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Compound drought and extreme temperature impacts on Australian wheat yields under climate change

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Abstract: The frequency and intensity of extreme climate events have increased in many global agricultural regions since the twentieth century. However, the quantification of extreme events impact on crop yield was mainly focused on individual events like drought or heat stress. While there is evidence from numerous instances showcasing the destructive effects of compound extreme events on crop yield, surpassing those of individual events, the precise magnitude and long-term implications of these impacts remain unclear.

Here we used Australia's wheat growing belt including 12 subregions as the study area. The 32-year wheat yield data (1990-2021) for each region were obtained from Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). The APSIM model forced with historical climate data in 1990-2021 was used to simulate the wheat phenology and daily plant available water. We then determined the daily intensity of drought, heat, and frost events during the wheat reproductive period (WRP) based on the modelling outputs. Furthermore, the annual intensity of compound drought and extreme temperature (DET) was obtained by calculating the sum of the daily intensity during DET events in WRP. After removing the DET episodes, the daily intensities of the remaining stages for drought, heat, and frost were accumulatively summed, respectively, to represent the corresponding annual intensity of these three individual extreme events. Finally, we developed multiple linear regression models to determine the contribution of DET to wheat yield change. We aim to (1) study the characteristics of single and compound drought and extreme temperature events in 1990-2021; (2) quantify the impacts of DET on wheat yields in 12 subregions in the Australian wheat belt; (3) identify the relative importance of DET in low-yield years.

We found that DET intensity had a large inter-annual variation. DET was highest in the northeastern wheat belt. We developed MLR models to quantify the drought, heat, and frost impacts on yield and found that they can explain 45% of yield change. When we included DET in the MLR model, the R^2 increased to 55%, indicating that DET contributed 10% to the change in wheat yields. In addition, the contributions of DET were region-specific. The highest contribution was 23% in the northern and eastern wheat belt of Western Australia. Furthermore, we found that DET dominated the yield change in extreme low-yield years (10^{th} percentile), and the relative contribution exceeded 50%. However, in the moderate low-yield years (20^{th}-50^{th} percentile), the relative importance of DET (18%-23%) was second to that of drought events (70%-74%). These results indicated that DET played a non-neglectable role in long-term yield change, especially in these extreme low-yield years, its importance exceeded the sum of other single extreme events.

Identifying the contributions of DET to yield changes allows for better risk assessment and management. Farmers, agricultural policymakers, and stakeholders can use this information to implement targeted measures to reduce the impact of compound stressors. For example, adjusting planting dates, selecting heat-tolerant or frost-resistant wheat varieties, implementing irrigation strategies, or adopting precision farming techniques can help mitigate yield losses. In addition, our quantitative analysis of the relative importance of DET to wheat yield in low-yield years provides crucial insights into the leading factors for major yield losses, which can provide advance warning to stakeholders to take necessary precautions during years when DET occurs frequently.

Keywords: *Compound drought and extreme temperature, wheat yield, Australian wheatbelt, APSIM*