Characterising the risk of heat stress on wheat in South Australia: meteorology, climatology and the design of a field heating chamber

Bronya Alexander[1], Peter Hayman[1], Glenn McDonald[2], ASM Hasim Talukder[2] and Gurjeet Gill[2]

[1] SARDI Climate Applications, GPO Box 397, Adelaide SA 5001 www.sardi.gov.au Email Bronya.Alexander@sa.gov.au
[2]School of Agriculture, Food and Wine, University of Adelaide, Waite Campus PMB 1 Glen Osmond SA Email

Abstract

High temperatures during spring have long been recognised as one of the weather risks for grain farmers. Recent events such as 12 October 2004 and 15 November 2009 raise questions about the likelihood of this risk and the consequences on grain crops. This paper reports on work first characterising the *likelihood* of heat events by considering meteorology (synoptic weather patterns) and climatology (analysis of climate records) and second studying the *consequences* by reproducing these heat events in the field using a purpose built chamber. Spring heat events in the SA grains belt are due to a northerly flow of air associated with a passing high pressure system to the east of the region and an approaching cold front to the west. Analysing the climatology of heat events in the context of crop phenology typical of a region, it is apparent that a medium rainfall region like Roseworthy (flowering later in October) may be at a greater risk of heat events than a much warmer, low rainfall location like Minnipa (flowering in September). Preliminary results indicate that a relatively inexpensive chamber can be used to impose a single day heat event in the field (maximum temperature of 35?C). The chamber was able to heat by up to 12?C above ambient.

Key Words

High temperatures, spring heat events, Australian grains belt, phenology, humidity, thermal regulation

Introduction

October 12th 2004 was an unusually hot day in SA and Adelaide's maximum temperature peaked at 37.4?C (average maximum for October is 21?C). Some agronomists estimated the yield loss as high as 50%. In 2009 there were a number of severe heat events in early and mid November. These events have raised questions about the changing likelihood of spring events and the impact that these events have on the crop. Risk can be defined as the product of likelihood and consequence. Currently we can offer grain farmers better guidance on both the likelihood and consequence of moisture stress and frost on grain crops than we can for heat events. This paper describes work on likelihood of heat events and the characteristics of a chamber to impose these events in the field. Early results from the field chamber are reported in Talukder et al. (2010).

During the southern hemisphere spring, cereal crops in the southern grains belt will pass through growth stages that are sensitive to high temperatures. A heat event for the south-eastern grains belt in spring coincides with a high pressure system to the east of Australia and an approaching cold front from the west. This combination leads to a northerly flow of air (and associated hot conditions) followed by a south westerly (associated cool conditions). There are broad similarities with synoptic patterns of summer heat events (Grace et al. 2009) but unlike wine grapes where sensitive phenostages occur in summer and experience heat waves (eg 5 days over 35?C), in spring wheat is subject to short events, often followed by cold conditions or even a frost.

It is well documented that the consequence of heat stress in cereal crops can be reduced yields due to heat events at a number of growth stages, particularly around anthesis (Barnabas et al. 2008). There is considerable interest nationally and internationally in testing some of the findings from growth chambers in representative field conditions. This paper looks at an experimental design of a chamber that enables heating of crops growing in the field. The chamber had to be portable and control the air temperature around the wheat heads to a range of set temperatures stepping up to 35?C. The aim was to minimise secondary effects on the light and to monitor changes in humidity following suggestions by Hall and Sadras (2009).

Heat events (unlike frost and many rain events) tend to be widespread due to the large synoptic systems driving them. Figure 1 shows that Minnipa, a low rainfall crop production region (average April-Oct rainfall of 245mm) located at the upper edge of the grains belt on the Eyre Peninsula in South Australia, experiences warmer temperatures than Roseworthy (average April-Oct rainfall 324mm) about 50km north of Adelaide.

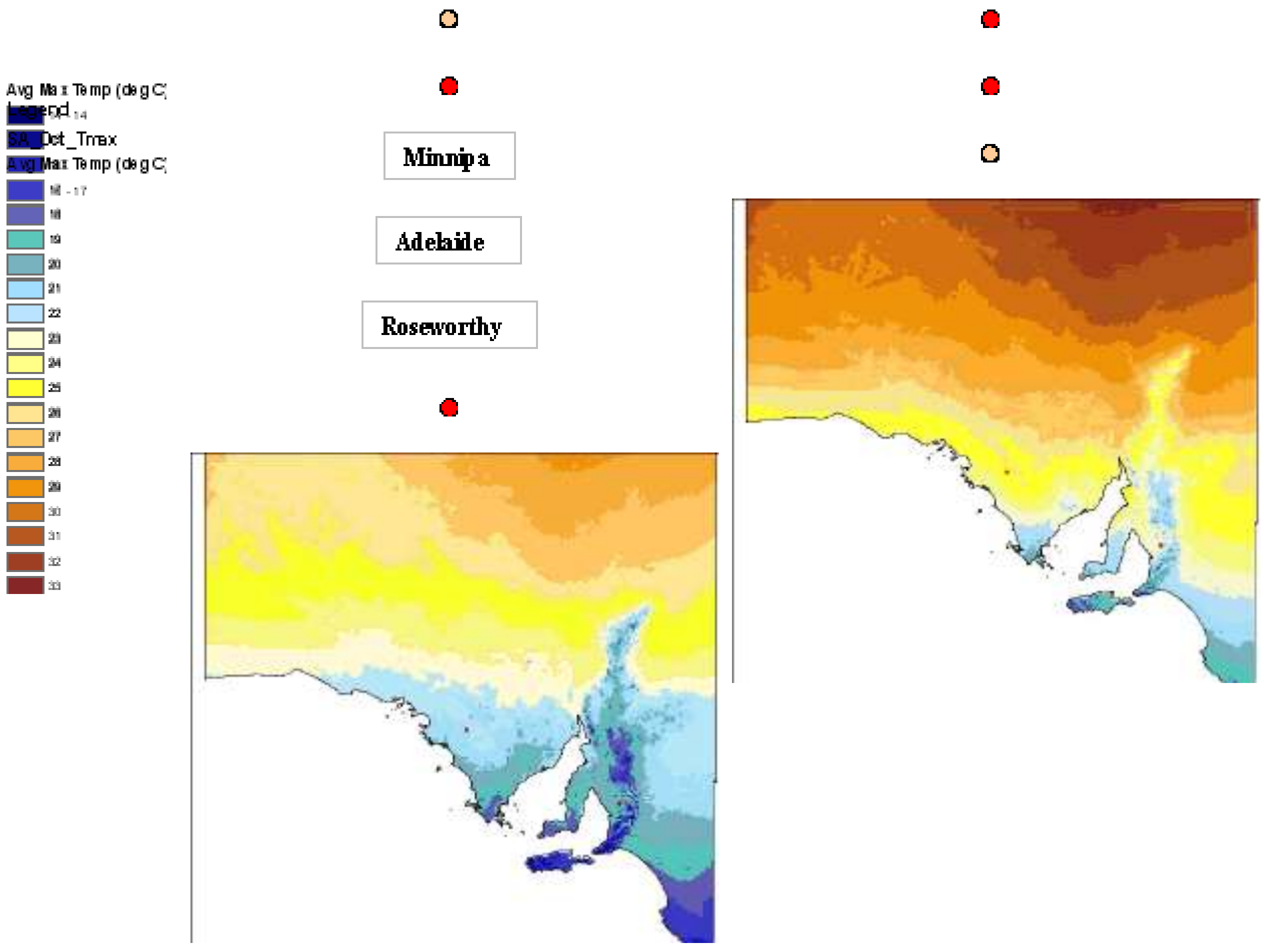

Figure 1: Average maximum temperature (degrees Celsius) across South Australia for September (left) and October (right), 1957-2009. Data source is from SILO (Queensland Climate Change Centre of Excellence). Data analysis by SARDI Climate Applications.

Methods

The four main components required to impose the heat treatment on field crops were: the chamber, heater, thermostat control and monitoring equipment. The chamber, with dimensions of 1.5 x 0.5 x 1.2m (L x W x H), was constructed with materials available from general hardware stores at a cost of $200-$300 per box. Standard-Clear-Greca polycarbonate sheeting was used as it blocks most UV radiation (200 to 400nm) and has a very high (90%) and uniform transmittance between 400 and 1600nm (Soar and Sadras 2009). An adjustable lid was also constructed which allowed some air flow in/out due to the corrugation of the polycarbonate. The heating was provided by a standard 1200W fan heater available for around $20, with the power in the field being supplied by a generator. We used a commercially available control thermostat (Carel) that allows temperature control to 0.1^{0}C. The thermostat, attached to a power board (total $560) controlled the heater. Temperature and humidity inside the box was monitored at 5min intervals using a TinyTag Ultra2 temperature and humidity logger ($470) placed inside a small Stevenson type screen ($70).

Field trials were at the Waite Campus, Urrbrae (6km south of Adelaide), South Australia, and involved four wheat genotypes (Excalibur, Krichauff, Gladius and Janz) heated for a single day at two growth stages – pre-anthesis (green anther stage, Zadok growth stage ZGS 57-59), and a few days post anthesis (7-10 days after anthesis, ZGS 73-75). Four heat chambers were used to cover four replicates of the same genotype on the heat treatment day. Each chamber enclosed two rows of wheat for a length of 1.5m. The TinyTag inside the Stevenson screen was hung in the middle of the chamber just below canopy height. The temperature probe for the thermostat was inserted into the Stevenson screen next to the TinyTag, and the thermostat control was set to turn the heater on when the chamber temperature cooled down by 0.5?C under the required threshold. The thermostat control was used from 10am to slowly increase the temperature to a maximum of 35?C at midday, and maintained for 3 hours before being allowed to decrease steadily back to ambient temperature by 5pm. Chambers were removed at 5pm. On days that treatments were imposed, a TinyTag was hung a few metres from the edge of the plots at 1.5m height (standard measurement height used by the Bureau of Meteorology) and another placed amongst the crop canopy on a control plot about 5m from the boxes.

Prior to the field trials a number of experiments were undertaken with the chambers to look at the uniformity of temperatures at different positions inside the box. The results (not shown) indicated that the envelope of air at crop head height was reasonably uniform. There was a high degree of circulation in the chamber as, even when the lid was fully closed, the corrugations in the lid allowed air to flow freely out of the box. On the low setting (1200 W) there is a relatively high ratio of air flow to heat.

Results

Climatology

There has been an increase in the average number of hot days (>35?C) for Australia since digitised temperature records from 1957 (http://www.bom.gov.au/cgi-bin/climate/change/extremes/timeseries.cgi). Minnipa and Roseworthy are consistent with this trend (Figure 2) having set new records in the number of days over 30, 35 and 37?C. Minnipa has more hot spring days than Roseworthy. Table 1 shows that between 15-Sept and 24-Nov there is an equal or higher chance of getting a hot day at Minnipa than Roseworthy. However, when assessing the risk of heat stress on crops, phenology must be considered. Wheat crops in Minnipa would commonly be flowering mid-September, whereas most crops at Roseworthy flower mid-October. The earlier flowering at Minnipa is due to warmer growing conditions and also variety choice to match spring moisture availability and avoid frosts at Roseworthy. The chance of getting over 30?C at Minnipa around 15-Sept is only 0.2% compared to 1.2% at Roseworthy on 15-Oct, suggesting Roseworthy crops are at higher risk of heat stress at flowering than Minnipa. Late sown crops in a mild year could still be flowering into November at Roseworthy, but hot November temperatures in Minnipa are aiding the harvest. Table 1 also shows the increase in heat stress risk for every 10 days later that flowering occurs.

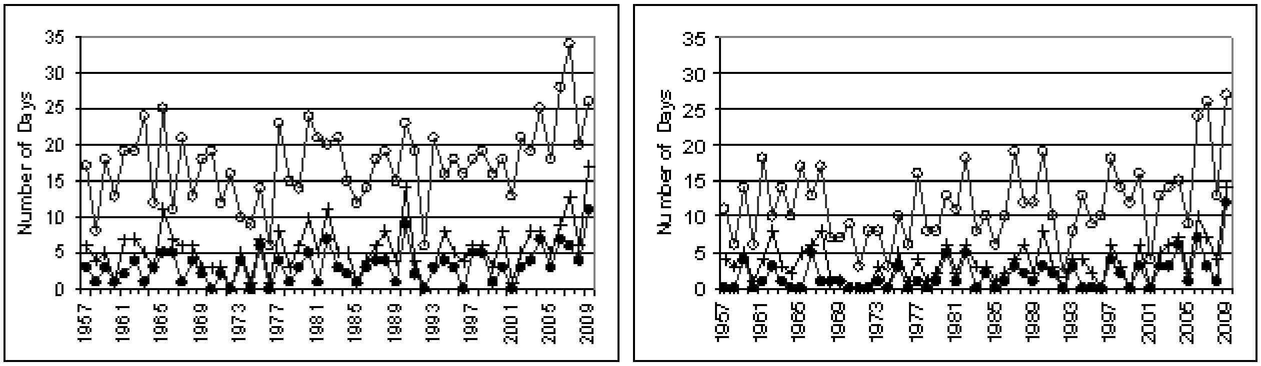

Figure 2: Number of days during September to November each year with a maximum temperature at or above 30^{0}C (open circles), 35?C (plus signs) and 37?C (closed circles) from 1957-2009 at Minnipa (left) and Roseworthy (right), South Australia. Data from SILO (http://www.nrw.qld.gov.au/silo/).

Table 1: The chance (%) of getting a maximum temperature of 30, 35 or 37?C at least once during a 10 day window centred on the given date between September 15 and November 24. Probabilities are for Minnipa (left side of column; M) and Roseworthy (R), South Australia, 1957-2009.

Temp	15-Sep	25-Sep	5-Oct	15-Oct	25-Oct	4-Nov	14-Nov	24-Nov
(^{0}C)	M R	M R	M R	M R	M R	M R	M R	M R
30	3.6 0.7	7.6 2.7	12 5.2	16 8.7	24 15	28 18	35 27	41 33
35	0.2 0.0	1.1 0.0	1.9 0.4	3.5 1.2	5.7 2.9	8.4 5.0	13 9.6	18 14
37	0.0 0.0	0.0 0.0	0.7 0.2	1.7 0.5	2.8 0.7	4.6 2.2	7.5 4.5	11 8.0

Heat chamber

Results are presented here for the heat treatments imposed on the four wheat genotypes at 7-10 days post anthesis, October 2009 (Image 1). While there was variation between boxes, the TinyTag loggers showed internal temperatures were within about 3?C of the desired 35?C for the 3hr period from midday (Figure 3). On the warmest days such as Oct 20th where ambient temperature reached over 30?C, the challenge was to keep internal temperatures from being too high. On these days the heater didn't run for long and the passive heating alone caused internal temperatures to be maintained around the required 35?C. On cooler days, such as Oct 21st (ambient temperature < 24?C), the heater ran constantly to reach the required temperatures.

Image 1: Chamber set up in the field (left) over two rows of wheat, showing a heater at the bottom and TinyTag in a Stevenson screen hanging at canopy height within the chamber. Four chambers running at once (right).

For three of the days - October 19th, 20th and 22nd - the internal relative humidity was similar to the ambient humidity which was quite low (Figure 3). On the 21st, a cooler day, the heaters ran more often leading to lower internal relative humidity. However the synoptic patterns that lead to spring heat days are associated with hot dry winds and we were pleased to see the humidity maintained at low values in the chambers (due to significant airflow from the heaters) rather than be substantially increased due to transpiration.

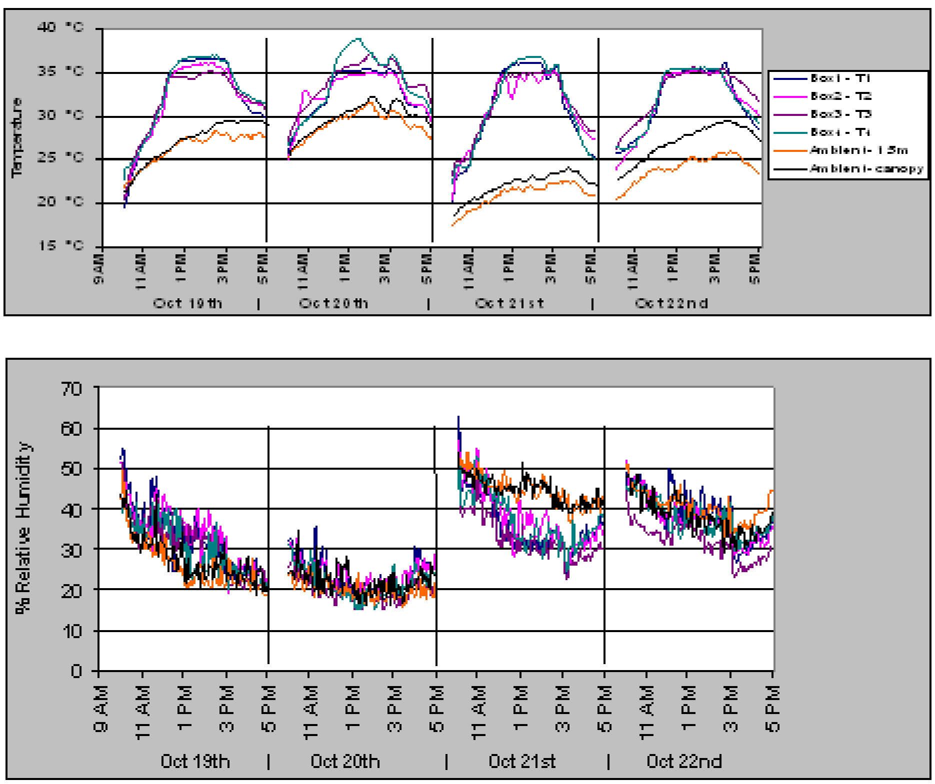

Figure 3: Temperature (top) and relative humidity (bottom) at crop canopy height in four chambers (Box 1-4) exposed to high temperatures during post anthesis stage, Oct 2009. Ambient air temperature was taken at the edge of the plots at 1.5m height, and at canopy height in non-treated crops. Measurements were recorded using a TinyTag shielded in a Stevenson screen. All

chambers were placed over the same wheat genotype on a single day, with Krichauff, Gladius, Excalibur and Janz exposed to the heat treatments on Oct 19th-22nd respectively.

Conclusion

We have briefly described the synoptic systems leading to heat events. The likelihood of these events is increasing, but there is a strong seasonality whereby the likelihood of events increases from September to November. The likelihood of heat events needs to be carefully considered because one of the outcomes of warmer conditions is to shift flowering earlier in spring. Using relatively inexpensive chambers in the field we were able to impose heat events to 35^{0}C with a minimum of secondary effects.

Acknowledgements

Thanks to the funding body, Managing Climate Variability (project MCV-2 SRD005103, “Assessing and managing heat stress in cereals”), and Uday Nidumolu (SARDI Climate) for producing the maps in Figure 1.

References

Barnabas B, Jager K and Feher A (2008). The effect of drought and heat stress on reproductive processes in cereals. Plant Cell and Environment 31, 11-38.

Grace WG, Sadras VO and Hayman PT (2009). Modelling heatwaves in viticultural regions of southeastern Australia. Australian Meteorological and Oceanographic Journal 58, 249-262.

Soar CJ and Sadras VO (2009). Development of methods for heating canopies and bunches under realistic vineyard conditions. In Managing grapevines in variable climates: the impact of temperature. Eds VO Sadras, CJ Soar, PH Hayman, MG McCarthy. Report to the Australian Grape and Wine Research and Development Corporation. SARDI Publication Number: F2009/000372-1.

Talukder ASM, Gill G, McDonald G, Hayman P and Alexander B (2010). Field evaluation of sensitivity of wheat to high temperature stress near flowering and early grain set. Proceedings of the 15th ASA Conference, 15-19 November 2010, Lincoln, New Zealand.