/2023	-0.6	2.75	-1.3	8.75	-0.7	6.00
9/09/2023	-0.8	2.00	-1.9	8.00	-1.1	6.00
26/10/2023	-1.1	2.50	-2.2	2.25	-1.0	-0.25

Crop development and damage.

Frost damage with the potential to reduce yields typically occurs between stem elongation (GS31) and the end of flowering (GS69). Weekly assessments of crop maturity were undertaken beginning in mid-July (when the earliest treatments reached GS31). This data captured comparative dates for head/ear emergence (GS51-59) for the different frost risk zones, varieties and times of sowing (Table 4). Growth stage assessments conducted on 26 July (9 days after a severe frost event) saw little observable crop damage in either frost risk zone. At this time, the most advanced treatment was at GS49 (TOS1 Vixen in the MRZ, and GS45 in the HRZ) with the least advanced treatments at GS25 (TOS2 Bennett and Mohawk on both trials). When crop maturity assessments were undertaken on 16 August (8-9 days after consecutive severe frosts) there was noticeable damage (bleaching of awns and pinched heads) observed on treatments in the HRZ where heads had emerged prior to this date, but no noticeable damage on the same treatments in the MRZ (Table 4).

Table 4. Varieties trialled, relative development speed and date head emergence recorded at Tooligie site in 2023.

			Date head emergence recorded			
			TOS1		TOS2	
Crop	**Variety**	**Phenology**	**MRZ**	**HRZ**	**MRZ**	**HRZ**
Wheat	Vixen	Very Fast	29-July	6-Aug	27-Aug	27-Aug
	Calibre	Fast	6-Aug	6-Aug	2-Sep	2-Sep
	Scepter	Fast-Medium	29-July	13-Aug	2-Sep	9-Sep
	LRPB Matador	Medium	13-Aug	13-Aug	2-Sep	9-Sep
	LRPB Bale (awnless dual purpose)	Slow	9-Sep	2-Sep	15-Sep	15-Sep
	Denison	Slow	25-Aug	13-Aug	9-Sep	9-Sep
	LRPB Mowhawk	Fast winter	2-Sep	9-Sep	19-Sep	23-Sep
	DS Bennett	Long winter	30-Sep	30-Sep	7-Oct	30-Sep
Barley	Commodus CL	Fast-Medium	13-Aug	13-Aug	27-Aug	27-Aug
	Maximus CL	Fast-Medium	13-Aug	19-Aug	2-Sep	2-Sep
	Neo	Medium	27-Aug	13-Aug	2-Sep	2-Sep
Oat mix	Winteroo and Bannister		27-Aug	27-Aug	9-Sep	9-Sep

Further frost events were recorded in late August and early September with frost damage noted on TOS1 Calibre and Matador in the MRZ. At crop maturity assessments on 5 September all wheat varieties in the HRZ, which had crop maturity more advanced than GS59 had noticeable frost damage to the heads, but there were no noticeable symptoms on the barley or oat mix treatments. These field observations were reflected in grain yields. Treatments which contained early sown faster maturing wheat varieties in the HRZ yielded less than these treatments in the MRZ, and less than later sown and/or later maturing long season varieties, or oats/barley (Table 5). On the HRZ later maturing wheat varieties (Bennett, Bale) yielded less when sown later compared to early. On the MRZ (which did not seem to suffer severe frost at critical growth times) all treatments yielded the same or more when sown early compared to late. Despite being a later maturing variety Mowhawk yielded well on both the MRZ and HRZ in 2023.

Table 5. Grain yield results from Tooligie Phenology trials, 2023

	High Risk (t/ha)		Moderate Risk (t/ha)	
Variety	**TOS 1**	**TOS 2**	**TOS 1**	**TOS 2**
Vixen	0.32	1.79	2.18	3.09
Calibre	0.58	2.44	2.55	3.58
Matador	0.34	1.38	2.92	3.37
Scepter	0.45	2.58	2.33	3.7
Denison	0.34	2.25	2.76	3.47
Bale	1.21	0.77	1.89	2.36
Mowhawk	2.39	2.13	3.17	3.54
Bennett	1.34	1	1.69	1.86
Denison+Vixen	0.34	2.06	3.04	3.48
Denison+Vixen+Scepter	0.25	2.34	3.17	3.36
Denison+Scepter	0.39	2.19	2.72	3.61
Mowhawk+Vixen	0.78	1.44	2.83	3.51
Mowhawk+Vixen+Scepter	0.77	1.77	2.77	3.25
Mowhawk+Scepter	0.99	1.71	2.73	2.66
Commodus_Barley	1.92	1.64	1.92	3.48
Maximus_Barley	1.27	2.31	3.67	3.75
Neo	1.8	2.59	4.05	3.72
Oats_Winteroo+Banister_mix	1.83	1.46	2.17	2.05

Results from the crop nutrition trial (Sub-trial B) showed no response from the application of copper (Cu) on the HRZ, but indicated some yield improvement from the addition of potassium (K) to this site in 2023. There was no significant yield improvement from the addition of extra nutrition to on the HRZ.

Table 6. Grain yield results from Tooligie crop nutrition trials, 2023

Potassium + Copper	HRZ - Yield (t/ha)		MRZ – Yield (t/ha)
No additional K or Cu	2.28	a	3.09
0K + Cu	2.51	abc	3.21
25kg / ha K	2.29	c	2.98
25kg/ha K + Cu	2.46	ab	3.24
50kg/ha K	2.57	bc	3.07
50kg/ ha K + Cu	2.85	bc	3.14
100kg/ha K	2.68	bc	3.02
100kg/ha K + Cu	2.62	bc	3.03
			ns

These results reflect the lower K values observed in the early season soil tests on the HRZ compared to the MRZ. There were no significant yield benefits from any of the novel amendments used at the site in 2023.

What does this mean?

Multiple frost events were experienced in the period from the start of July to the end of October. The most severe frost events were recorded on the high-risk site on 17 July, 7 and 8 August and 9 September with air temperatures at 1.2 m at or below -2.0°C and each event longer than 7 hours duration. Despite some early sown (TOS1) treatments being near or at GS31 (where plants begin to be more prone to damage by frost events) there did not appear to be significant leaf or stem frost damage at the Tooligie sites following the July frost event.

However, following the consecutive severe frosts on 7 and 8 August significant frost symptoms were observed on emerged heads in the HRZ in treatments which were early sown with faster maturing wheat varieties. These symptoms where not seen in the MRZ where temperatures were both warmer and the period below 0°C was less.

The later sown (TOS2) wheat, as well as the barley and oat treatments were not impacted as heavily by these frosts. However, grain yield results suggest that given the dry finish in 2023 some of the slower maturing varieties (Bennett and Bale) struggled and yielded well below quicker maturing varieties.

The risk of multiple severe frosts across key crop development periods, (even into the grain fill period as evidenced in 2023), highlights the difficulty with selecting varietal maturity as a strategy for growing wheat in areas with a high frost risk. Mowhawk seemed less affected by the frost

events in the HRZ regardless of TOS and yielded well in the MRZ, which could present some opportunity to use it in areas where there is some frost risk but wheat fits the rotation best. Early sown (TOS1) wheat mixtures which included Mowhawk also seemed to yield higher than those without. However, 2023 results indicate that barley might still be the best cereal option for areas with a high frost risk.

Acknowledgements

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Trial Location: Tooligie

Farmer Name: Dylon Kay and Family

Rainfall:

Av. Annual (mm): 334 **Av. GSR (mm):** 248

2023 Total (mm): 280 **2023 GSR (mm):** 188

Soil type: Modified (Delved) sandy over clay.

Plot size Dimensions: 1.5 m x 10 m

Trial design: randomised complete block

Yield limiting factors: Frost, early finish.

Demonstrating the impact of deep ripping as a tactic for managing frost in 2023.

Brett Masters[1] and Andrew Ware[1]

[1]EPAG Research

Key Messages

- ***Deep ripping could be a useful strategy for reducing the risk of frost damage on sandy soils in the Central and Eastern EP.***
- ***Ripping increased minimum temperatures and soil moisture and reduced the length of time air temperatures were below O°c at the sites in 2023.***
- ***Harvest index values at Wharminda and on the HRZ at Tooligie suggest that deep ripping was not able to mitigate the impacts of the extreme frost events (<-4°C), but that in less severe events the temperature difference afforded by ripping might be effective in reducing the level of crop damage.***
- ***The barley at Moody was less affected by the severe frost events than the wheat at Wharminda and the canola in the HRZ at Tooligie, with improved grain yields on the ripped treatments likely to result from overcoming other factors.***

Why do the trial?

Large areas of Central and Eastern Eyre Peninsula are prone to frost events which can cause extensive crop damage and financial losses. Historical work and anecdotal evidence suggest in frost prone area on sandy soils the risk of yield losses from these frost events can be reduced by soil modification practices such as clay spreading, delving, and ripping. Work was conducted on Zacher's property at Tooligie in 2022, where a Bendar ripper was used to modify the sandy soil profile across two frost risk zones, high (HRZ) and moderate (MRZ) risk.

How was it done?

At Tooligie additional ripping treatments were applied on the 2022 ripping demonstration site in 2023. Sites where duplex sandy soil profiles had been deep ripped were also monitored at Moody and Wharminda.

Table 1. Site details for 2023 'Frost Tactics'

Site #	Landholder and Location	2023 Crop	Treatments	Measurements taken
1.	**Hunt, Wharminda**	Wheat	• Unripped control • Ripped	• Temperature using tiny-tags at canopy height. • Soil moisture taken around the time that severe frost events forecast/observed. • Crop maturity • Biomass (at harvest), Grain Yield, Harvest
2.	**Modra, Moody**	Barley	• Unripped control • Ripped	
3.	**Zacher, Tooligie**.	Canola	• Unripped control • New Rip (Bednar 2023) • Old rip (Bednar 2022)	

			• *Treatments applied across 2x frost risk zones (moderate and high risk)*	Index, Grain protein/Oil

Temperature sensors were placed in the canopy at all sites to record frost events as they occurred. Assessments for soil gravimetric moisture content (%) and crop maturity (Zadoks growth stage) were taken in crop. Hand harvest cuts were taken in late October to assess head density, harvest index, grain yield, grain protein/oil content, screenings, and test weights. Results were analysed using simple T-tests (Paired samples) in MS Excel. Only a selection of these measurements are reported here.

What happened?

Air Temperature

Results showed that all sites had multiple events where air temperatures in the canopy fell below 0°C during the critical growth periods period (27 July to 31 October 2023). The highest intensity of frost events was in July and August. At Tooligie the high-risk site recorded many more frost events than the moderate risk site, particularly in August and September during which crop maturity was at the stage where yields are most likely to be affected by frost damage.

The frequency of frost events was still high in September at all sites but started to drop off with warmer and drier spring conditions in October (Table 2). The number of frost events was generally higher per month on the unripped controls compared to the ripped treatments.

Table 2. Sum of frost events (<0°C) for deep ripping demonstration sites at Tooligie, Wharminda and Moody, July/August to October 2023.

		# events <0°C				Total <0°C events during critical growth period	# severe frost events during critical growth period*
Site	**Treatment**	**July**	**August**	**September**	**October**		
Zacher Moderate Risk, Tooligie	**Unripped control**	8	9	5	0	22	6
	Rip 2023	11	12	9	1	33	14
	Bednar Rip 2022	9	9	4	0	22	6
Zacher High Risk	**Unripped control**	20	17	18	6	61	31
	Rip 2023	12	11	14	5	42	16
	Bednar Rip 2022	14	12	14	5	45	19
Hunt, Wharminda	**Unripped control**	***	18	12	6	36	27
	Rip 2023	***	16	9	3	28	19
Modra, Moody	**Unripped control**	***	18	15	10	43	34
	Rip 2023	***	14	10	6	30	22

Below -1°C frost events from 27 July to 31 October.

****data logger not installed until late July.***

The number of severe frosts (<-1.0 °C) recorded was 40-80% higher on the unripped controls compared to the ripped treatments at Wharminda, Moody and in the HRZ at Tooligie (Table 2). Multiple very severe frost events (<-3.0°C) were recorded in the period between 7 August and 11 September, with particularly severe events on the 7-8 August where minimum temperatures were below -5.0 °C at Wharminda, Moody and the HRZ at Tooligie (Table 3). Temperatures below -4.0 °C at canopy height were also recorded on 11 August and 9 September. Temperature loggers showed that during frost events the unripped controls at Moody were on average 1.7 °C colder than on the ripped treatments, 0.6 °C colder on average at Wharminda and 1.0 to 1.4 °C colder on the HRZ at Tooligie (Table 3). At the MRZ site at Tooligie the

average difference in temperature between the unripped treatments and the new rip (2023) was -1.0 °C but there was little difference in temperature between the control and 2022 rip in this zone.

Table 3. Minimum temperature on unripped controls during key frost events 7 August to 11 September.

Site:	Wharminda		Moody		Tooligie High Risk Zone		Tooligie Moderate Risk Zone		
Date of frost event	Minium temperature Untreated Control (°C)	°C warmer on Ripped vs Untreated Control	Minium temperature Untreated Control (°C)	°C warmer on Ripped vs Untreated Control	Minium temp-Untreated control (°C)	°C warmer on Ripped vs Untreated Control	Minium temp-Untreated control (°C)	°C warmer on Ripped 2023 vs Untreated Control	°C warmer on Ripped 2022 vs Untreated Control
7/08/2023	-5.6	0.9	-5.1	1.5	-5.8	2.1	-2.2	-1.4	0.1
8/08/2023	-7.1	1.0	-6.7	1.9	-7.2	2.0	-3.1	-1.6	-0.1
9/08/2023	-3.9	0.3	-2.9	1.3	-5.1	2.1	-1.2	-1.3	-0.1
11/08/2023	-4.3	0.5	-4.4	1.5	-4.7	2.2	-1.2	-1.2	-0.1
23/08/2023	-3.4	0.4	-4.0	1.9	-3.4	1.9	0.1	-0.8	-0.1
24/08/2023	-3.7	0.7	-3.8	2.1	-4.2	1.8	-0.3	-1.0	-0.2
9/09/2023	-4.9	1.1	-5.0	2.2	-4.6	1.3	-0.73	-1.0	-0.2
10/09/2023	-3.6	0.9	-3.0	1.7	-3.5	1.2	-0.6	-1.0	-0.1
11/09/2023	-3.2	0.7	-2.8	1.6	-2.8	1.1	-0.1	-0.9	0.1

When comparing the risk of frost events with the potential to impact final crop yields, it is important to not just note the number of frost events, but also the length of time that temperatures remained below 0°C. Logging data showed that not only was it colder on the unripped controls, but temperatures remained below 0°C for longer (Table 4).

Table 4. Average difference in minimum temperature and number of hours below 0°C **between the unripped controls and ripped treatments.**

	Temp difference between treatments - unripped vs rip 2023 (°C)	Time difference below zero (hours more than ripped 2022)
Tooligie Moderate Risk Zone	**0.1-1.0***	**0.1-2.5***
Tooligie High Risk Zone	1-1.3	1.6-2.4
Wharminda	0.6	1.1
Moody	1.7	3.2

The range includes Rip 2022 and Rip 2023 treatments. In 2023 the difference between the 2022 rip and unripped control in the moderate risk zone was less than for the 2023 ripping treatment.

Soil moisture during frost events

Soil sampling was undertaken to assess gravimetric soil moisture around frost and rainfall events. Results indicated that gravimetric soil moisture in the 0-10 cm layers was generally higher on the ripped treatments than the unripped controls but soil moisture during the season was generally low (<10%) at all sites (Table 5). The higher moisture levels in the ripped treatments might result from the introduction of clay into the topsoil during the ripping operation.

Table 5. Difference in gravimetric soil moisture (%) in the 0-10 cm layer between unripped and ripped treatments.

	Gravimetric soil moisture (%)						
	Modra, Moody		Hunt, Wharminda		Zacher High Risk Zone, Tooligie		
Date of frost event	**Unripped control**	**Ripped treatment**	**Unripped control**	**Ripped treatment**	**Unripped control**	**Ripped 2023**	**Ripped 2022**
2/08/2023	9%	10%	2%	4%	5%	7%	5%
22/08/2023	9%	10%	3%	5%	3%	4%	4%
1/09/2023	6%	8%	3%	4%	4%	6%	6%
11/09/2023	6%	10%	2%	3%	3%	3%	3%
Average difference in minimum temp (°C) during frost event.	1.5		0.8		1.7		
Average hours below 0°C	3.9		1.3		2.0		

Crop development and damage.

Frost damage with the potential to reduce yields typically occurs between stem elongation (GS31) and the end of flowering (GS69). Assessments of crop maturity were undertaken when sampling for gravimetric soil moisture (Table 5). This data shows that at the time of the most severe frosts in early August and early September, crops on these demonstration sites were at a growth stage where crop growth and yield could be impacted by these frost events (Table 6). Frost symptoms including bleached and shrivelled heads were observed in the cereals at Wharminda and Moody, but only on isolated plants in the canola at Tooligie.

Table 6. Crop maturity at soil sampling intervals.

	Wharminda	**Moody**	**Tooligie**
Date	**Wheat**	**Barley**	**Canola**
26/07/2023	GS43- swollen boot	GS31 - first node	GS60 - first flower
22/08/2023	GS53 - ear emergnce	GS41 - flag leaf	GS65 - 50% flower

1/09/2023	GS69 - anthesis	GS49 - awns visible	GS68 - full flower
11/09/2023	GS71 - grain fill	GS65 - anthesis	GS80 - seed ripening

Hand cuts were taken in late October with biomass and grain weights extrapolated to dry matter and grain yield (t/ha) (Table 7). Results showed high biomass production at all sites, but with much lower yields in cereals on the unripped controls compared to the ripped areas. The differences between treatments on the MRZ and HRZ were not significant ($P<0.05$), however there was the MRZ of this paddock yielded better than the HRZ overall.

Table 7. Harvest biomass and grain yield and quality results from 2023 demonstrations sites at Wharminda, Moody and Tooligie.

Site	Crop type	Treatment	Biomass (t/ha)	Grain Yield (t/ha)	Harvest index (%)	Protein/Oil (%)
Modra, Moody	Barley	Rip	12.4	4.69	0.36	10.5
Modra, Moody	Barley	Unripped Control	7.6	2.62	0.34	8.2
Hunt, Wharminda	Wheat	Rip	9.8	0.96	0.1	15.2
Hunt, Wharminda	Wheat	Unripped Control	8.9	0.21	0.02	15.2
High Frost Risk	Canola	2023 ripped	6.6	0.7	0.1	33.8
High Frost Risk	Canola	2022 Bednar rip	5.8	0.7	0.1	36.1
High Frost Risk	Canola	Unripped Control	6.1	1	0.2	34.7
Moderate Frost risk	Canola	2023 ripped	5.2	1.4	0.3	41.6
Moderate Frost risk	Canola	2022 Bednar rip	5.1	1.3	0.3	42.1
Moderate Frost risk	Canola	Unripped Control	4.9	1.3	0.3	42

Harvest index was very low on the Wharminda site and at the HRZ at Tooligie. These sites had high biomass production, but comparatively poor grain yields which might reflect the impact of the very severe frost events (<-5 °C) at grain development. Although these very low temperatures were also recorded at Moody, harvest index was largely unaffected suggesting that the barley on this site was less affected by frost but and that the significantly higher yields on the ripped

treatment compared to the control was the result of ripping addressing another production constraint.

During severe frost events the HRZ recorded temperatures which were at least 3 °C colder than those on the MRZ. Harvest index ratios show much lower conversion of biomass to grain yield in this zone compared to the MRZ. This suggests that whilst the canola at this site produced good early biomass, grain development was checked by the extremely cold conditions in this zone, will both the unripped and ripped treatments affected equally. There did not seem to be any major trends with protein/oil content on the unripped and treated areas in the Tooligie canola.

What does this mean?

All sites experienced multiple frost events from late July to the end of October, with consecutive severe frost events in early August as well as number in early September. This makes trying to manipulate crop maturity as an avoidance tactic to reduce frost risk challenging. Good conditions in early winter resulted in high biomass production at all sites. However extremely low temperatures at Wharminda and on the HRZ at Tooligie saw poor conversion of biomass to grain yield. Temperatures were higher on the ripped treatments vs unripped, but at Wharminda and in the HRZ at Tooligie did not significantly mitigate the impact of the extreme low temperatures on grain development. The higher temperatures on the ripped compared to the unripped treatment however might be enough to reduce the risk of crop damage during less severe frost events.

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Trial Location: Tooligie, Wharminda and Moody.

Farmer Name: Tim Zacher, Evan and Lauren Hunt, Justin/Ryan Modra, and families.

Soil type: Modified (Delved) sandy over clay.

Plot size Dimensions: Strip demonstrations – single/double pass with deep ripper x 100 m across paddock and landscape zones.

Trial design: demonstration strips

Yield limiting factors: Frost, early finish.

GLOSSARY AND ACRONYMS

Below is a sample abbreviations and acronyms list. Be sure to include all abbreviations and acronyms that appear in the report.

DPIRD	Department of Primary Industries and Regional Development
DAP	di ammonium phosphate
DArT	Diversity Arrays Technology
DAT	days after treatment
Db	bulk density
EP	Eyre Peninsula
TOS	Time of sowing

REFERENCES

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