Can N mitigate adverse effects of elevated temperature in wheat?

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Abstract
Delaying sowing reduced yield potential at 0.67 t/ha per °C of mean temperature during critical period for yield determination (20 days pre-10 days post anthesis). Good N nutrition and longer-season spring cultivars reduced the yield gaps in relation to temperature. Responses to N become more erratic when temperatures during the critical period increase above ~14.5 °C. Strategic N management (50-100 kg N/ha) may help to mitigate the effect of higher temperatures on grain number and yield.

Key Words
Heat stress, G x E x M, risk, sowing time

Introduction
The combined effect of chronic, non-stressful high temperature and heat shock produces yield penalties between 10-15 % in Australia (Wardlaw et al., 1989). Nitrogen management remains one of the most important and risky decisions for farmers (Monjardino et al., 2015), and appropriate combination of cultivar and sowing time to match the optimal flowering period is important to reduce yield gaps (Flohr et al., 2017; Flohr et al., 2018). However, while early sowing may improve the yield of some late maturing cultivars, it could also increase the risk of frost for early maturing cultivars sown too early. To tailor nitrogen input to sowing time and cultivar, we need understanding the interaction between N, temperature and crop phenology. Here we report two experiments designed to investigate the 3-way interaction between N, cultivar and sowing date.

Materials and Methods
Experiment 1. We factorially combined, 6 cultivars of different maturity (Table 1) (Axe, Cobra, Mace, Scout, Spitfire and Trojan), 4 sowing times (from mid May to early July), and 4 N rates (unfertilised control, and 50, 100 and 200 kg N ha^{-1}) in four locations of South Australia and seasons: Hart and Turretfield in 2017, and Roseworthy and Mintaro in 2018. Nitrogen was equally split in two applications at emergence and mid tillering). The statistical design was split-split-split plot with 3 replicates, with sowing time allocated to the main plot, cultivar to the sub-plot and N the sub-sub-plot. At maturity, we measured grain yield and yield components. For the pooled data we estimated an upper limit of yield (95 percentile) as a function of the mean temperature during the critical period (20 days before and 10 days after anthesis). For each treatment, a yield gap was obtained as the difference between actual yield and yield at the boundary.

Table 1. Wheat cultivars grown Hart and Turretfield in 2017, and Roseworthy and Mintaro in 2018

Cultivar	Maturity type
Axe (AGT)	early flowering and very early maturity cultivar suited to SA.
Cobra (LongReach)	high yielding early-mid maturity cultivar suited to high yielding areas of SA.
Mace (AGT)	early to mid-season maturity and has been the leading wheat cultivars in both WA and SA in recent seasons.
Scout (LongReach)	mid maturity variety.
Spitfire (LongReach)	early mid maturing cultivar with high grain size and consistently high grain protein.
Trojan (LongReach)	mid-late maturing cultivar.

Experiment 2: to untangle the effect of temperature and other factors confounded in sowing time trials, we used a subset of treatments from experiment 1 where heated and unheated controls were compared (Photo 1). The subset included heated and unheated controls of the combination of 2 cultivars (Mace and Spitfire), 2 N rates (unfertilised control, 100 kg/ha), and two timing of heating. The timing of heating was from booting to 10 days after flowering, and from 10 days after flowering till maturity. The experiment was evaluated in

three sowing times at Hart 2017 (26 May, 9 June, 23 June) and two sowing times at Roseworthy 2018 (27 May and 23 June). We used three replicates for each treatment combination.

Photo 1: Open-top passive heating system before anthesis (left) and during grain filling (right) at Hart.

Results & Discussion

Grain yield ranged between 5.96 t/ha (Mace, 200 kg N/ha sown at Hart on 13 May 2017) and 0.13 t/ha (Cobra, 200 kg N/ha at early sowing at Mintaro date 2018). Across two seasons, yields averaged 3.5 t/ha in 2017 and 1.54 t/ha in 2018. The variation in grain yield was mainly due to rainfall, N availability, and frost. The relationship between grain yield and the average mean temperatures during critical period had an upper limit (boundary) function indicating a potential yield loss of 0.67 t/ha per °C (Figure 1a) (P<0.001). In all locations, delaying sowing decreased yield (P<0.0001) with the exception of Mintaro, where recurrent frost favoured yield in later sowings (Figure 1b).

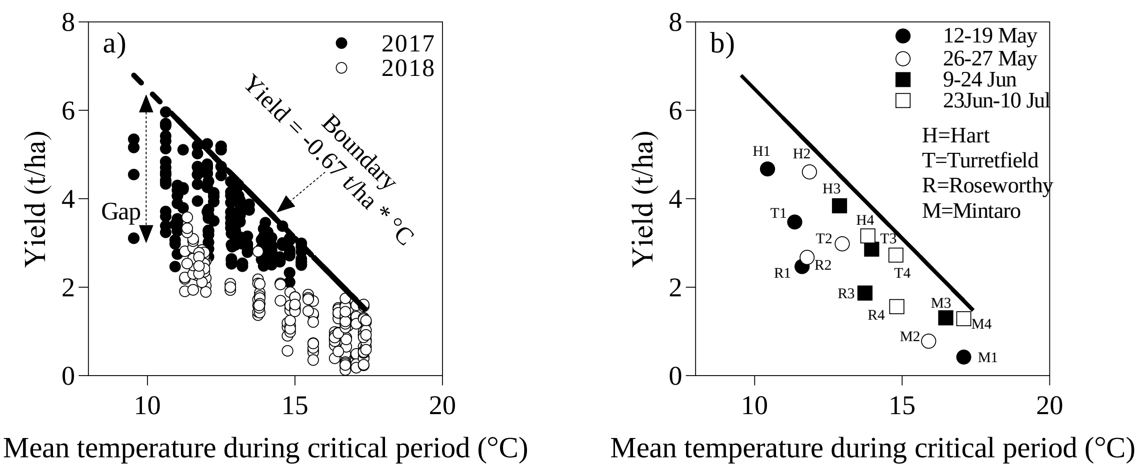

Figure 1. (a) Yield as a function of mean temperature during the critical period for all treatments in 2017 (closed symbols) and 2018 (open symbols). (b) Average yield across cultivars and N treatments for each sowing time and location combination as a function of mean temperature during critical period. Lines are the 95th percentile regression fitted to the pooled data in (a).

Yield gaps reached up to 3.72 t/ha (e.g. Axe sown in early May at Roseworthy) and on average were larger in 2018 (1.67 t/ha) than in 2017 (1.07 t/ha) (Figure 1). Yield gaps were larger at early (mid-May) sowing than at late sowing (mid-late June) (P<0.0001) and larger in early than in late maturing cultivars (Figure 2) (P<0.0001).

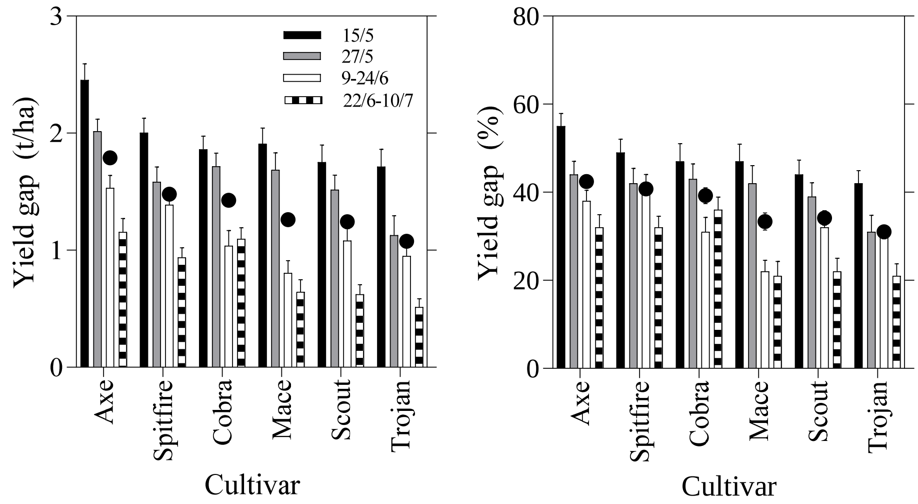

Figure 2. Average yield gaps expressed in t/ha (left panel) or as % of the maximum yield (right panel) for each cultivar and sowing time over two seasons. Closed circles indicate average yield gap across sowing times for each cultivar.

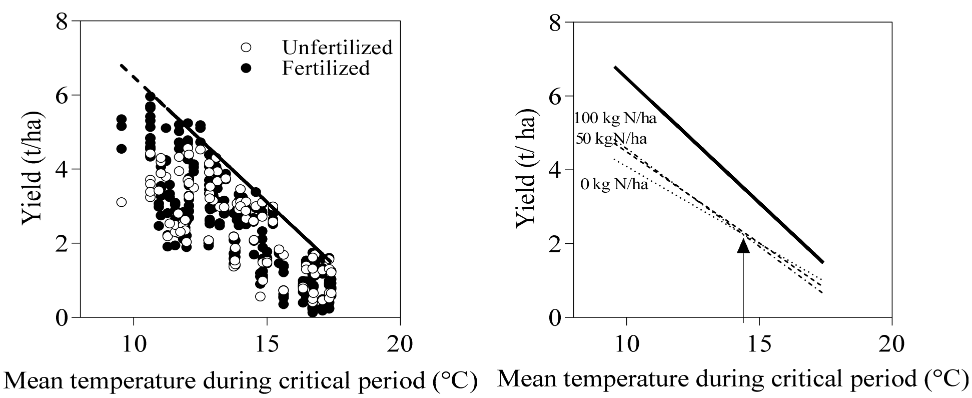

Figure 3. Grain yield as a function of mean temperature during critical period for fertilized (closed symbols) and unfertilized (open symbols) plots (left panel) and crops no fertiliser and 100 kg N/ha (right panel). Lines indicates the average regression line for each treatment, continuous line indicates the boundary function. Vertical arrow indicates crossing over between treatments.

The response of grain yield to N depended mainly on location (N availability, rainfall), time of sowing and their interaction. In general, N had a positive effect on grain yield across locations and cultivars (P <0.001). However, there was interaction with the average mean temperature during critical period. Advantages of N fertilised treatments disappear when mean temperatures during critical period increase over 14.3 °C (Figure 3).

Results from Experiment 2 were in line with the sowing date trials indicating a positive effect of N on yields, especially when higher temperature occurs during the period of grain number determination before anthesis Figure 4). Heating before and after anthesis reduced yield in comparison to controls (Figure 4). Cultivar-by-temperature interaction was significant for heating after anthesis indicating a higher impact of heat in Mace than in Spitfire. Fertilising crops with 100 kg N/ha reduced the impact of higher temperatures mainly through sustaining the grain number per square meter (data not shown).

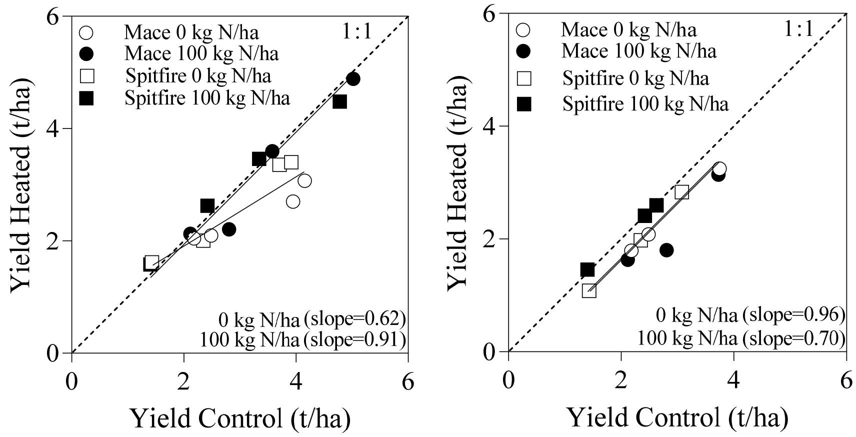

Figure 4. Relationship between grain yield of control and heated treatments for both cultivars (Mace= circles, Spitfire= squares) and fertilized conditions (unfertilized =open symbols, fertilized=closed symbols) at pre-anthesis heat stress (left panel) or post-anthesis heat stress (right panel) Dashed line represent the 1:1 relationship between yields of both temperature conditions.

Conclusion

The interactions between N, temperature and cultivar are important and need to be accounted when deciding the management practices. Early sowing increased yield potential, i.e. yield in the absence of stress. Delaying sowing reduced yield potential at 0.67 t/ha per °C during critical period. Good N nutrition and longer-season spring varieties reduced the yield gaps in relation to temperature. Responses to N were not apparent for temperatures during the critical period above ~14.5 °C. Strategic N management (50-100 kg N/ha) may help to mitigate the effect of higher temperature on grain number and yield.

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Flohr, B. M., Hunt, J. R., Kirkegaard, J. A., and Evans, J. R. (2017). Water and temperature stress define the optimal flowering period for wheat in south-eastern Australia. *Field Crops Research* **209**, 108-119.

Flohr, B. M., Hunt, J. R., Kirkegaard, J. A., Evans, J. R., and Lilley, J. M. (2018). Genotype × management strategies to stabilise the flowering time of wheat in the south-eastern Australian wheatbelt. *Crop and Pasture Science* **69**, 547-560.

Monjardino, M., McBeath, T., Ouzman, J., Llewellyn, R., and Jones, B. (2015). Farmer risk-aversion limits closure of yield and profit gaps: A study of nitrogen management in the southern Australian wheatbelt. *Agricultural Systems* **137**, 108-118.

Wardlaw, I., Dawson, I., and Munibi, P. (1989). The tolerance of wheat to hight temperatures during reproductive growth. 2. Grain development. *Australian Journal of Agricultural Research* **40**, 15-24.