Modelling the interaction between nitrogen and temperature during the critical period of yield in wheat

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Abstract
Experiments showed wheat yield response to nitrogen shifts from positive to negative with a crossing-over at a mean temperature during the critical period of 14.5 °C under South Australian conditions. We modelled wheat crops to establish the probabilities of the critical period exceeding the threshold of 14.5 °C in response to cultivar and management in 10 locations under current and future climates. The early-season cultivar (Axe) had lower probabilities of exceeding the temperature threshold for nitrogen response. Mid-season cultivars (Mace, Spitfire) had low probability of exceeding the threshold for sowings within the modelled optimal flowering period, even in scenarios with a temperature increase of 1°C. South Australia locations were clustered in two groups. Two locations, Cleve and Maitland, had a high probability of temperature above the threshold, with lower probabilities in the other 8 locations.

Keywords : Interactions, high temperature, simulation models.

Introduction

Sowing date, nitrogen management and cultivar selection are the key to risk management. Despite their importance, interactions between nitrogen and temperature have been overlooked. Current wheat production requires higher N amounts to accommodate the potential of modern varieties (G) (Sadras and Lawson, 2013), shifts in sowing date (Hunt et al., 2019) (M), and adaptation to warmer seasons and more frequent heat stress (E). Mean temperature during the Critical Period (CP) for grain set and yield determination (20 days before flowering to 10 days post flowering) is particularly important. A yield penalty up to 0.60 t/ha per ºC increase in mean temperature in relatively wet seasons (average yield 3.54 t/ha), that drops to 0.27 t/ha per ºC increase in mean temperature in drier seasons (average yield 1.54 t/ha) (Cossani and Sadras, 2021). A positive response to nitrogen application when mean temperatures during the CP were below ~14.5 °C (Cossani and Sadras, 2021). The objective of this work was to determine the probability of temperature during the critical period to exceed the threshold for nitrogen response as affected by sowing time and cultivar, and actual and future temperature scenarios in 10 locations of South Australia.

Methods

A risk analysis of temperature during CP for yield determination (20 days before to 10 days after flowering) was conducted using APSIM (V7.10) for the factorial combination of: 10 locations, 4 cultivars of different phenology and 5 sowing dates (Figure 1). Nitrogen was applied as nitrate with a fertiliser rule, which was maintained above 100 kg ha^{-1} in the top three layers of the soil throughout the season such that nitrogen supply did not limit yield. The simulation was done for a period of 62 years (1957 to 2018). For the analysis of future conditions, we used four approaches. Firstly, we analysed the effect of 0.5 °C, 1.0 °C, 1.5 °C and 2.0 °C warmer temperatures on the probabilities of exceeding the temperature threshold with current phenology. Secondly, we tested the probabilities of exceeding the threshold temperature if the critical period would occur 10 days earlier or later. Thirdly, we ran the analysis with modified temperatures and same flowering dates, and calculated the probability of occurrence of mean temperature higher than the threshold during the critical period in climates that are 0.5 °C, 1.0 °C, 1.5 °C and 2.0 °C warmer. Lastly, we used spatial analogues as surrogates to warmer climate. We compared counts when each location matched to all other locations for all combinations of the 10 locations, with counts at a 10 day period using mean bias and root-mean square error (RMSE). Finally, we modelled a multifactorial experiment combining four dates of sowing, six cultivars and four nitrogen rates. We simulated the year 2017 at Hart and Turretfield locations, and 2018 at Roseworthy and Mintaro locations, and compared simulated and actual data.

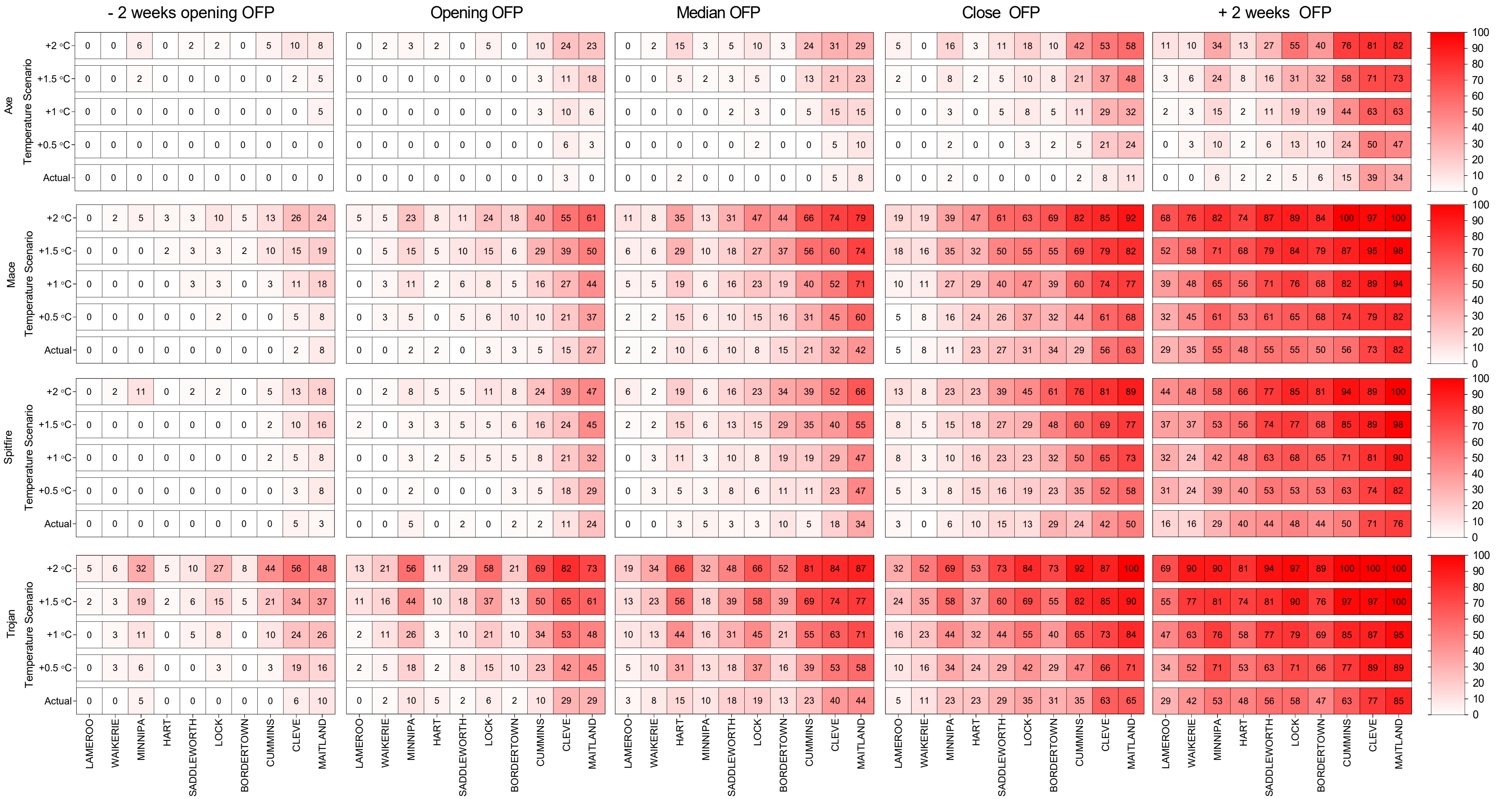

Figure 1. Probability (%) of mean temperature exceeding 14.5 °C during the critical period (20 days before and 10 days after flowering) for 4 cultivars in 10 locations with sowing to fit different times of the optimal flowering period (OFP) (15 days before opening, opening, median, closure, and 15 days after closure) at four warming scenarios (+0.5 °C, +1 °C, +1.5 °C, +2 °C in mean temperatures).

Results and discussion

Temperature during the critical period

We found a difference of 1.9 °C between the 2 cooler (Lameroo, Waikerie) and 2 hotter (Maitland, Cleve) locations for the critical period when sowing the crop at median recommended dates (Flohr et al. (2017). Temperatures increased with later sowing especially for mid and long season cultivars, with most locations reaching median mean temperatures above 14.5 °C (Figure 1). For sowing at the closing date recommended for optimal flowering period (OFP), the 90th percentile was above 14.5 °C in 7 out 10 locations on average for all four cultivars (Figure 1). For sowing delayed more than 4 weeks over the closure of the optimal period, almost 90% of the locations were above 14.5 °C for mid and long season cultivars. In comparison, the early season cultivar was over 14.5 °C only in two locations. The probabilities of exceeding the 14.5 °C during the critical period increased with the delay of sowing as expected. All four cultivars had the same kind of response among locations, although mid-season and long-season cultivars had high probabilities of exceeding 14.5 °C during the critical period even in optimal sowings. For the cultivar Axe, the probability of exceeding 14.5 °C only reached around 10% when sowing to fit within the median of the OFP, and 20% probability when sowing to fit the closing date of the OFP. All other cultivars exceeded 20% probability in at least 6 of the 10 locations when sown in the closing date. Delaying sowing increased the probability up to 80-90% in Cleve or Maitland locations. Cleve and Maitland locations always had the higher probabilities of exceeding the 14.5 °C during the critical period while Lameroo and Waikerie locations showed the lower ones. The locations at Minnipa, Lock, and Hart were intermediate (Figure 1). It is important to note that although the crop stage is the same (20 days before and 10 days after flowering), the calendar dates differ between cultivars, locations, sowing times and temperature scenarios.

Probabilities of exceeding the temperature threshold during the next 30 years

As expected, warming at same sowing dates would increase the probabilities of exceeding the temperature threshold (Figure 1). Mace and Trojan had higher probabilities of exceeding the threshold during the critical period. The short-season Axe had lower probabilities, similarly to the actual data. Noticeably, Trojan had three times the maximum probabilities of Axe, when sowing to fit the median of the optimal flowering period, reaching 87% for the scenario of 2 °C higher mean temperatures at Maitland.

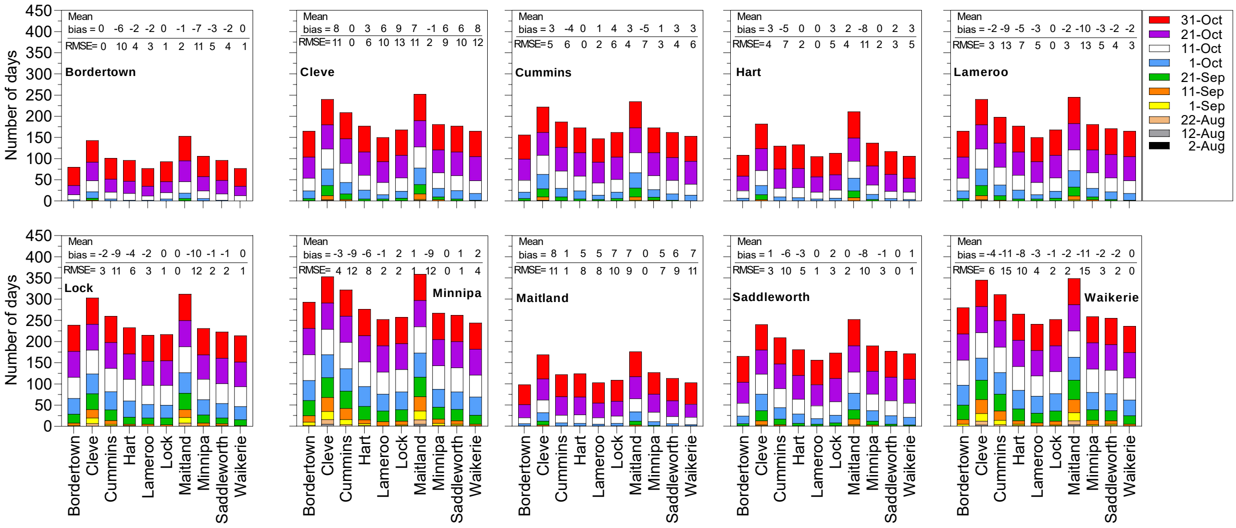

Figure 2. Number of days with mean temperatures exceeding 14.5 °C during critical period for each of the 10 locations of SA (bars) at different flowering dates (colours) when matched to analogue locations.

Using the spatial analogues, locations clustered into two main groups (Figure 2). A first group includes Bordertown, Hart, Waikerie, Minnipa, Cummins, Saddleworth, Lock and Lameroo, while Cleve and Maitland clustered separately. In most cases, Cleve and Maitland showed the highest accumulated chances of exceeding the temperature threshold. This result can be useful for identification of field trial locations such as NVT.

APSIM did not capture the interaction between nitrogen and temperature as observed experimentally (Figure 3). APSIM captured the main effect of temperature qualitatively, but modelled slopes of yield-temperature relationships were smaller than actual (dashed lines vs solid lines in Figure 3). For instance, the modelled slope for unfertilised crop was -0.22 t ha^{-1} $^{o}C^{-1}$ (R^2= 0.22, p <0.001) compared to the actual rate -0.42 t ha^{-1} $^{o}C^{-1}$ (R^2= 0.57, P<0.001). Differences between fertilised and unfertilised treatments were not noticeable with simulated data.

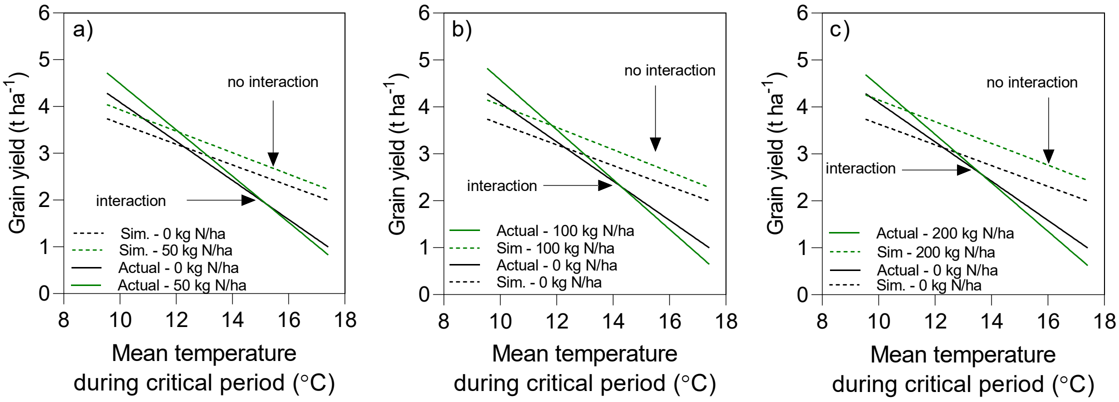

Figure 3. Comparison of actual (solid lines) and modelled (dashed line) response of grain yield to temperature and nitrogen. Nitrogen treatments are unfertilized controls vs a) 50 kg N/ha, b) 100 kg N/ha, and c) 200 kg N/ha) for all combinations of cultivar and location. Lines are least-square regressions with $0.22 \leq r^2 \leq 0.67$, P < 0.0001

Conclusion

This modelling has shown that early season cultivars such as Axe are less likely to exceed the temperature threshold for N response. However, their yield potential is usually lower than that of long season cultivars. Mid-season cultivars, such as Mace or Spitfire, had low probabilities of exceeding the temperatures threshold for sowing within the OFP. Even with an increase of 1℃, their probabilities did not exceed 10% in 8 of the 10 locations when sowing within the recommended dates for fitting the median OFP. The probabilities increased with cultivar season length. Most of the locations responded similarly to temperature, with two main groups identified. Cleve and Maitland had a high chance of temperatures above the threshold in comparison to the other 8 locations. Simulation models need attention in addressing the interaction between nitrogen and temperature due to

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