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Developing frost and heat stress damage functions to quantify yield loss for canola and wheat with APSIM

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Abstract: Climate change continues to increase the frequency and intensity of extreme weather events, such as frost and heat, which pose a significant threat to crop production. These events challenge global food security and hinder efforts to meet the rising food demand driven by population growth. Canola and wheat are major contributors to the global food supply and agricultural economies and require focused attention. Understanding and accurately quantifying yield losses caused by frost and heat events is therefore critical in the context of a changing climate.

Crop modelling is a widely used approach to assess the impacts of climate change on crop productivity. However, most crop models, including APSIM-Canola and APSIM-Wheat, lack explicit mechanisms to quantify yield loss from extreme temperature stress (Barlow et al., 2015). Knowledge gaps in the underlying physiological processes and the variability of yield responses under extreme conditions limit our ability to robustly parameterise these processes in crop models. To address this challenge, we applied a data-driven inverse parameterisation as a promising alternative.

Building on the conceptual models proposed by Barlow et al. (2015), this study developed damage functions within APSIM to estimate yield reductions due to extreme events. The damage function is the product of the potential yield reduction induced by extreme events (i.e., frost and heat) and the crop's sensitivity to stress at the growth stage when the event occurs. We modelled yield reduction as a piece-wise linear function of daily minimum (frost) or maximum (heat) temperature, ranging from 0 (no loss) to 1 (complete loss). The sensitivity of daily reduction was also represented as a piecewise linear function of crop growth stage, ranging from 0 (non-sensitive) to 1 (most sensitive).

Crop-specific temperature thresholds and sensitive periods for frost and heat stress were calibrated by minimising the difference between the simulated frost- and heat-limited yields and the corresponding field data. Field yield data were collected from a total of 224 canola and 358 wheat growing seasons across the Australian grain belt. A data-driven approach, which combines *k*-fold cross-validation with the differential evolution optimisation algorithm, was employed to estimate the parameter values of the damage functions.

Integrating these yield damage functions into APSIM significantly improved model performance. In calibration datasets, the relative root mean square error (RRMSE) for yield decreased by 17.7% for canola and 12.8% for wheat. In independent testing datasets, RRMSE decreased by 13.9% for canola and 15.3% for wheat. These enhancements enable more accurate yield simulations, better identification of optimal flowering periods, and improved assessment of extreme temperature impacts on crop yield. We can further refine these functions by incorporating more diverse field datasets, such as yield maps, in future work.

REFERENCES

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