Frost response in wheat

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Abstract

Frost can significantly reduce grain yield of dryland cropping systems. Understanding the impact of frosts given their timing and severity and early identification are all important factors for effective management and limiting financial loss associated with frost effected areas. An important step in developing frost management tools and technologies is the development of field based methodologies for applying artificial frost treatments to both quantify response and test the utility of sensors at the crop canopy level. This paper reports on the testing of a methodology for imposing frost treatments to field wheat and the subsequent impact on crop yield. Purpose built frost chambers (600 mm W×600 mm D×1200 mm H) clad with Foilboard® and internal platforms containing multiple trays, 300 mm above the crop canopy, allowed for stepped additions of dry ice. Imposed frost treatments were applied over one and two progressive nights and varied in severity from -0.7 to -4.2°C which corresponded to a range in cold sums of 2 to 19°Chr (< 0°C). Wheat response was an 8.8% and 7.2% reduction in grain number and yield respectively, for every degree Celsius below zero (up to -4°C) for a single frost event. This respective reduction increased to 15.7 and 11.8% per degree Celsius below zero, (up to -3°C) when frost was imposed over two progressive nights. For cold load equivalent, which combines temperature and duration, there was a 2.2% reduction in grain number per Chr (below 0°C), which translated to a yield reduction of 1.9% per °Chr (below 0°C). Importantly, these results demonstrate that the current frost chamber methodology effectively created a backdrop of wheat, differentially effected by frost.

Keywords

Artificial frost, low temperature, remote sensing.

Introduction

For field crops grown in Mediterranean-type environments, frost has the potential to significantly reduce production (Zheng et al. 2015). For Australian dryland crops, economic losses due to frost damage for wheat have been estimated up to $100 million per year (Juttner 2014). Frost represent a risk management dilemma to the Australian Grain Industry, where growers face the challenge of bracketing the crop flowering window between extreme temperature impacts of frost and heat waves. Under climate change scenarios the impact of frost may also increase due to drier atmospheric conditions and clear nights resulting in an increase in night-time radiative-energy-loss combined with more rapid development of crops and earlier flowering under warmer day time temperatures (IPCC 2012). If proximal sensors could make rapid, spatial assessment of frost damage, this could limit losses through timely management decisions on whether to continue growing the crop for grain or cut portions (or all) of a field for hay. Frost damage at ear emergence and anthesis, generally occurs within a narrow temperature range, where beyond a threshold temperature a steep reduction in grain set occurs. For example, a one degree difference in temperature could result in frost damage escalating from 10 to 90% in wheat (Rebbeck and Knell 2007). The threshold ear temperature identified by Marcellos and Single (1984) was between -4 and -5°C for a range of cultivars. To test the utility of remote sensing for 'seeing' crop damage, crops affected by a range of frost scenarios need to be tested. Possible experimental options for such studies include utilising natural spatial variability in the field, although this can be unpredictable. Small pot trials and cold chambers can be utilised, although significant artefact effects may limit applicability for sensor response at the canopy level. For the current study, we tested purpose built mobile frost chambers that could be used to impose short term cold (frost) treatments to field wheat. This methodology provided a range of frost scenarios to be imposed and the immediate response of wheat to be measured using proximal sensors. This paper reports on the design and performance of the mobile frost chambers, as one potential methodology for undertaking frost studies within field crops. The response of wheat to a range of cold scenarios is also reported. The utility of proximal sensors for detecting early frost damage is reported elsewhere.

Methods

Mobile frost chambers were used to examine the impact of simulated frost on wheat yield. Temperatures below 0°C were applied to wheat at anthesis in a field experiment at Horsham, Australia during 2016. The experimental design consisted of six different frost scenarios that were applied to wheat (*cv*. Yitpi), where a first set of three (treatments #1 to #3) frost treatments were applied over a single night (31/10/16) with increasing intensity of chilling and a second set of treatments (treatments #4 to #6) were applied over two consecutive nights (01/11/16 & 02/11/16), also with increasing intensity. These were compared with two sets of control plots, constituting wheat growing in both ambient air and within frost protection chambers. All treatments were replicated four times in a randomised complete block design. Frost chambers consisted of right-angle hollow section (RHS) frame boxes (600mmW×600mmD×1200mmH) that were clad with Foilboard® (Figure 1).

Figure 1. Frost chambers a) Performance testing using visual IR thermometer, Fluke VT02 (temperature at 32.7 °F (0°C)) and b) Simulated frost being applied to wheat to determine impact on yield and ultimately the link between frost induced sterility and proximal sensor response.

Internal platforms within the frost chambers were suspended 300 mm above the crop canopy and supported multiple trays which allowed for stepped additions of dry ice. Mesh diffusers were also installed between the trays and the crop canopy. The chilling process commenced at 2000H with dry ice addition to a single tray, with a follow up addition to the second tray at 2115H. Treatments were applied at night time, although chilling was imposed earlier than compared with natural frosts, due to experimental constraints. Differential chilling was achieved by varying the 'top-up' regime of dry ice at 2300H. For monitoring temperature, thermocouples were installed at canopy (head) height and temperature was logged at five minute intervals using TGP-4505 (external temperature and relative humidity probes). Leaf and ear temperature of crop were not recorded in this experiment. Cold load was used to describe the varying severity of frost treatments which integrated duration and temperature crops were exposed to. Cold load was calculated as a sum of °C below 0°C and expressed as °Chr (< 0°C) that the plants were exposed to. A regression approach using data at the plot level was applied, as the co-efficient of variation within treatment means was large and likely to mask crop response to frost treatment.

Results and Discussion

Frost chamber performance

The frost chambers effectively reduced canopy temperature of wheat to below zero degrees, Figure 2. The simulated frosts were characterised by a rate of cooling ca 2°C per hour with a duration below zero degrees of around eight hours applied during the night. For frost treatment 1 to 3 which occurred over a single night, average minimum temperatures ranged from -2.2 to -3.4°C which corresponded to a range in cold sum of 8.6 to 11.8 °Chr (< 0°C) (Table 1). For the treatments (4 to 6) applied over two consecutive nights average minimum treatment temperatures ranged from -1.4 to -2.6°C the first night and from -1.0 to -1.6°C the second night. The corresponding range in cold sum, totals over the two nights was 5.0 to 12.9 °Chr (< 0°C).

Wheat yield

For wheat grown under open ambient temperature, in the absence of naturally occurring frost (or heat wave) events during the growing season, grain set and yield was 15890 grains per m^2 and 6822 kg/ha respectively (Table 2). Frost treatments applied over a single night with a minimum temperature of – 2.2°C and cold sum of 8.6 °Chr < 0°C (treatment 1) did not reduce grain number or yield. In contrast all other frost treatments induced a significant average reduction in grain set of 28%. For these treatments, there was some compensatory increase in kernel size, however, this was not sufficient to maintain yield under frost conditions. There was an average decrease in yield of 20% for frost treatments 2 to 6.

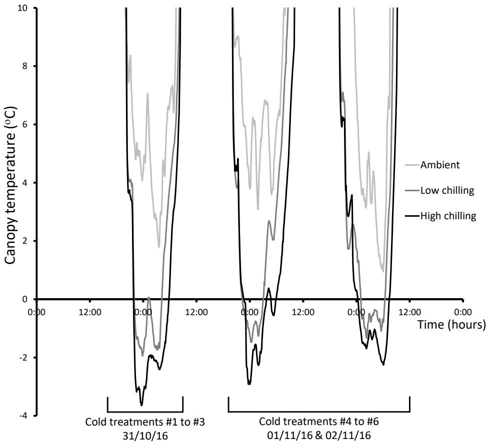

Figure 2. Range in crop canopy temperature (per plot basis) for frost treatments applied to field wheat (cv. Yitpi) at anthesis, compared with ambient air temperature. Frost treatments #1 to #3 were applied over a single night (31/10/16) at varying chilling intensities and frost treatments #4 to #6 were applied over two consecutive nights (01/11/16 & 02/11/16), also with varying chilling intensities.

Table 1. Frost treatments applied to wheat and their corresponding minimum temperatures and cold sums. Standard error of mean for four replicates are in parentheses.

Frost treatment	Duration	Minimum (°C)	Cold sum (°Chr < 0°C)
Ambient (control)			0
1	1 night	-2.2	8.6 (4.4)
2	1 night	-2.8	11.5 (4.5)
3	1 night	-3.4	11.8 (4.1)
4	2 nights	-1.4/-1.0	5.0 (3.2)
5	2 nights	-2.5/-1.3	12.2 (2.7)
6	2 nights	-2.6/-1.6	12.9 (4.1)

Table 2. The yield response of wheat (*cv.* Yitpi) to frost treatments.

Frost treatment	Grain no. (grains/m^2)	Kernel size (mg/kernel)	Yield (kg/ha)	HI
Ambient (control)	15890	43.0	6822	0.39
1	14804	45.8	6783	0.38
2	11263	47.1	5284	0.33
3	11712	46.7	5454	0.33
4	11930	48.3	5763	0.37
5	11577	48.3	5578	0.32
6	10236	48.8	5081	0.31
lsd (P<0.05)	3027	2.0	1149	0.05

Cold load and crop response

When wheat yield was compared with minimum temperature associated with the frost treatments (per plot basis) applied over a single night, there was an 8.8% and 7.2% reduction in grain number and yield respectively, for every degree Celsius below zero up to -4°C (Figure 3 *a*). For those frost treatments applied over two nights, where the minimum temperature was averaged, the reduction in grain number and yield increased to 15.7 and 11.8% per degree Celsius below zero, up to -3°C, respectively, which indicates a cumulative effect of the multiple frost nights exists. This points to an approximate linear additive effect of multiple frosts supporting the view that thermal duration below a threshold (zero here) will be a useful model describing the expected damage to grain set in wheat. Marcellos and Single (1984) measured critical ear temperature between -4 and -5°C, whereas we observed progressive reduction in grain set for minimum canopy temperatures ranging up to -4°C. Evidently thermocouple position is important in interpreting crop damage due to low temperatures and has implications for estimating response of crops to frost across the plant, canopy and paddock scales. To account for exposure time and temperature, cold load was compared with yield. The response of wheat was a 2.2% reduction in grain number per Chr (below 0°C), which translated to a yield reduction of 1.9% per Chr (below 0°C) (Figure 3 *b*).

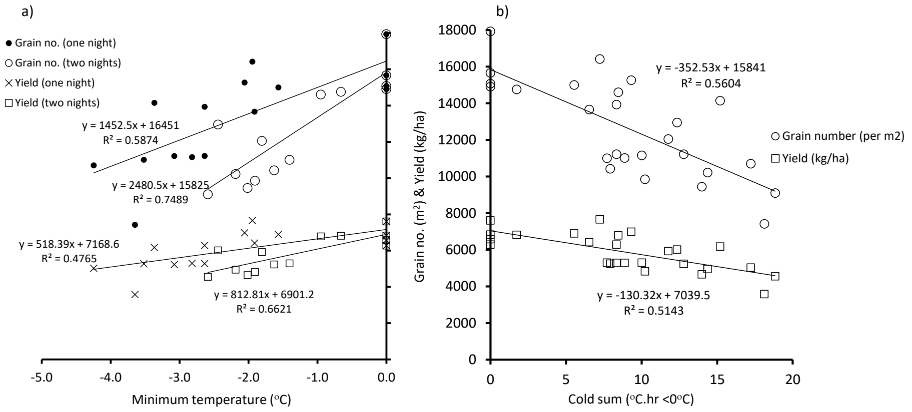

Figure 3. Relationship between wheat yield components and a) minimum temperature and b) cold sum (°Chr < 0°C) for frost treatments.

Conclusions

The current study provides response data of wheat to artificial frost treatments applied in the field. The chamber design and approach appears to be an effective means of applying frosts of varying intensities to crop and could provide a methodology for other such frost studies in field crops. Overall, the current work provides the basis for testing the utility of proximal sensors including hyperspectral reflectance and active light fluorescence to determine the utility of remote sensing for pre-visual crop damage due to frost and assessing options for optimising management of frost affected crops.

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