Association between wheat yield and temperature in south-eastern Australia

M. Fernanda Dreccer[1], Justin Fainges[1], **Victor Sadras**[2]

[1] CSIRO Agriculture Flagship
[2] South Australian Research and Development Institute

Abstract
We analysed the yield of wheat in National Variety Trials to explore links with weather, with emphasis on temperature, using the method of Mercau et al. (*Agric Syst* 67, 83-103). Median yield for 182 wheat crops in the south-east was 3.1 t/ha. We separated high yielding crops (≥ 90th percentile, 4.9 t/ha) and low yielding crops (≤ 10th percentile, 1.4 t/ha). The crop cycle was split in 16, 100-^{o}Cd developmental windows centred at flowering of a mid maturity cultivar. Low yield was associated with low rainfall during establishment, grain set and late grain filling; high vapour pressure deficit during all the growing season; high minimum temperature during grain filling; high maximum temperature during most of the growing season; and low photothermal quotient corrected by vapour pressure deficit in the critical period of grain set before flowering. The relationships found are agronomically robust and provide a guide for experimental research but cannot be taken as proof of cause-and-effect because weather variables are confounded.

Association between wheat yield and weather
The aim of this work was to explore associations between wheat yield and weather, with emphasis on temperature. We analysed mean yield of 182 National Variety Trials (NVT) from the South East region between 2009 to 2013. Fig. 1 shows the frequency distribution of actual yield; the median was 3.1 t/ha, the 90th percentile 4.9 t/ha and the 10t^{h} percentile 1.4 t/ha.

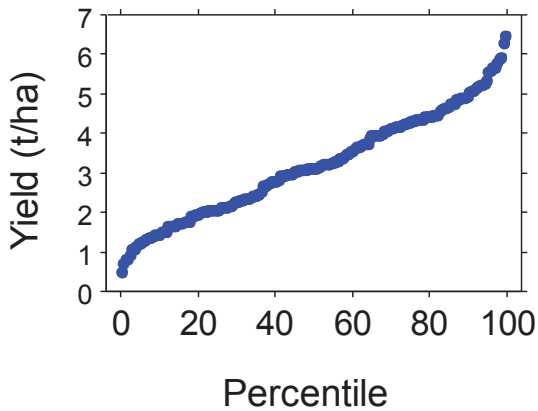

Figure 1. Frequency distribution of wheat yield in NVT in south-eastern Australia 2009-2013; n = 182.

We used APSIM to estimate flowering time of a mid-season cultivar for each NVT location and season, and the following variables were calculated for 100 ^{o}Cd (base = 0 ^{o}C) windows centred at flowering: rainfall, average vapour pressure deficit, average minimum and maximum temperature, number of days with temperature above 25°C and 30°C, incident photosynthetically active radiation (PAR), the photothermal quotient PTQ - the ratio between cumulative intercepted PAR and daily mean temperature (Fischer, *J Agric Sci* 105:447) and the PTQ corrected by vapour pressure deficit PTQvpd (Rodriguez & Sadras, *Austr J Agric Res* 58:287). The conditions associated with high (≥ 4.9 t/ha) and low yield (≤ 1.4 t/ha) were evaluated with the method of Mercau et al. (*Agr Syst* 67:83).

Low yield was associated with low rainfall during establishment, tillering and early stem elongation and late grain filling (Fig. 1A) and with high vapour pressure deficit during all the growing season (Fig. 1B). Of all the variables investigated, vapour pressure deficit was the one that showed the strongest and more consistent association with yield. The agronomically meaningful links between yield, rainfall and vapour pressure deficit reinforce our confidence in our analytical approach.

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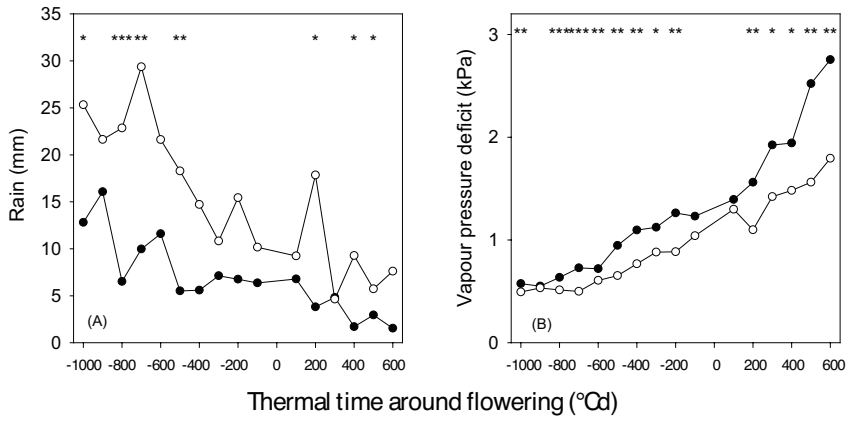

Figure 2. (A) Rainfall and (B) vapour pressure deficit associated with high (open symbols) and low (closed symbols) yielding wheat crops in south-eastern Australia. Asterisks indicate significant differences at P<0.0001 (***), P < 0.01 (**) and P < 0.05 (*).

Low yield was associated with high minimum temperature during grain filling (Fig. 3A). There was a strong and consistent association between low yield and high maximum temperature during most of the growing season (Fig. 3B). Low yield was related with more days with maximum temperature over 25 °C (Fig. 3C) and more days over 30 °C during grain filling. Maximum temperature exceeding these thresholds is unlikely before flowering, hence the lack of associations for the early part of the season. There was a weak association between low yield and high radiation late in the season that possibly reflects the link between high radiation and high temperature (Fig. 3E). Low yield was associated with low PTQvpd in the critical period of grain set before flowering, and there was a secondary association during grain filling. For this data set, yield and PTQ were unrelated.

Conclusion

We used an indirect method (sensu Bonada & Sadras *Austr J Grape Wine Res* 21:1) to explore associations between yield and weather. The relationships found are agronomically robust, but cannot be taken as proof of cause-and-effect. Weather variables are confounded because they are related in time over short (day) and long scales (season or longer) and they are also related in space, e.g. dry locations normally have higher temperature and higher radiation (Rodriguez & Sadras, *Austr J Agric Res* 58:287). Of particular interest, the strong signature of vapour pressure deficit deserves work to untangle the effect of temperature per se and the effect of temperature mediated by vapour pressure deficit. Direct manipulation of temperature in field experiments is necessary.

Acknowledgements

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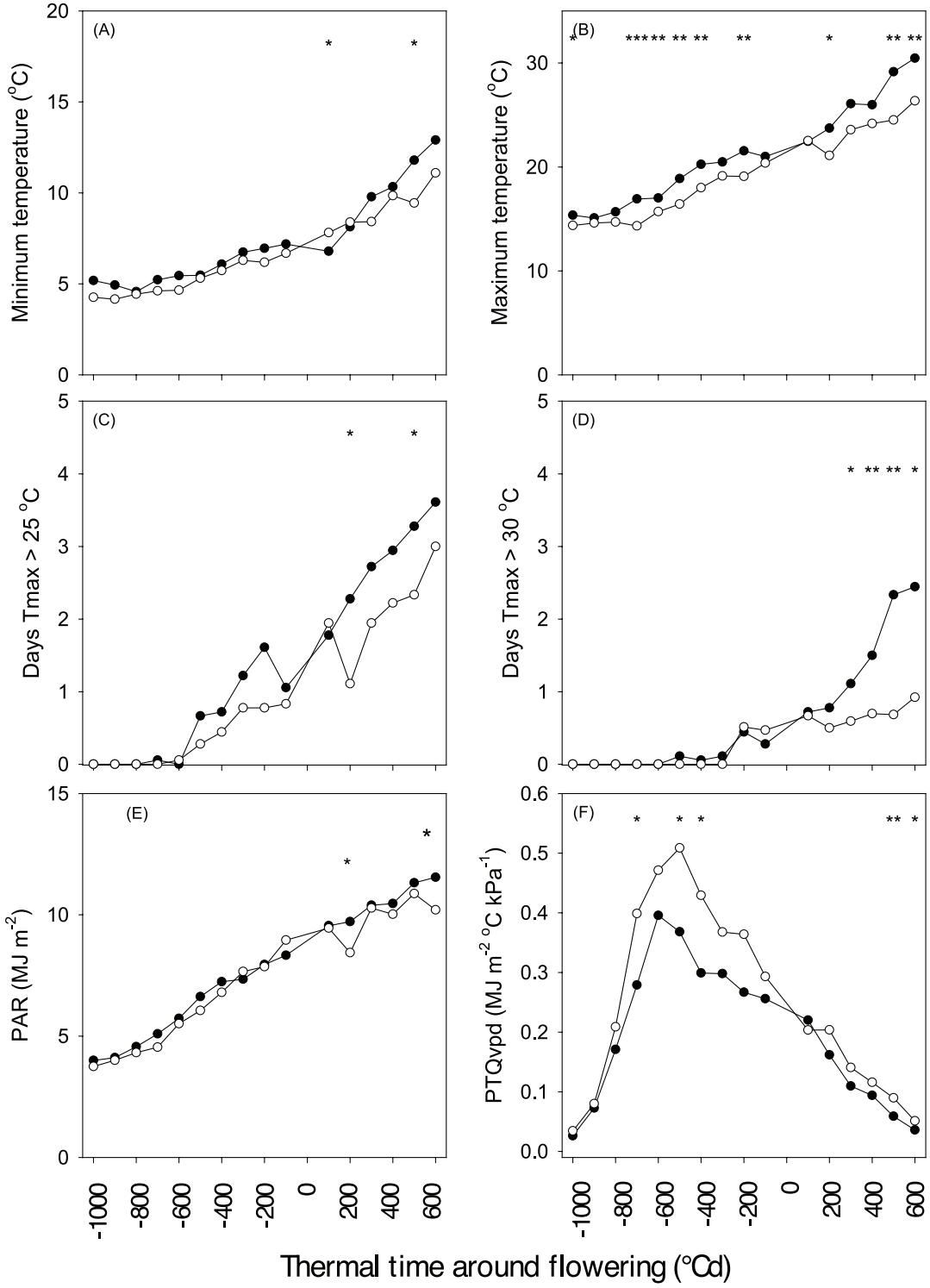

Figure 3. Photothermal conditions for high (open symbols) and low (closed symbols) wheat yielding crops in south-eastern Australia. Asterisks indicate significant differences at P<0.0001 (***), P < 0.01 (**) and P < 0.05 (*).