Managing heat stress in wheat

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Why was the trial/project done?

Heat stress at sensitive growth stages such as flowering and grain filling has been shown to adversely affect grain yield and is common across much of the Australian wheat belt, particularly southern Australia. Gaining an understanding of the effects of heat stress on wheat, the economic impacts and understanding varietal responses to heat are the primary objectives of this SAGIT funded project. Here, we present a study investigating the effect of heat stress on wheat production in 2013.

How was the trial/project done?

Field trials were conducted at six locations across South Australia in 2013, using a set of 24 varieties that display contrasting performance to heat stress under controlled environment conditions. Weather data for each location was collected using in-trial temperature loggers and the nearest bureau of meteorology station. This allowed for a preliminary regression analysis between site mean yield and various climatic factors suspected to have impacts on grain yield.

Controlled environment experiments were conducted at Roseworthy using the AGT-SAGIT heat chamber that included the same 24 varieties from the field experiments. Heat stressing occurred at a range of growth stages from booting (GS45) through to 10 days after anthesis (GS72), to determine the effects on a number of traits including, leaf damage, grain number and size at each of the growth stages.

Key Messages

- Heat stress is a key yield limiting factor in crop production.
- Heat stress has been shown to adversely affect yield as early as growth stage 45.
- Post flowering heat stress is most common in South Australia.
- Delayed sowing increases the chance of the crop being exposed to heat stress, particularly at the vulnerable pre-flowering growth stages.

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Background

Wheat crops in most productions zones of Australia, and more specifically southern Australia, frequently experience temperatures which inhibit optimal plant growth. Heat stress during flowering and grain filling has been shown to adversely affect grain yield, through both of its constituents, grain number and grain weight. Work is being undertaken to determine the effect of heat stress on wheat and its economic impacts, and to investigate different variety responses to heat stress. We aim to develop a detailed understanding of the genetic basis of heat stress tolerance to help develop varieties that are better able to handle the harsh growing conditions encountered by wheat in South Australia.

This study aims to build on work previously conducted by AGT (funded by SAGIT) at Roseworthy, where varietal differences have been identified in controlled environment conditions. Although work is still being conducted to dissect and understand plant responses under these controlled conditions, preliminary field testing across southern Australia has started to validate these findings. Here, we present a study investigating the effect of heat on wheat production in 2013.

About the trial

Field experiments were conducted at six locations across South Australia for this project in 2013 and the grain yield, screenings and HLW were recorded for each plot. The locations were Angas Valley, Booleroo, Minnipa, Pinnaroo, Roseworthy and Winulta, with sowing dates for each site shown in Table 1. Climatic data was collected using in-trial temperature loggers, and rainfall from the nearest bureau of meteorology station. A set of 24 varieties, which consisted of locally grown varieties, a group of varieties that display contrasting performance to heat stress under controlled environment conditions, as well as a selection of exotic introductions that are of potential interest for heat stress tolerance.

Additional experiments, using the same set of varieties, were conducted in the AGT-SAGIT heat chamber at Roseworthy, which generates a growing environment with temperatures of 36°C and 40 km/hr winds, while allowing us to remove confounding effects such as drought and maturity. Plants were placed in the chamber for three consecutive eight hour days, 10 days after the main tiller had finished flowering (GS72). Additional stresses were also tested at; booting (GS45), three quarters head emergence (GS57), start of flowering (GS62) and the end of flowering (GS69). Measurements were then taken to assess leaf damage, grain number, grain weight, and harvest index.

Results

The 2013 season started solidly, with sufficient rain through the growing season for most of South Australia. Unfortunately, by spring the situation changed quickly, with stresses typical of our environment, such as frost, heat and drought coming to the fore. Although the dataset presented in this study is quite small, and is only from one year, it clearly demonstrates the negative impact of heat stress on production in 2013. Preliminary analysis of the average site grain yield for each of the six location is shown in Table 1, along with growing season rainfall, the average maximum daily temperature experienced for the duration of both flowering and grain filling, and the number of days over 30°C experienced during both flowering and grain filling. Although these variables are used to explain the variation seen in the grain yield at each of the sites, they are not necessarily completely independent, so can only be used as an indicator of interaction with grain yield potential. Changes in average daily maximum temperature during flowering and grain filling had a negative effect on grain yield of 518 kg/ha and 1140 kg/ha (Figure 1), respectively for every 1 degree increase in average maximum temperature. During grain filling in particular this accounted for a large component of the variation within the dataset (98%). Interestingly this is larger than the variation accounted for by growing season rainfall (84%).

Table 1. Summary of preliminary analysis of 2013 field trials across six locations in South Australia. Included is the average site grain yield, sowing date, the average maximum daily temperatures during flowering and grain filling, as well as the number of days with a maximum temperature over 30°C. For each climatic parameter, the significance of its correlation with site average yield is shown, along with the effect on grain yield for every one unit change in the parameter.

Site	Grain yield (kg/ha)	Sowing date	Growing season rainfall	Average maximum temperature °C during flowering	Number of days > 30°C during flowering	Average maximum temperature °C during grain fill	Number of days > 30°C during grain fill
Angas Valley	1789	23-May	263	26.0	6	27.7	8
Booleroo	3119	17-May	291	24.7	2	26.3	7
Minnipa	2295	15-May	225	23.2	5	27.3	10
Pinnaroo	2318	28-May	204	24.1	3	27.4	10
Roseworthy	3489	17-May	286	21.9	2	26.3	9
Winulta	5222	10-May	444	20.2	1	24.8	5
Significance (P Value)			0.01	0.022	0.022	<0.001	0.049
% variation accounted for			84	77	77	98	66
Effect (kg/ha)			14	-518	-570	-1140	-603

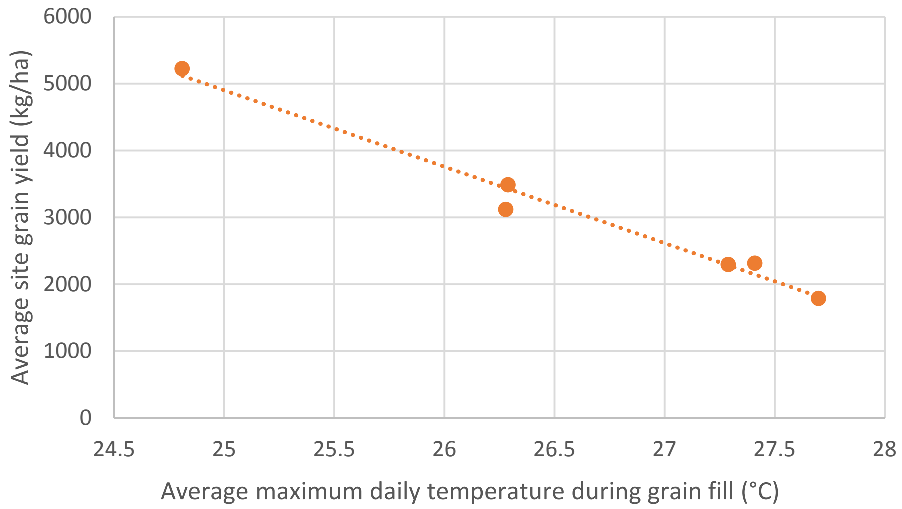

Figure 1. Average site grain yield plotted against the average maximum daily temperature (°C) during grain fill.

This data set demonstrates the significant negative impact that heat stress can have in South Australia. The 2013 growing season generally setup a high yield potential, with limited stress conditions experienced until late in the season, when rainfall cut off. This left crops exposed to terminal drought stress and heat stress. Probably exacerbating the impact of heat stress, the 2013 season provided little opportunity for plants to acclimatise themselves (a factor which has been shown to be important for stress tolerance). The 2013 dataset also provided a good yield potential contrast, the average grain yield at Winulta was 5221 kg/ha, contrasting with Angas Valley which had an average grain yield of 1788 kg/ha. Associated with this was a good contrast in heat stress experienced, with Winulta being the coolest site (Table 1 and Figure 1).

The varieties included in the field experiments were also evaluated in controlled environment experiments that investigated the effect of heat stress at different growth stages. The role of abiotic stresses such as excessive heat, at early growth stages has been proposed to be important in determining final grain yield. This study stressed wheat at five growth stages, ranging from booting through flowering to early grain fill. The impact of heat stress, conducted at each of these growth stages, on fertility, and the change in leaf damage, 3 and 10 days after stressing are shown in Figure 2. These results confirm that heat stress during early growth stages have large negative effects on the plant that result in corresponding yield penalties. Growth stage 45 or booting showed the greatest decline in fertility compared to the control. Stress at this time corresponds to the formation of the pollen within the plant which is very sensitive to stress, with the size of the effects decreasing as stress occurs later in the plant's development. Flowering is also known to be sensitive to abiotic stress, with the pollen aborting or having reduced viability when subjected to stress. However, the opposite was observed for leaf damage, with less leaf damage observed at the earlier growth stages, while the rate of leaf senescence was increased if heat stress occurred post flowering and during early grain fill.

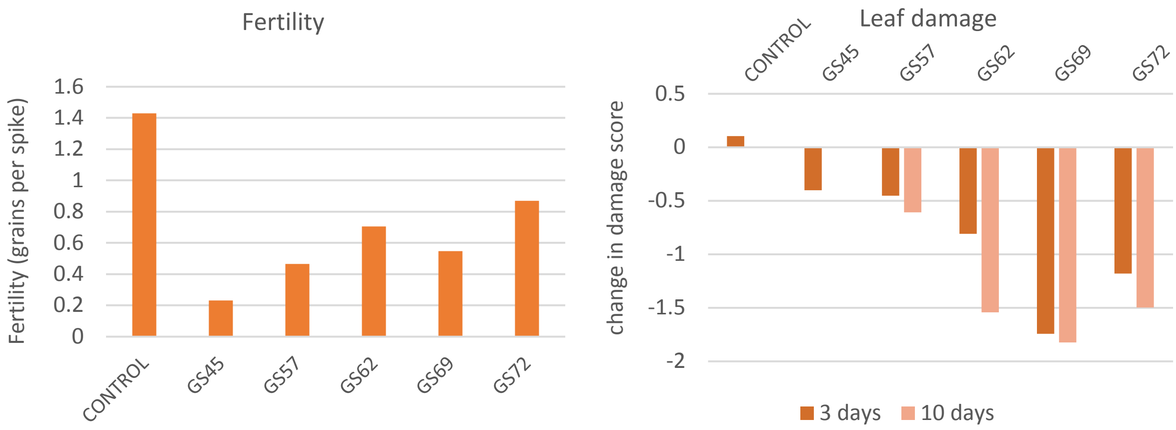

Figure 2. Treatment mean responses for fertility (grains set per spike), and change in visual score 3 and 10 days after stressing (visual leaf score, based on the proportion of leaf area remaining viable).

Although the controlled environment experiment showed that there is greater potential for damage to occur to the plant's reproductive structures in earlier growth stages (Figure 2), from as early as GS45 through to grain filling, it should be noted that heat stress generally occurs during grain filling in South Australia. Due to the increased chance of heat stress occurring during grain filling, the effects on grain yield are generally of greater economic importance, as demonstrated by the 2013 field trials. The implication of this is to ensure appropriate sowing times are chosen for crops to minimise the risk of exposure. Although not presented here, analysis of other datasets from late sown trials, has shown the considerable increase in exposure to heat stress with later sowing times.

Implications for commercial practice

Heat stress had a significant impact on wheat production in South Australia in 2013. This study confirmed that variety selection and early sowing are still the most effective means to reduce the risk of a crop being damaged by excessive heat. A later sown crop will have an increased likelihood of being exposed to the heat stress at more sensitive growth stages, particularly pre-flowering, and will have greater consequences to the potential grain yield. Some of the effects on grain yield published in this study are higher than those previously seen, possibly due to the harsh conditions seen at times during the latter part of the growing season. Additional data will be required to improve this response calibration.

Further research is being carried out to dissect and understand the genetic basis to variation in heat stress tolerance exhibited by different varieties.