SA Drought Hub Technical Report

Understanding frost and minimising financial risk due to frost in the MNHRZ

PROJECT LEAD: Mid North High Rainfall Zone

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PROJECT SUMMARY

The financial and emotional exposure of individual farm business to frost damage varies depending on the relative percentage of high damage compared to low or no damage on each property, the financial status of each business and the success or otherwise of avoidance and mitigation strategies.

Strategies to reduce the financial impact depend on the relative exposure to high damage potential, classified as frost red zones compared to no damage potential, green zones and where frost is a variable feature, amber zones.

2024 was both a high frost damage year as well as a drought year. However, frost occurs at damaging levels almost irrespective of seasonal conditions in the Mid North region. Drought impacts because of the impact over all three frost zones whereas frost, by itself is confined to red and amber zones. For this reason, the impact of frost in drought years can have a large impact. Mitigation options are reduced in drought years because of low biomass production for hay production or grazing of frosted crop, as well as lower stubble quantities for summer and autumn grazing, and poorer recovery of grain potential after frost due to low soil water.

The project successfully investigated and extended avoidance, mitigation and tolerance strategies and highlighted where they were both appropriate, and less likely to succeed.

EXECUTIVE SUMMARY

The project aims were to articulate the methods to reduce the financial impact of frost for those farmers who experience frost losses. In order to do so, the concept of determining frost red, green and amber zones and calculating the percentage impact of each of those on profitability was an important first step in identifying and mitigating risk.

It is an important extension message of the project that zones are identified and that management is aligned to zones. It is just as important for farmers to not limit productivity and profitability where frost is not a limiting factor, as to reducing risk where it is.

Where frost impact is so severe that most grain crop choices are severely limited, the option of productive pastures for livestock, hay, out of season crops and dual purpose crops were addressed in the project. A range of annual, single and mixed species forage options were compared, super high oleic acid safflower production methods were trialled where the vulnerable period of the crop is anticipated to be much later than the anticipated frost period. While hay was not a research component of the project, each extension opportunity covered the role of hay options, export hay opportunities and dual purpose cereals, which can be cut for hay if the crop is frosted.

The use of frost damaged wheat and barley seed from the previous year has been a question asked by farmers. The response has typically been that if the grain is visually impacted by frost then it is best not to use it as seed. What was not addressed are two very important aspects of saving seed from frosted crops. Firstly, if there is no visual impact of frost damage, which usually occurs when severe frost impacts not long before physiological maturity of the crop, is there still a degree of damage or interruption to the seed that can affect germination, establishment, early growth and yield. Secondly, is it possible that ice nucleating bacteria within the grain develop in the germinating seed to colonise the following year's plant? If that were to occur then a hypothesis might be that inoculating plants early with bacteria might lead to rapid proliferation, increasing frost damage potential.

Seed of 3 wheat varieties and 3 barley varieties from frosted and unfrosted plots from a 2023 experiment were used to conduct the trial. The seed from the frosted crops were not visually damaged by frost and were graded to the same size as the seed from the unfrosted crop. Germination and early vigour were impacted, although there were differences between varieties within each species. When sown at the same density, the average establishment from frosted seed compared to unfrosted (plants per m^2) was 110 and 167 for barley and 123 and 173 for wheat. There were varietal differences, with Bale wheat being largely unaffected compared to Calibre and DS Bennett. There were no statistical differences between barley varieties. Growth and phenological development during the year from the frosted seed was always impacted compared to the unfrosted. Vigour scores and NDVI readings were used to confirm early vigour. However, due to later maturity from the frosted seed, these treatments actually avoided the most severe damage caused during a severe frost period over 3 days in September. Grain yield declined in barley due to frosted seed being sown but in wheat the reverse occurred where crop from frosted seed actually outyielded that from unfrosted seed for the earlier maturing Calibre and Bale. Being later by around 7-10 days resulted in lower damage and higher grain yields compared to the controls (from unfrosted seed). To support the influence of maturity being the dominant factor was that there was

no difference in final grain yield between frosted and unfrosted seed of the winter variety DS Bennett.

Barley is promoted as being more tolerant to frost but many farmers report that frost during grain filling has a severe impact on grain size. Yield can be impacted but even when yield losses are low, the resultant grain can incur large penalties, or even be undeliverable to bulk handling companies or private buyers. As barley is heavily awned, if it is cut for hay because of frost, it has limited markets. Awned barley is not accepted in export fodder markets. The project was to assist farmers and advisers in determining the relative risk of growing barley in red zones. Results support that varieties of barley that have similar maturity to wheat varieties had higher grain yield, but that late maturing wheat (DS Bennett) had similar yield to early maturing barley. Conversely the winter barley variety Newton, produced low grain yield compared to Commodus, Maximus and Neo, which was probably independent of frost impacts. The comparative advantage of winter wheat over winter barley is an interesting observation as a frost avoidance strategy.

The influence of canopy size, and seeding rate and nitrogen nutrition separately, is a question often asked at workshops. It has not been proven in local research that there is a consistent response. Air temperature at canopy height indicates it is colder when the canopy is large, but the relationship with frost damage is less clear. Results from this project clearly show that lower plant density (from lower seeding rates) had the highest grain yield, irrespective of nitrogen application rate. Visual assessment of vegetative frost damage indicated higher levels of damage at high density than low density. The occurrence of severe drought, followed by rain on Oct 15th/16th favoured recovery of low density wheat compared to high, without significance of nitrogen application rate. In many respects grain yield results reflect this response rather than any direct attribution to frost.

Oats are considered the most frost tolerant cereal. In this project oat grain yields were low compared to barley and wheat. It is likely that this response is due to intolerance of drought conditions, which is well documented. Of additional concern is that grain oats produced insufficient dry matter to be considered for hay and a response has been that a number of growers intend reducing their oat hay area in favour of wheat hay. The potential dual purpose oat, Goldie, produced grain yield 1 to 1.8 t/ha below barley and approximately 1 t/ha below wheat.

A wheat genetics trial conducted with Adelaide University indicated a range of tolerance of varieties and novel traits. One trait is the production of more fertile grain sites with the hypothesis that if a fixed percentage are rendered infertile by frost, then having more in the first place leaves a higher number to form viable grain. Unfortunately, vegetative frost had such severe impacts that reproductive frost data could not be collected. Despite this, there were interesting observations. The degree of damage caused by frost and the avoidance in late maturing varieties were evident. One experimental line, OW2, was very severely damaged compared to other entries while DS Bennett (winter wheat – 2.8 t/ha) and McNeal (long season photoperiod wheat – 2.4 t/ha) had highest grain yield. One key observation that does not appear to be related to phenology was the variety LPB Major suffering almost no vegetative or reproductive damage and producing high grain yield (2.4 t/ha).

The project results can be used by farmers and advisers to reduce risk. Firstly, confirming that frost mitigation strategies would potentially reduce profit in Green zones, where frost is almost never an influence on productivity. Secondly having a conversation about what strategies can be used to

reduce losses in Red zones varies between farms and individual choices that a business might pursue. Discussion about reducing the area of Amber zone that is impacted is important and the difference between strategies that can be implemented between Red zones and Amber zones depends on the relative areas of each and the financial risk individual businesses are prepared to take.

Frost damage is highly correlated to landscape impacts with small variations in elevation often producing large differences in frost damage. This is most likely a direct response to temperature due to pooling of cold air and rising comparatively warmer air. There could be localised humidity differences that likewise could influence frost damage but that has not been studied in this project. In field research, there have often been trials that have confounding outcomes or very high variability, which may be due to very small elevation differences. This project measured, to 2cm accuracy, the variation in elevation across a number of trials. Comparing elevation and treatments on a wheat variety trial showed that vegetative damage and grain yield were correlated with elevation within maturity groups. However, phenology (winter, late spring varieties) had at least the same impact as elevation. The observation is important for future research and the advice generated from it. It also puts into perspective observations from many project participants on their own properties.

The influence of ice nucleating bacteria (INB) on freezing of plant liquids is well known and the subject of research in WA. This project aimed to compare topically applied products that potentially have a role in controlling or reducing the impact of INB. As vegetative damage had occurred prior to the application of these products there was no response to their application. Products included those known to increase frost damage by causing nucleation and there was no response to those or others that have had laboratory success in inhibiting INB. Leaf samples taken for determination of ice nucleating activity (INA) as a result of INB, were taken but results have not been received to date.

PROJECT BACKGROUND AND OBJECTIVES

The project was instigated because frost is a major constraint on farm profitability in some locations, including the Mid North of SA. An important part of the project is to reinforce the identification of where financial impacts occur as a result of frost on each farm. Once zones are identified, strategies can be developed that are suited to individual farm businesses based on real and perceived risk, availability of machinery and technical expertise, and the relative size and proportion of each zone.

An important objective of this project is to empower farmers in making decisions that are specific to their individual risk profile, to understand that frost is always a risk in red zones and never a risk in green zones. Using technologies that increase productivity and profits in green zones may be totally inappropriate in red zones while using frost mitigation that is appropriate to reduce risk in red zones, might lead to missed opportunities for financial performance and soil improvement in green zones.

The project also understands that frost can be a devastating outcome for farmers. Frost can, in a very short time frame, take a crop from being something highly anticipated to having little value. This rapid impact is unique to frost and occurs irrespective of seasonal conditions. For some participants frost occurring when drought conditions exists is an additional financial and emotional blow while in other years when others are celebrating a high yielding year the impact of frost can be

particularly draining. Those with high exposure to frost sometimes express the frustration that they never seem to catch up or get ahead.

As farmers have strived for efficiency and simplicity, fences have often been removed, livestock reduced, or abandoned, and continuous cropping expanded. These factors have increased exposure to frost as previous generations would have had high risk areas separately fenced into paddocks that were often dedicated to sheep or cattle, where pastures were grown, and largely unaffected by frost. By incorporating these areas into mainstream farming operations, they have been treated similarly to low frost risk areas in order to streamline operations. This practice can be successful when those areas are small in comparison, but as the relative area of the frost affected areas increases so does the risk of farming them the same way as the frost free areas. Reducing risk may not mean replacing fences and running livestock, although this remains an option, but it may require management changes. This project has an aim to discuss potential management options and to allow interchange of ideas.

Many of the suggestions around reducing frost damage have not been scientifically validated and this project uses a research approach to validate, and question, extension messages.

It uses the principles of using avoidance, tolerance and mitigation options in reducing exposure and financial impacts of frost. Avoidance means having a crop at vulnerable growth stages outside of a period when frosts occur. This is more difficult to achieve in the Mid North because frosts can occur later into spring. The opportunity to avoid frost damage needs to be weighed against low yield caused by heat and dry and the probability that unseasonally late frosts can still occur. The ultimate in avoidance is growing a crop completely outside when damaging frosts occur, in this project SHO safflower is used to demonstrate this concept. In most of SA the use of 'summer' crops to reduce frost risk increase the risk of crop failure due to heat and dry or results in soils extremely depleted of soil water that impacts productivity of the following crop. Mitigation centres around decisions made during the preceding summer and autumn months, prior to sowing, as to what can be done to reduce the impact of frost should they occur in spring. The third principle of frost management is tolerance. There are currently no options that are completely frost tolerant so the project weighs up the options that reduce risk incrementally. Adopting more oats or barley can reduce the area of the amber zone (ie increase the area of the green zone for that year) and sometimes result in avoiding frost in red zones. However simply adopting these slightly more tolerant crop options also changes the risk profile if severe frost occurs, drought is an impact, severe frost occurs or grain quality is impacted. Openly communicating the change in risk profile is part of the project.

The final objective of the project is to give farmers and advisers more confidence and competence in identifying frost damage. Skills in this area have improved markedly in the last 10 years and the project aims to enhance them even more so.

METHODOLOGY

Replicated trials were conducted on:

Wheat, barley and oat varieties

Canopy, seeding rate and nitrogen interactions and exposure to risk

Pasture options in frost prone and cold environments

Using frosted seed of wheat and barley

Measuring canopy air temperature

In addition field days incorporated discussion of GRDC co-located research activities, SHO safflower and hay production.

Learning processes were centred on field days and discussion groups and presentation of results at workshops.



Figure 1 Wheat variety & novel trait trial

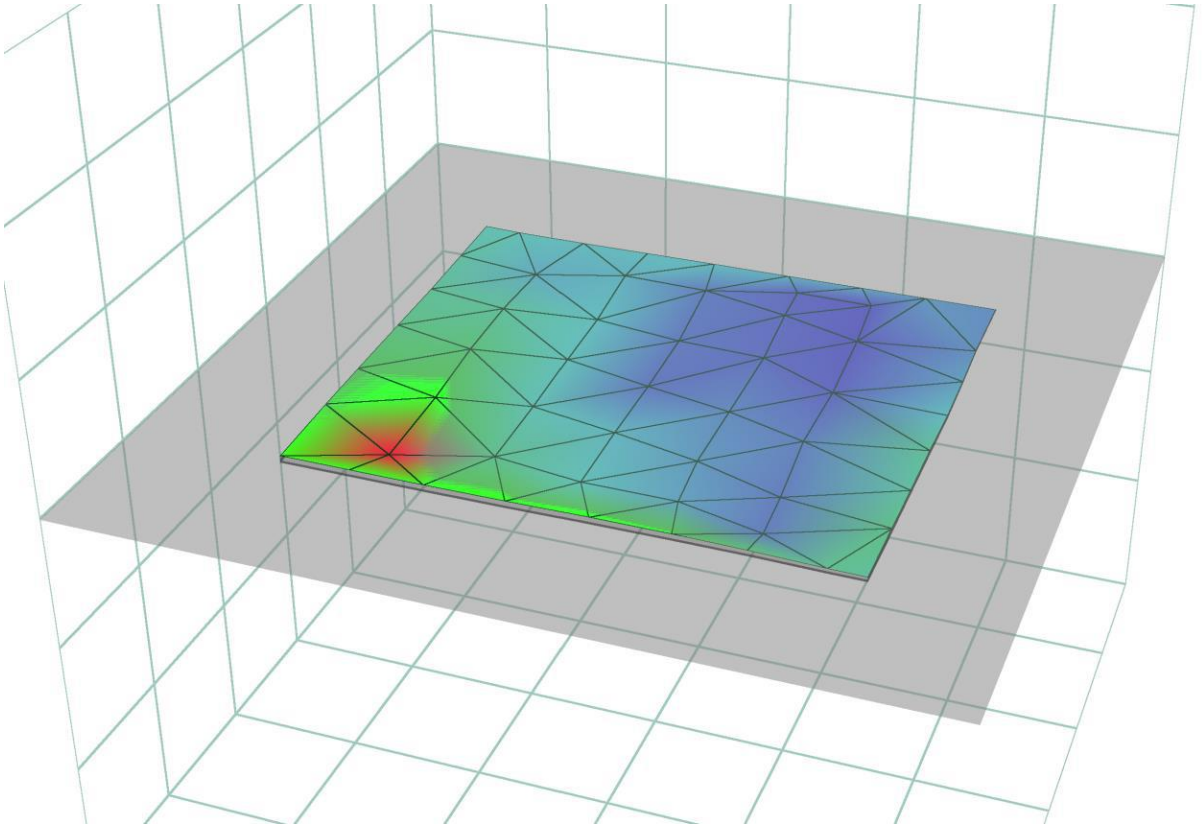


Figure 2 Example of elevation variation (Canopy trial)

LOCATION

Site # and name	Latitude (decimal degrees)	Longitude (decimal degrees)	LGA
Trial Site #1 / Farrell Flat	-33.838328	138.772295	Clare & Gilbert

RESULTS

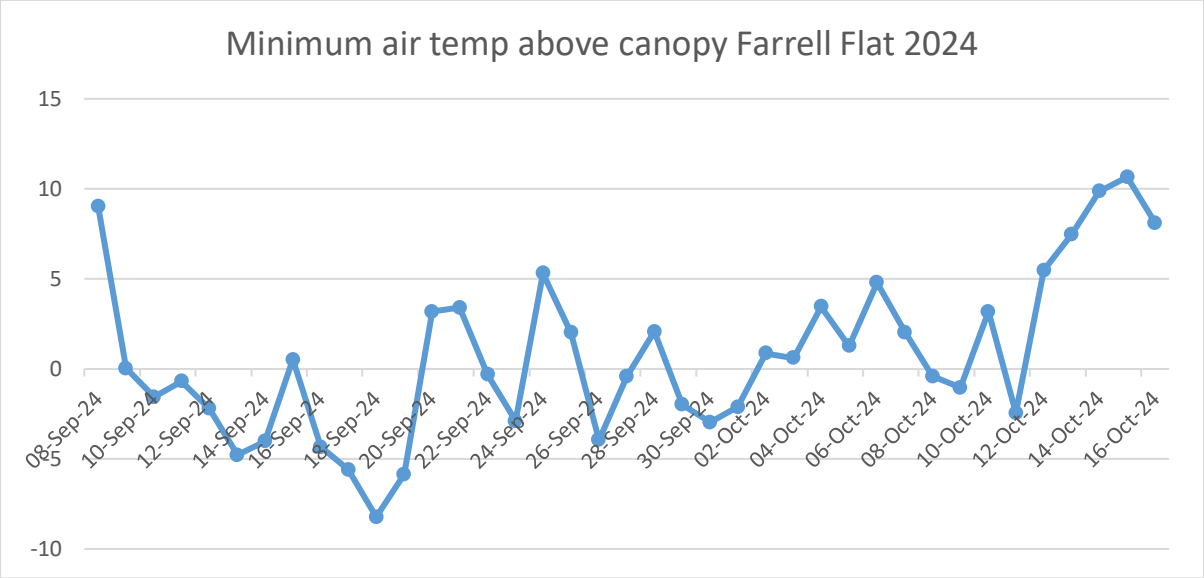


Figure 3 Minimum canopy air temperature above crop canopy Sep/Oct 2024

Figure 3 illustrates the minimum temperature immediately above the canopy of Newton barley. Newton was chosen because it created a complete plant canopy while other wheat and barley varieties had incomplete canopy cover due to drought conditions. The results indicate a large number of potential damaging events. Not included are conditions in late August and earlier in September that caused significant vegetative damage and grain yield loss.

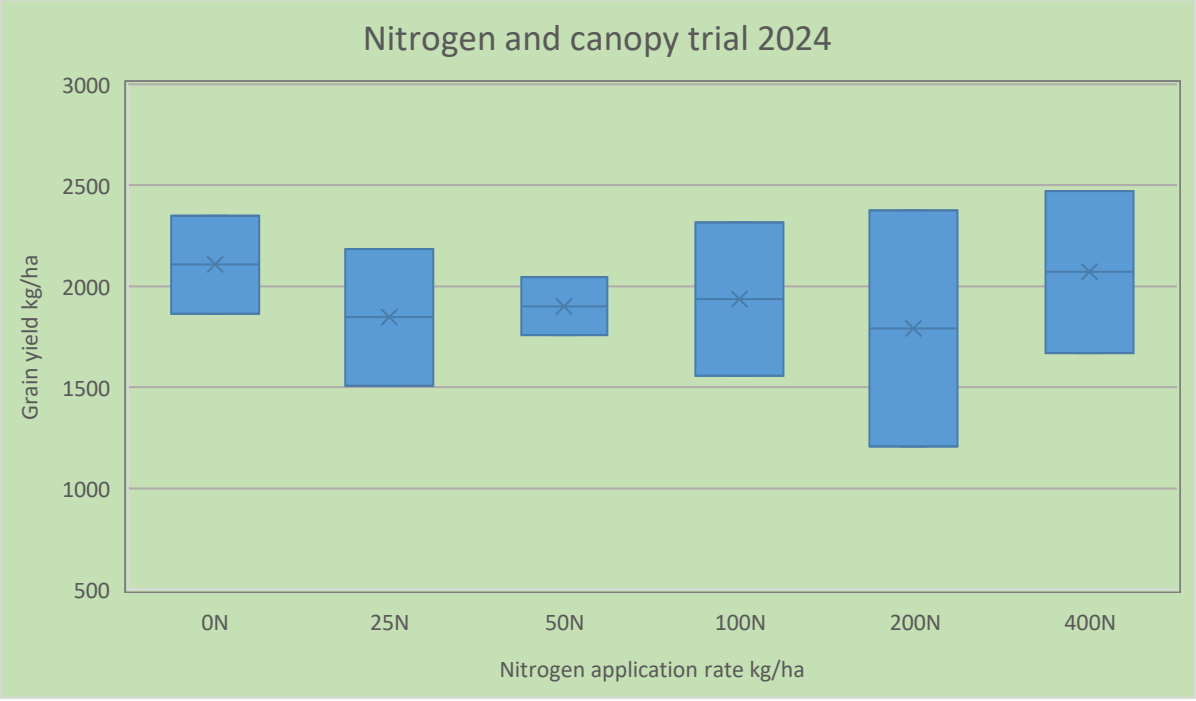


Figure 4 Grain yield response to nitrogen application rate

Figure 4 indicates no response in grain yield due to the addition of fertiliser nitrogen in winter (incorporated by rain). It can not be concluded from this graph if nitrogen had any influence on frost susceptibility or degree of damage.

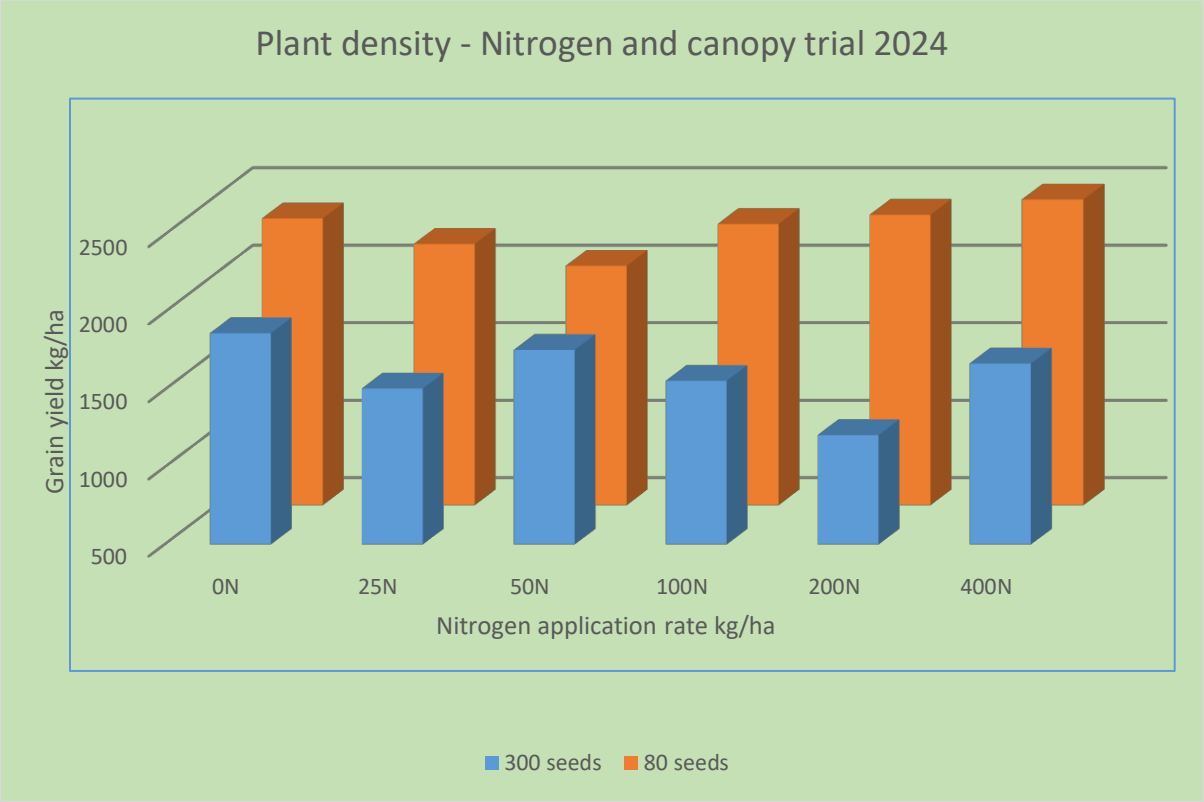


Figure 5 Grain yield response to canopy manipulation by nitrogen and seeding rate

Results in Figure 5 indicate no response to added nitrogen at either low or high plant density. There is a significant difference at all nitrogen rates between low and high seeding rates. At all nitrogen rates grain yield was higher at low plant density (80 seeds sown/m^2) than high plant density (300 seeds sown/m^2). This could be a response to the extremely low rainfall (driest on record) for the year and growing season and also because at low density there was a greater ability to recover due to moderate rainfall events in mid October.

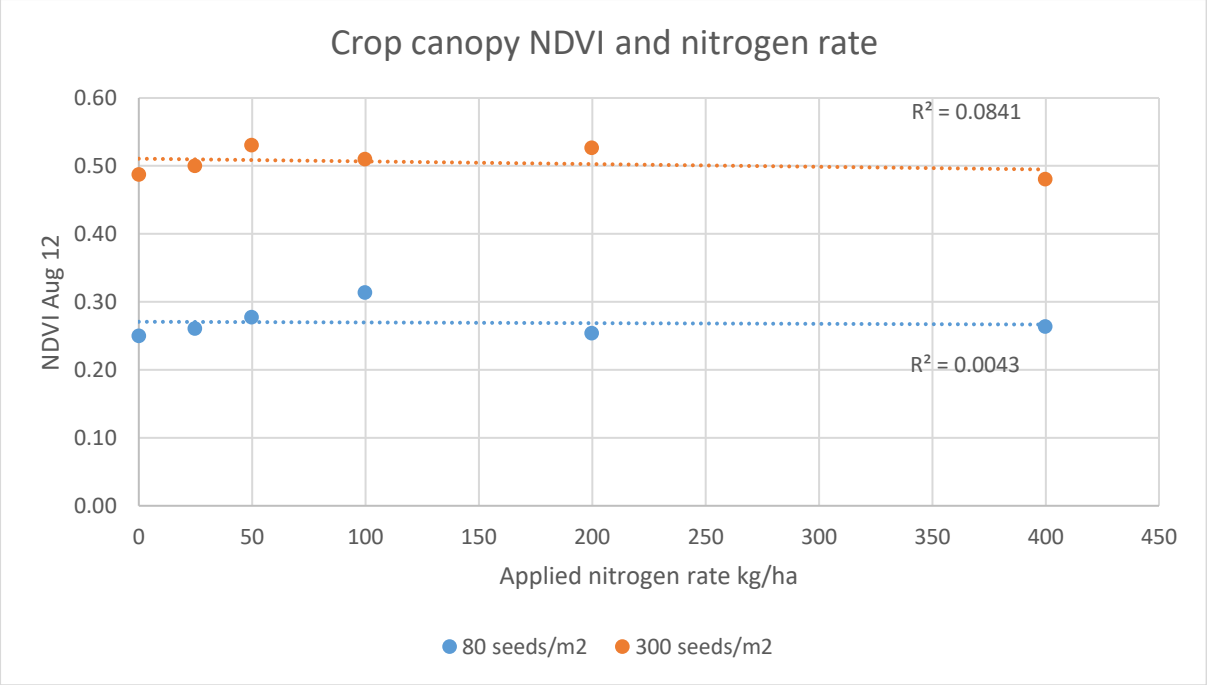


Figure 6 Influence of seeding rate (80 seeds and 300 seeds/m^2) and nitrogen rate on canopy size as determined by NDVI on August 12, 2024

Figure 6 indicates that nitrogen rate did not contribute to canopy size in 2024. This may be different when starting soil nitrogen levels are low or when sufficient soil water results in increased plant demand. However, there was a strong relationship between seeding rate and NDVI with substantially higher NDVI at the high seeding rate.

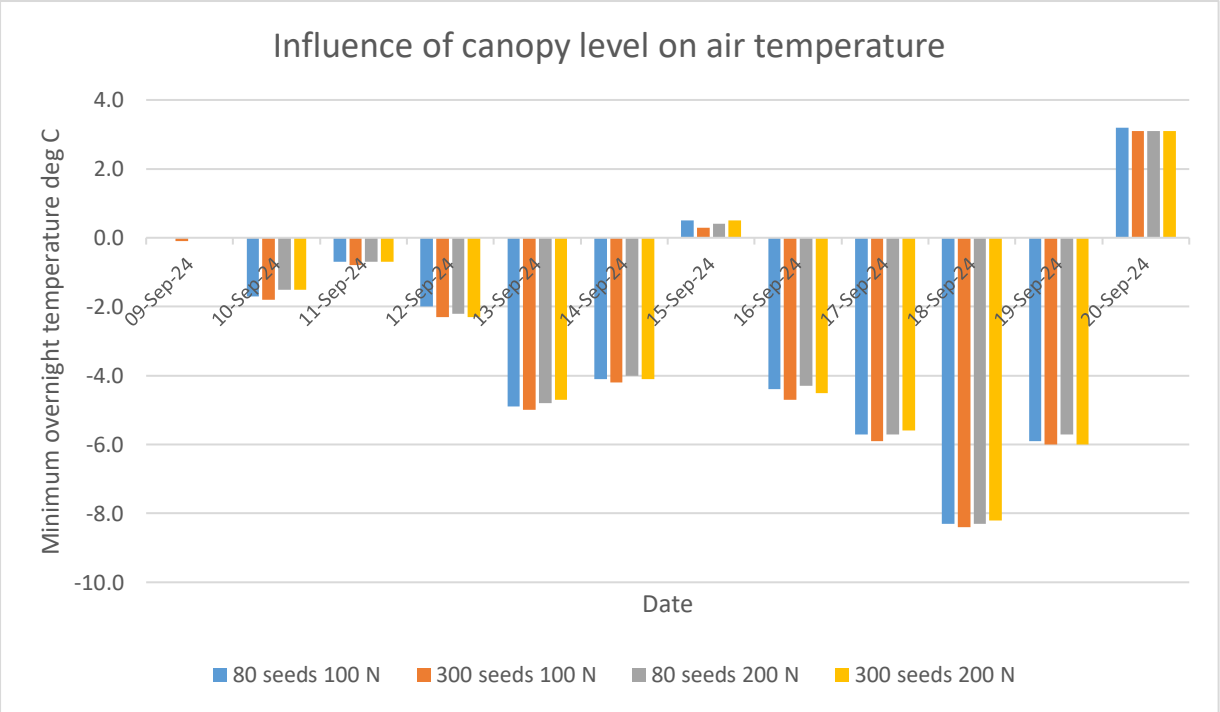


Figure 7 Influence of seeding rate and nitrogen rate on minimum temperature for 2 week period in September 2024

Figure 7 shows variable response of canopy air temperature to crop canopy influences for a two week period in September. As has already been discussed there was no influence of nitrogen rate on canopy size. This data shows that at one nitrogen rate (100 kg/ha) there was a negative correlation with canopy air temperature but variable response at 200 kg/ha. The data would be insufficient on its own to conclude larger canopies produce colder canopy air temperature.

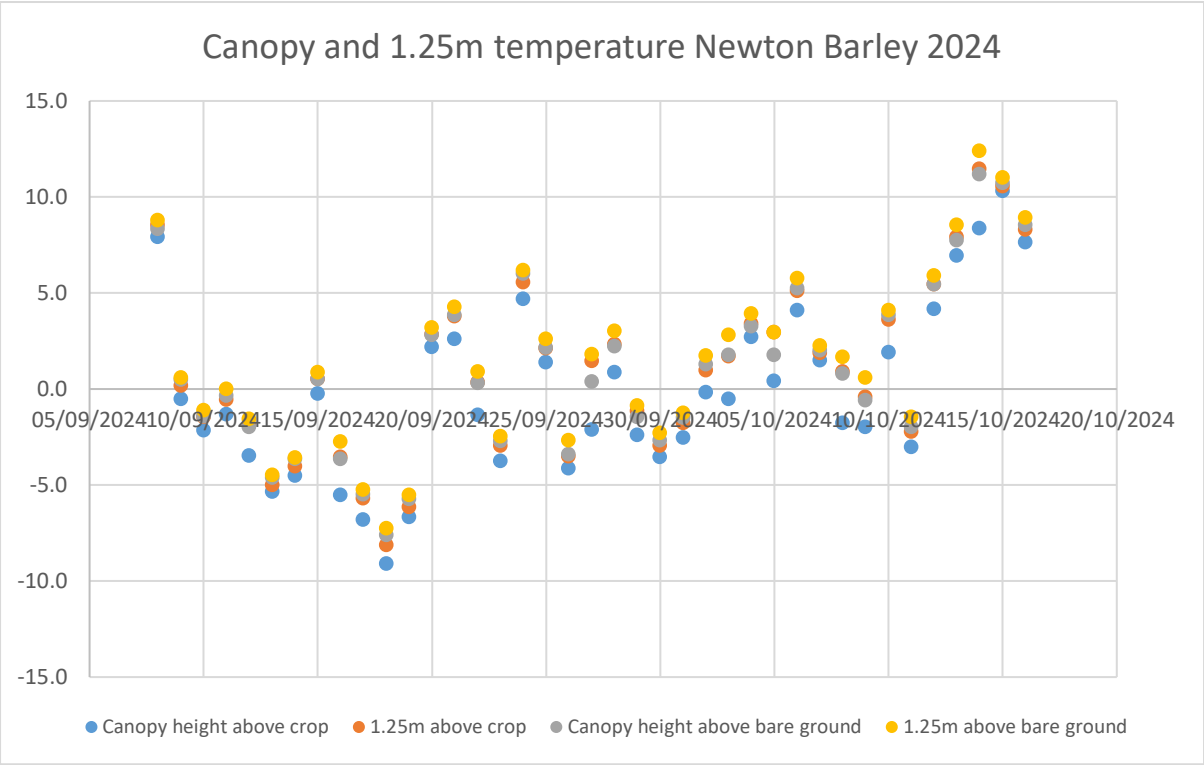


Figure 8 Influence of sensor position on temperature

Figure 8 indicates that logger position is important in determining air temperature near the plant. Temperature at 1.25m (screen height) above bare ground always had higher minimum temperature than at canopy height above bare ground which, in turn was always higher than at canopy height in the crop itself. Temperature at 1.25m above the crop canopy had inconsistent relationship other than it was always below the same height when above bare ground and always above the temperature at canopy height. The spread of observations of different logger positions was not consistent between nights.

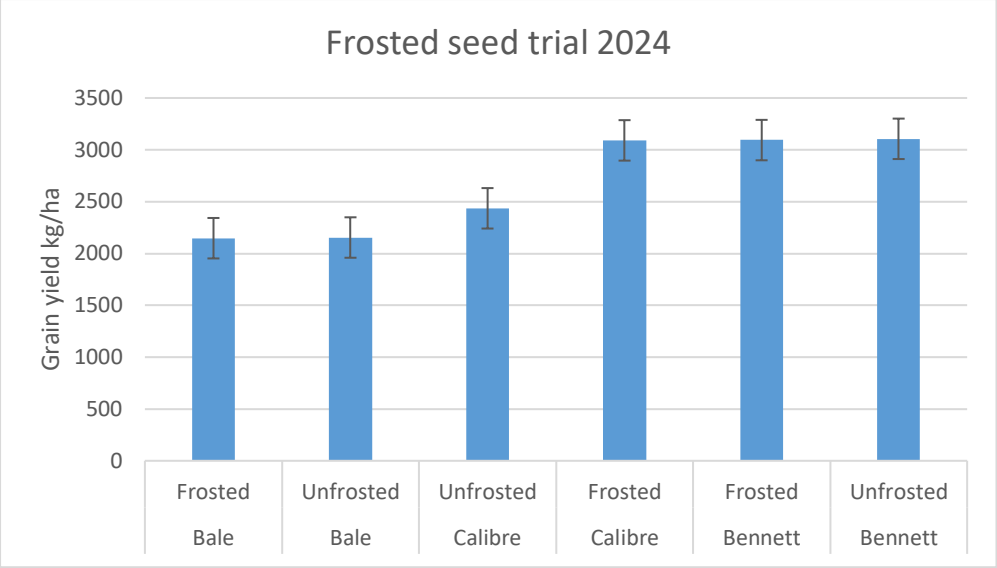


Figure 9 Grain yield result from using frosted compared to unfrosted seed of wheat cv Bale, Calibre, DS Bennett

Grain yield indicate in Figure 9 that there was little difference between using frosted seed of DS Bennett and Bale wheat but a significant response for Calibre. Caution must be taken when interpreting these results as all three varieties had significant reduction in plant establishment and vigour when using frosted seed. These responses were less for Bale compared to DS Bennett and Calibre. Early vigour differences continued for the duration of crop growth. Later maturing, 'thinner' cops produced from frosted seed were able to avoid some of the most severe losses (because they were later) and more able to recover yield from moderate rainfall events in mid-October (and mid-November for both Bale and DS Bennett).

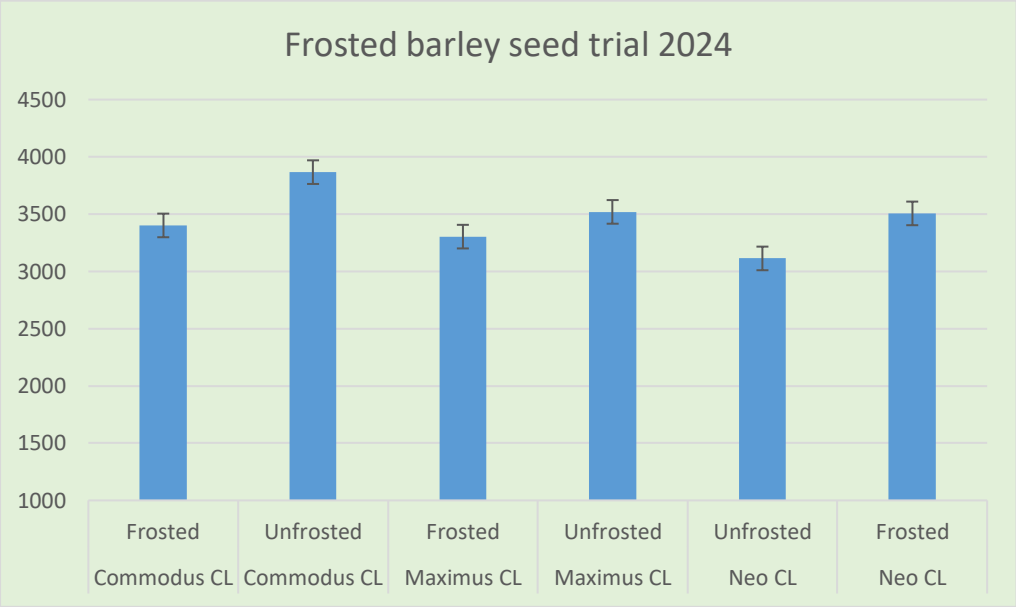


Figure 10 Grain yield result from using frosted and unfrosted seed of barley cv Commodus CL, Maximus CL, Neo CL

Barley grain yield using frosted seed was lower than unfrosted seed for all varieties.

It should be noted from Figures 9 and 10 that frost events that caused damage to the grain in 2023 that was used in the 2024 trial was extremely late in the season and well into the final stages of grain prior to maturity. There was no discernible frost damage to seed and grain weight was not affected. More severe impacts would be expected if grain was frosted during grain filling and used for seed, than was used in this experiment.

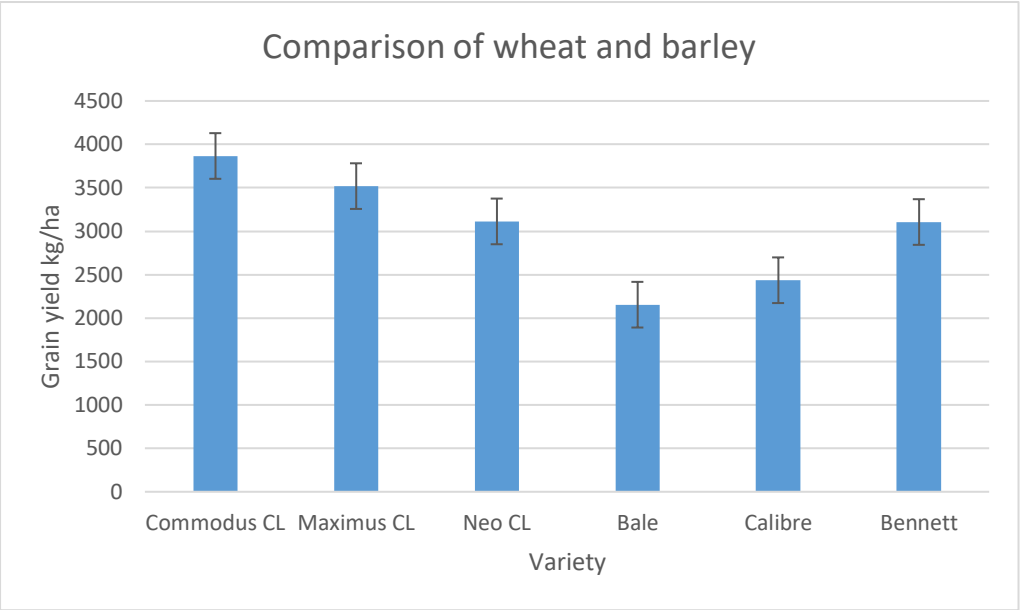


Figure 11 Comparison of wheat and barley grain yield 2024

It is commonly expressed that barley is more tolerant to frost than wheat. While that might be true for a defined period around anthesis it has not be proved across the range of developmental stages. While anthesis frosts might be indicative of the extent of damage that can occur at a particular point of crop development, they do not represent the majority of damage that actually occurs. Yet farmers in some environments benefit from including barley to manage risk while in others, barley exacerbates the risk. It is not common to see barley grown on the most frost prone areas of the mid north. Those farmers indicate that damage during grain filling (or the boot stage for some) results in high yield loss and severe quality loss.

The results of this project indicate there is variability between varieties within species and that Bale and Calibre wheat had lower yield than the barley varieties. As there was no frost during grain development there is no data on the impact on grain size and quality. DS Bennett produced the same yield as Neo CL and Maximus CL barley, but inferior to Commodus barley. There may have been significant impact of drought in these results and caution should be taken with interpretation.

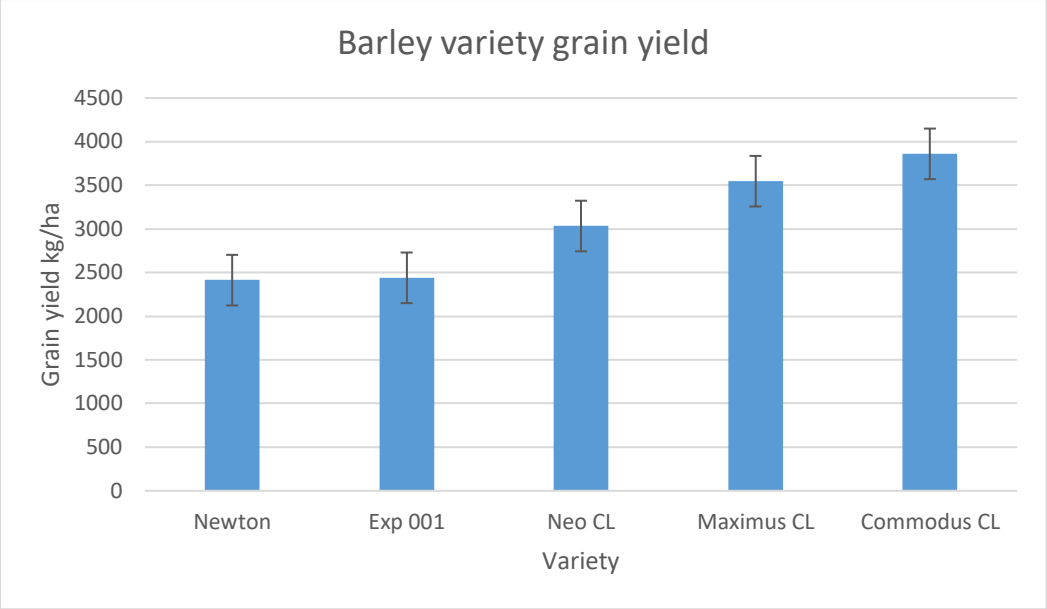


Figure 12 Grain yield of barley varieties 2024

Figure 12 indicates the difference in yield between Commodus Cl and Maximus CL compared to Neo CL. The awnless barley Exp 001 and the winter barley, Newton had significantly lower yield than all other varieties.

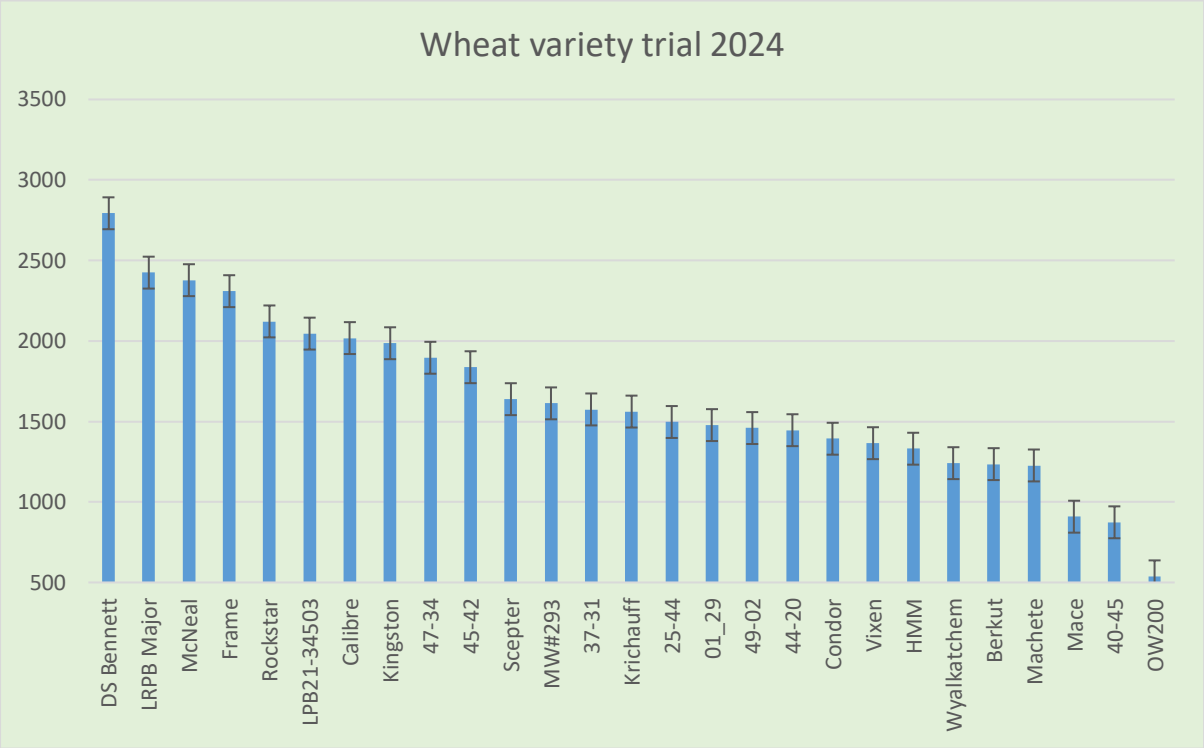


Figure 13 Grain yield of wheat varieties 2024

The wheat variety trial resulted in significant grain yield differences. The differences were a combination of vegetative damage (both pre post GS50) from a number of events in late August, early and mid-September. The potentially most severe frost events (Sept 15-18) occurred prior to anthesis of any variety, while those approximately a week later were around anthesis of some

varieties. The later maturing lines DS Bennett, LPB Major and McNeal had the highest yield and it might be an easy assumption that the response was due to phenology (avoidance) or recovery due to moderate rainfall events in mid-October and mid-November. However, vegetative damage scores (data not presented) would not support that hypothesis.

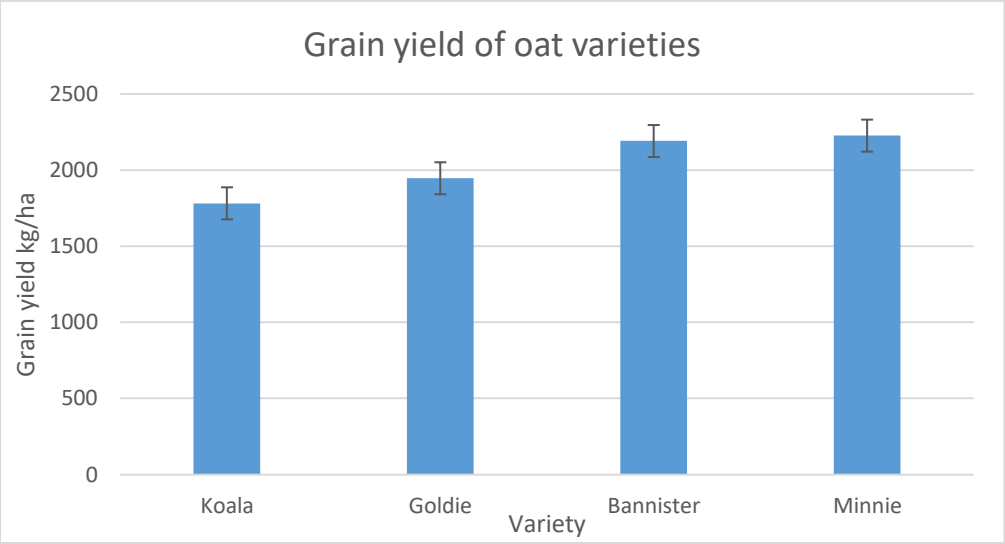


Figure 14 Grain yield of oat varieties 2024

Oats is reputed to be the most frost tolerant cereal. The results of this trial do not support or deny that assumption as low yields could have been due to drought intolerance or vegetative frost damage. However the results indicate that producing oats for grain may not necessarily reduce frost risk.

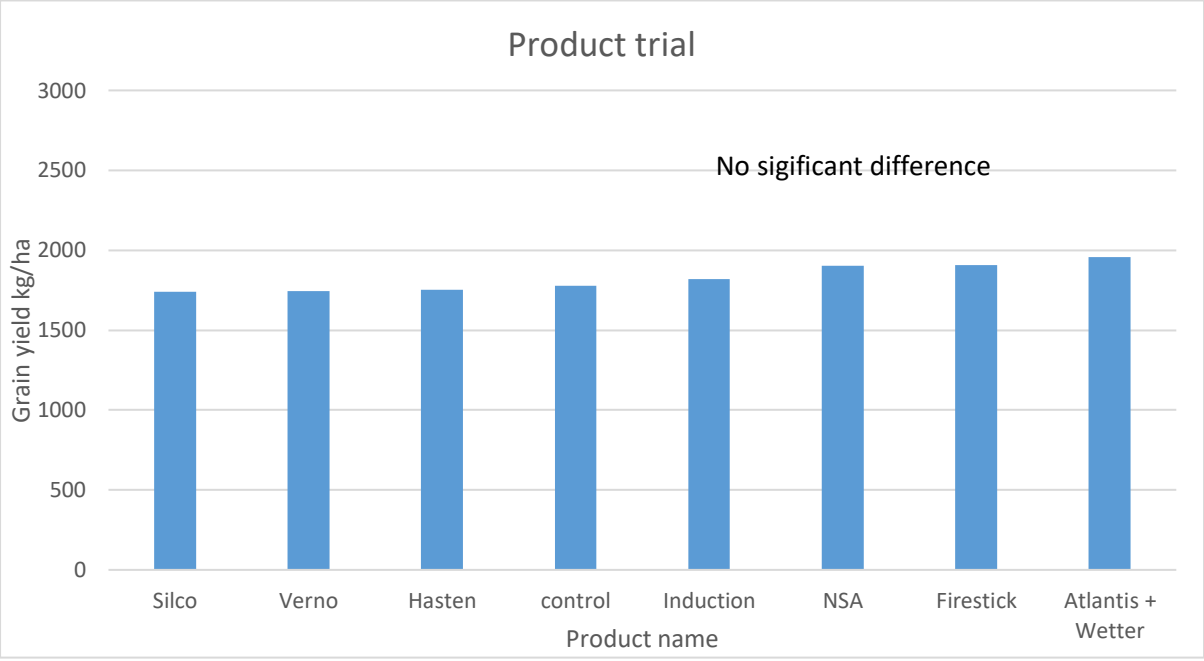


Figure 15 Response of wheat (cv Calibre) to the application of frost prevention products 2024

Foliar applied products are an attempt to control, or limit, the ice nucleating activity caused by ice nucleating bacteria, or to provide some mechanism to reduce cell damage when contents freeze and

thaw. Severe vegetative frost damage had already occurred before products were applied in this trial as timing was to provide protection at or near anthesis. There was no response to any application. In other experiments conducted locally the “Induction” treatment has been used to provide ice nucleation and has caused damage when there has been none otherwise (where treatments have not been applied). The fact that the Induction treatment had no negative impact on grain yield is indicative that the majority of damage was due to vegetative damage that occurred prior to anthesis.

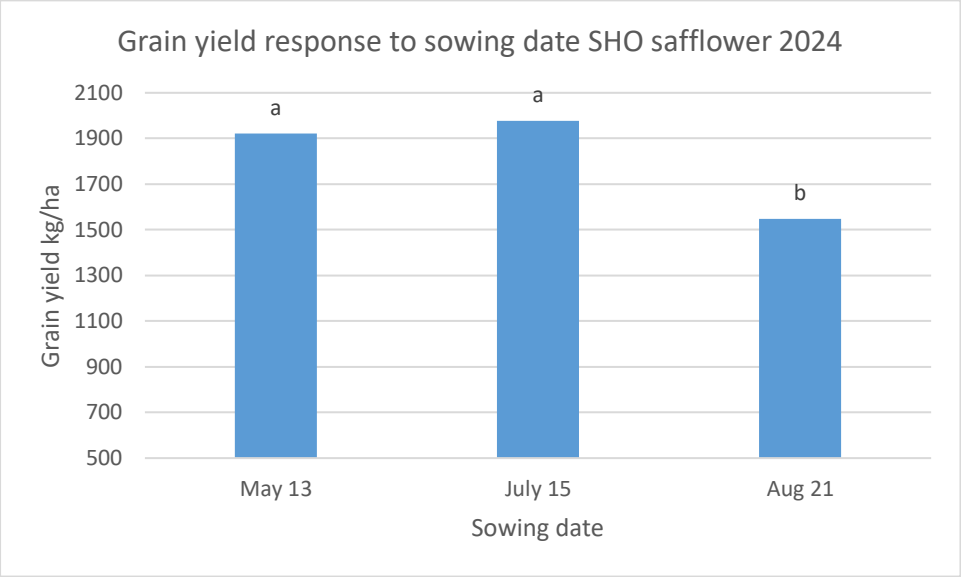


Figure 16 Grain yield of SHO safflower, variety E40-R in response to time of sowing, Farrell Flat 2024

SHO safflower yield was high in 2024, even though it was the driest year on record. It is likely that stored soil water, below the root zone of the 2023 faba bean crop, timely but moderate rain in mid-October and mid-November, and a high harvest index that resulted from plants that produced low levels of biomass in comparison to higher rainfall years.

CONCLUSION

Results confirm that frost risk can best be described using a zone approach where a Red Zone is where severe financial loss occurs, a Green Zone where frost is never a consideration and losses never occur and an Amber Zone, where damage has a significant damage range depending on severity of frost. Management of frost on a farm can best be subjectively assessed and managed depending on the relative areas of Green, Red and Amber Zones. Using this methodology allows individualisation of frost management.

The 2024 season was the driest on record, and while, drought was considered a prime driver of low yields and profitability, severe frost losses were evident over large areas of SA, Vic and NSW. This is in contrast to years such as 2014 and 2016, where severe financial loss to frost occurred in above average production years, and 2019 and 2021 when losses occurred in average or near average seasons. This spread of severe financial loss in different seasons indicates that there is a poor correlation between season type, rainfall and frost loss.

The occurrence of drought, vegetative frost and reproductive frost in the project makes it difficult to determine attribution of yield loss to any, or a combination, of these climate influences. High levels of vegetative frost confirm that frost is not simply something that causes damage at flowering and that avoiding frost at flowering does not significantly reduce impact in these regions. In addition, the wide window in which frost occurs from August until early November indicates that trying to avoid frost by phenology is very difficult. Predicting when damaging frosts occur, and when the last frost will occur, is exceedingly difficult.

Project results do indicate though, that wheat varieties with later phenology driven by vernalisation or photoperiod can minimise damage. In this project the last damaging frost occurred before these varieties reached vulnerable stages. However, at extension events farmers and agronomists indicated in 2023, it was these same varieties that had greater losses because the damaging frost was later in the season.

However, a range of maturity of wheat could be useful whereby not all varieties are at the same stage should one or more frosts occur. The concept of asynchronicity was discussed as a method of reducing risk.

Grain yield of barley was generally higher than wheat indicating lower frost losses. This could be the result of greater tolerance but the research design can not conclude that hypothesis with confidence.

While oats are reputed to have the highest frost tolerance of cereals, the grain yield was lower than the best performing wheat and all barley varieties. This could be a response to drought but indicates a downside to the inclusion of oats based solely on frost tolerance.

The project did not conclusively prove the role of plant population, nitrogen application rate or the combination of both in the degree of frost damage. In discussions, most farmers felt that a more conservative approach to nitrogen was warranted in Red Zones compared to Green Zones because of the financial exposure of input costs as compared to frost susceptibility per se.

ACKNOWLEDGEMENT

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This program received funding from the Australian Government's Future Drought Fund

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