Detecting frost damage in wheat

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Key points

- Differences between frosted and non-frosted wheat crops have been detected soon after frost events in a paddock using remote sensing, including spectral reflectance, fluorometer, multispectral, and thermal infrared instruments.
- Sensor measurements indicate differences in responses among wheat varieties. Likewise, there are differences in the responses across plant components (leaves, heads, and stems).
- Most of the 2016 measurements were made on plants or canopies where the frost treatments were visible to the eye. Additional analysis is being made on frost treatments where initial damage is not visible.
- Some measurements indicate a change in response over time following a frost treatment, highlighting the importance of the timing of measurements following a frost event.
- Further research will correlate the sensor readings with the level of frost damage incurred by plants and the impact on harvested grain.

Background

Across Australia's cropping regions, frost damage is a significant challenge for wheat growers. Frost can result in substantial wheat yield losses, estimated at between $100 and $300 million each year, across Australia's eastern cropping region alone. A similar scale of loss has been reported across South Australia and Western Australia in recent decades.

Currently, determining if frost damage has occurred requires physically assessing the crop within five to seven days after a suspected frost event, which is labour intensive. If non-destructive sensors could make a more rapid, spatial assessment of frost damage, this could allow more timely management decisions on whether to continue growing the crop for grain, reduce costly inputs, or cut portions (or all) of a paddock for hay.

This project aims to assess the potential for a range of sensors to detect frost damage through non-destructive measurement of leaf/canopy reflectance, chlorophyll fluorescence, and radiometric surface temperatures.

Research goal

The results reported here are part of a larger research project, which aims to increase the understanding of frost risk and frost damage at the national scale through three key research activities to examine:

1. available satellite and other spatial information to develop high resolution frost risk maps at different resolutions (i.e. 5km, 30m, 5m and sub 1m (where feasible)) for case studies across the Australian wheat belt.
2. effective ways to rapidly assess post-event damage. The research will consider a range of techniques including static, unmanned aerial vehicle (UAV), satellite or vehicle-mounted sensors to identify frost damaged, or potentially damaged, plants and areas.
3. the frost damage information derived from the national frost trials in order to improve current representations of frost damage in biophysical models.

Aim

The aim of this trial was to assess the potential of a range of sensors to detect changes in wheat after a frost event. This is the first step in determining the potential of remote sensing to be used as a tool to detect and manage frost impacts on farm.

Method

The experimental work presented here was carried out at Horsham and Yarrawonga, Victoria during 2016.

2016: Yarrawonga

The Yarrawonga site aimed to provide a large-scale opportunity to assess a range of sensors after a natural frost event. Collaborating with Riverine Plains Inc, we accessed four treatments in their Yarrawonga stubble management trial (part of the GRDC-funded *Stubble project*): long stubble, short stubble, cultivated, and burnt. These treatments were selected to provide a spread in frost severity (due to differences in canopy temperature) when a frost event occurred. Unfortunately, the site was only partially instrumented, as high rainfall resulted in waterlogging, which made accessing crops to install the large frost protection chambers difficult. However, CSIRO Arducrop radiometers were installed to monitor canopy surface temperature (Figure 1a) and one frost exclusion chamber (1m x 1m) was deployed (Figure 1b); along with the Tinytag sensors, already installed by Riverine Plains Inc, to measure air temperature in the canopy.

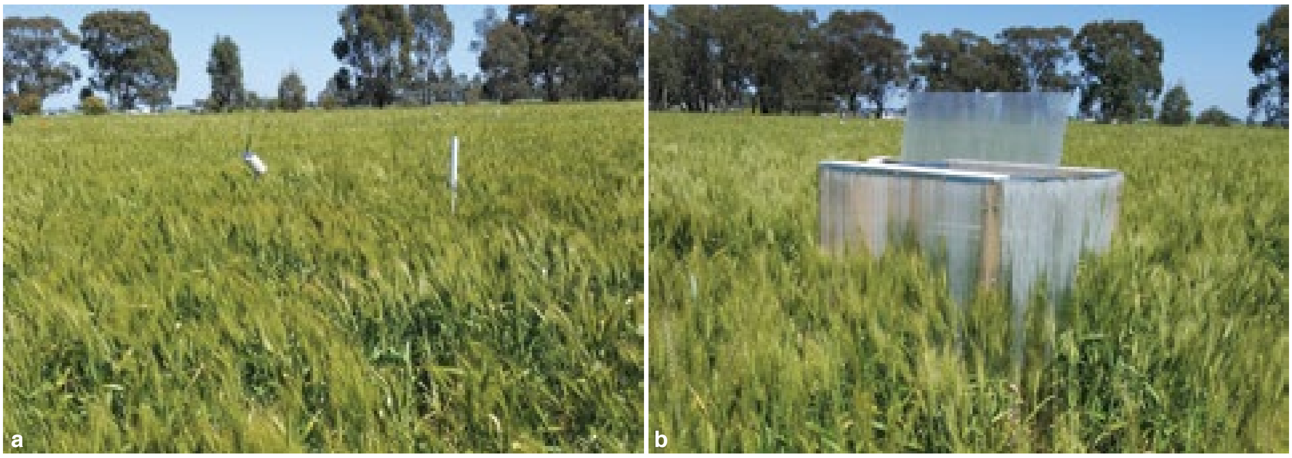


FIGURE 1 Instrumentation of the Riverine Plains Inc field site at Yarrawonga included (a) ArduCrop sensors, and (b) frost protection chambers

2016: Artificial frost trial, Horsham

A research trial was established at Horsham as part of the Regional Research Agronomists Program. The impact of simulated frost on wheat production was investigated by applying temperatures below 0°C to wheat using specially designed chambers and dry ice (Figure 2).

The experimental design consisted of cold treatments applied at heading (GS55) and flowering (GS65) (Table 1). At heading (GS55) three different cold scenarios were applied to wheat (*cv.* Yitpi) with chilling applied over one, two and three consecutive nights between 21 and 23 October, 2016. At flowering (GS65) six different cold scenarios were applied to wheat (*cv.* Yitpi). The first set of three frost treatments (1–3) was applied over a single night (31 October) with increasing intensity of chilling and a second set of treatments (4–6) were applied over

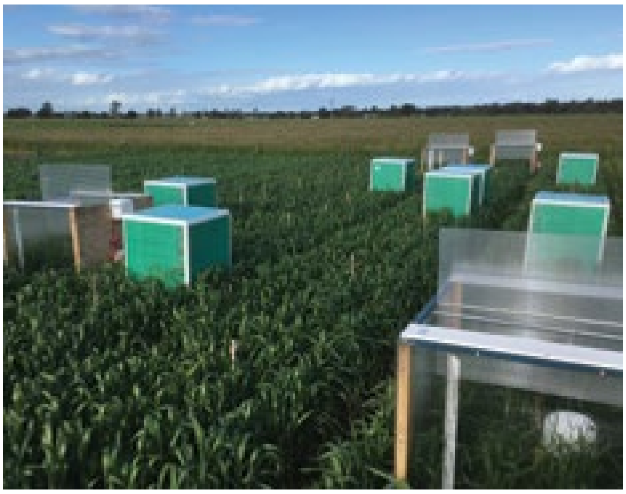


FIGURE 2 Simulated frost chambers in the field experiment, Horsham, Victoria, 2016

TABLE 1 Artificial frost treatments applied to wheat at heading (GS55) and flowering (GS65), their corresponding minimum temperatures and the frost exposure calculated by the total number of hours in which the canopy temperature was below 0°C multiplied by the temperature below 0°C (cold sum)

Frost treatment	Date	Duration (nights)	Minimum (°C)	Cold sum (°C.hr <0°C)
Heading (GS55)	**Control**		**-2.4**	**20.0**
	21/10 – 23/10	1	-8.0	45.0
		2	-8.1/-8.4	101.0
		3	-9.9/-8.3/-7.2	161.0
Flowering (GS65)	**Control**		**>0**	**0.0**
	31/10	1	-2.2	8.6
			-2.8	12.0
			-3.4	12.0
	01/11 – 02/11	2	-1.4/-1.0	5.0
			-2.5/-1.3	12.0
			-2.6/-1.6	13.0

two consecutive nights (1 and 2 November), also with increasing intensity. These treatments were compared with two sets of control plots, constituting wheat growing in ambient air.

The following measurements were collected:

- Canopy temperatures were monitored using thermocouples installed at canopy (head) height, and temperature was logged at five-minute intervals using external temperature and relative humidity probes.
- The level of frost exposure was determined by the total number of hours in which the canopy temperature was below 0°C multiplied by the temperature below 0°C, expressed as the 'cold sum' (°C.h). Biomass cuts were used to assess dry matter and grain yield differences across plots.
- Canopy reflectance was measured using a handheld spectroradiometer and a six-band multispectral camera following each frost treatment.
- Canopy reflectance was also acquired with a multispectral camera flown on a multi-rotor UAV on 28 October and 3 November 2016.
- Fluorometer measurements were made to determine the amount of light emitted from the chlorophyll in plants, and were made on several dates before the start of the frost treatments, and continuing through until the end of the season (harvest).

The reflectance spectra from the spectroradiometer and the multispectral camera were used to calculate a range of indices to see if differences between frosted and non-frosted plants could be detected. These indices (including NDVI) are calculated from the reflectance measured from the crop at a range of different wavelengths.

Results

Frost was not a widespread issue for Victorian growers during 2016. Warm temperatures throughout winter led to limited frosts and when combined with above-average rainfall resulted in strong winter growth. However, some low-lying areas of the Wimmera were still impacted by frost during spring.

2016: Yarrawonga

For the Yarrawonga site there were no recorded frost events at the trial site between crop flowering and maturity. The coolest canopy temperatures recorded by the Arducrop sensors was 0.5–2.5°C for several nights during October (Figure 3).

The lack of frost events meant no measurements of frost damage could be taken at this site. However, differences in canopy temperatures were detected between different stubble treatments on the paddock using the Arducrop sensors. Consistent with previous results reported by Riverine Plains Inc. as part of their GRDC *Stubble project*, the long stubble treatment was colder overnight than the other treatments. While there was only one Arducrop sensor per treatment, the average difference in temperature (calculated for overnight temperatures (10pm-6am) during September and October) was 0.5°C warmer in the burnt treatment than the long stubble and 0.7°C warmer in the short and cultivated treatments (±0.5°C standard deviation). However, differences of up to 2.5°C were recorded between the burnt and long stubble treatments on individual nights.

2016: Artificial frost trial, Horsham

The research trial established at Horsham used specially-designed chambers to replicate a radiant frost event in field plot trials. The frost chambers effectively reduced

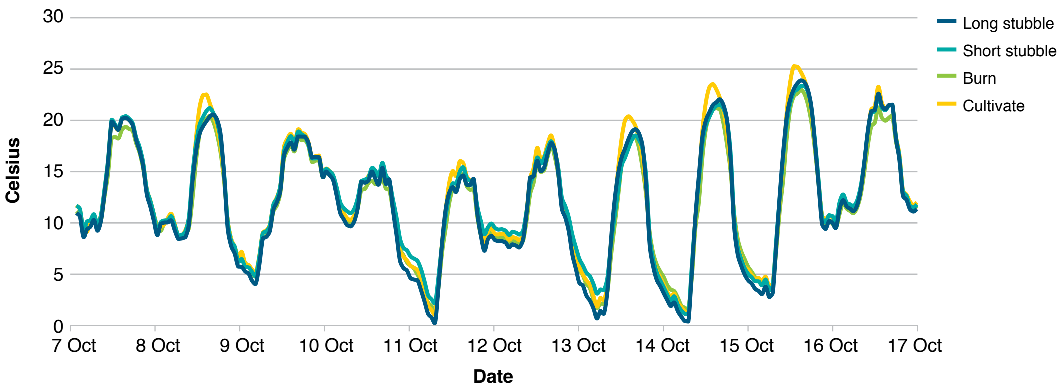


FIGURE 3 Canopy temperatures at the Yarrawonga field site measured using the Arducrop sensors for the period 7–16 October 2016. Results are shown for short stubble (aqua), long stubble (dark blue), burnt (green) and cultivated (yellow)

canopy temperature of wheat to below zero degrees and could produce different levels of cooling, as per Table 1 (treatment list). The heading (GS55) frost treatments had minimum temperatures from -6.6 – -9.6°C, with cumulative time and temperature below zero (cold sums) ranging from 0 (control plots) to 174 °C.hr (<0°C). The flowering (GS65) frost treatments produced a milder frost with average minimum temperatures ranging from -2.2 – -3.4°C, which corresponded to a range in cold sums of 8.6 – 11.8°C.hr (< 0°C).

Reflectance measurements made following the heading frost treatments showed obvious treatment differences the day after the frost (Figure 4), before there were any visible treatment differences. Four days after the heading frost treatment there were highly visible differences in the multispectral and thermal imaging obtained from the UAV (Figure 5), along with visible damage to the leaves of the crop. However, the heading frost treatments were quite severe, producing visible damage within days. The guidelines for detecting frost damage suggest a 5–7 day timeframe before damage is visible, with damage to the stem and head requiring some dissection of the plant before it can be identified.

To further test the potential for sensors to detect milder, non-visual frost damage the severity of the applied frost was reduced for the flowering frost treatment. The results from the flowering frost were used to test a number of parameters/indices (including NDVI) to see if there was a relationship between the magnitude of frost exposure (cold sum – Table 1) the crop was exposed to and the measured reflectance of the crop. Two of the indices appeared promising, showing a significant relationship between frost exposure and reflectance measured on the flag leaves. However, the indices computed from the UAV measurements (for the whole canopy) showed little response of the indices to the cold treatments. This suggests that while these indices have potential to detect frost damage further research is needed to test their application in the field, specifically in terms of the timing (number of days after frost) and scale (individual leaf versus canopy) of measurement to best identify frost damage.

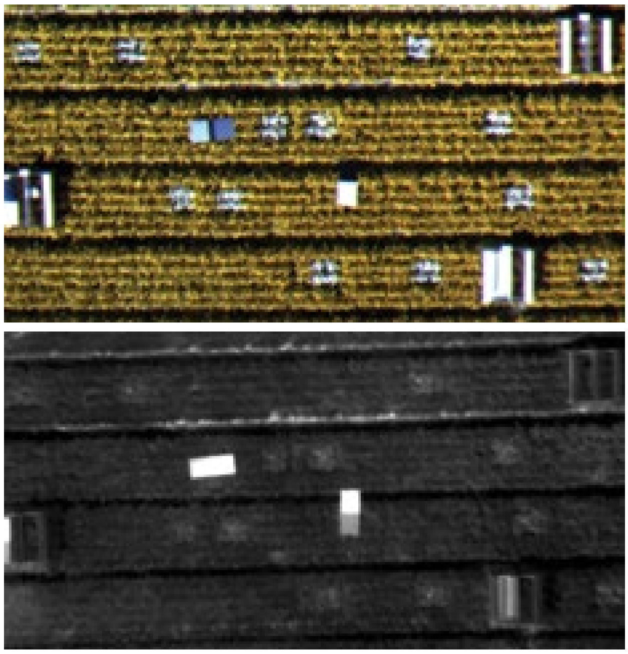
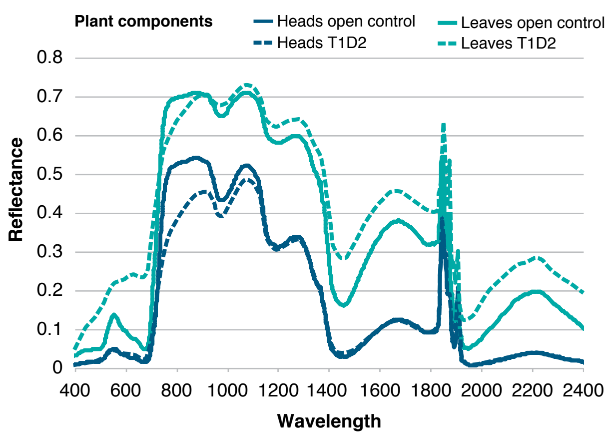


FIGURE 5 Multispectral imagery (top panel) and thermal imagery (bottom panel) both clearly show changes in the canopies reflectance of light (pale squares in the top photo) and temperature profile (white squares in the bottom photo) following artificial frost treatments imposed at Horsham Victoria. These measurements were taken on 28 October 2016, five days after the frost event. At this point the treated canopy was showing visible differences



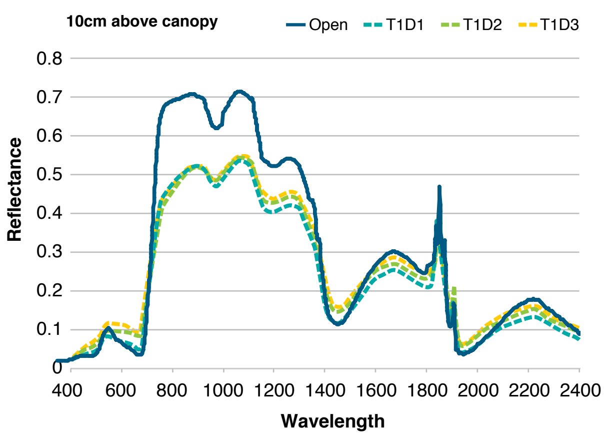


FIGURE 4 Reflectance measurements acquired on 24 October 2106, one day after the heading frost treatments. The reflectance spectra clearly show differences between the open control (non-frosted) plots and the plots with frost treatments. (T1 = heading frost (GS55); D1-D3 – 1–3 frost nights applied)

Further research will focus on correlating the sensor readings with the level of frost damage incurred by plants and the impact on final grain yield.

Conclusions

Improvements in the ability to measure frost damage in crops requires natural frost events to occur regularly. While 2016 was a successful year for growers, with no significant spring frosts across most of Victoria, this limited the research possible at the Yarrawonga site. However, through the use of chambers designed to simulate radiant frost events in the field we started testing the potential of a range of sensors to detect frost damage. If through further research we can identify sensors and appropriate methods for their use, this would allow for a more rapid, spatial assessment of frost damage across a paddock or property. This would then allow growers to make more timely management decisions on whether to continue growing the crop for grain, reduce costly inputs, or cut portions (or all) of a paddock for hay.

Acknowledgements

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