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# Response to Marijn van der Velde (Referee # 2)

**In italics the original comments; in normal font our responses.**

*The manuscript submitted by Luan and Vico investigates a relevant topic and does so using a newly developed mechanistic model that allows to develop a better understanding in the processes and feedbacks that determine the coupled impact of water and heat stress in irrigated crops. Irrigation can alleviate water stress but can also lower the maximum canopy temperature and period of heat stress experienced during heat waves.*
*The manuscript focuses on presenting the model and benchmarks its performance in a case study for wheat. Along with the manuscript comes an excellent and extensive model description included in the supplemental material. I advise the authors to eventually publish their full model and code in a citable open source repository.*
*I commend the authors for focusing on transparency and simplicity, for instance in defining the crop and phenology stage specific threshold temperatures that would trigger damage from heat stress. The authors explicitly consider the stochastic effects of temperature and precipitation.*

We thank Dr. van der Velde for the very supportive comments. For enhanced transparency and to facilitate further applications of the model, we will consider uploading our codes to an open-source repository (e.g., Zenodo).

*While I appreciate the illustration of the model in the case for a hypothetical wheat crop, I do look forward to further scrutiny of the model against data from field experiments.*

We consider a thorough comparison with observations beyond the scope of the current contribution. Such a comparison would require selecting a specific location, for which data for model calibration, environmental conditions, and canopy temperatures over several seasons or irrigation treatments are available. While some datasets are available (e.g., 'T-FACE-Maricopa'/Hot Serial Cereals and 'China wheat'; (Webber et al., 2018)), most results reported in the literature focus on the relations between leaf water potential to canopy-to-air temperature difference (which is affected by environmental conditions, including vapor pressure deficit). Even in the presence of irrigation treatments, information on the soil water availability is often not reported. For these reasons, we had qualitatively checked our model's results by comparing its estimates with field observations and other model results in Section 4.1 (Soil water availability and air temperature jointly affect canopy temperature). There, we had focused on canopy-to-air temperature differences under well-watered or water-limited conditions, to reduce the effects of the specific conditions. Should we be offered the possibility to revise the manuscript, we will further extend this comparison, based on a deeper literature review.

*A next challenge will be to untangle the net effects on biomass and yield.*

The net effects of compound heat and water stress on biomass and yields are indeed extremely interesting… and difficult to include in a process-based model, due to their complexity and high level of uncertainty in many processes and their parameterization. These difficulties explain why the compound effects of temperature and precipitation (and hence water availability) have received less attention in general than single abiotic stresses (Rötter et al., 2018). When considered, the role of co-occurring stresses have most often been determined based on statistical models (e.g., Carter et al., 2016; Matiu et al., 2017) but more rarely included in process-based models (Rezaei et al., 2015). Further, even heat stress in isolation has been seldom accounted for in models (Barlow et al., 2015). As also implicitly suggested by the Referee, these aspects deserve stand-alone future contributions. Nevertheless, we plan to add a short paragraph in Section 4.3 (Irrigation reduces but does not cancel the risk of heat stress) in a revised submission, to clarify the linkages between canopy temperatures and final yields.

*By lowering temperature, irrigation is also delaying harvesting and thus allowing for a longer grain filling period.*

This is an excellent point. For simplicity, we had chosen and explicitly mentioned (L148) that the length of the anthesis period was independent of the air temperature scenario. But also irrigation could alter the length of any stage of the phenology, thanks to its cooling effects, all else being the same. We plan to mention this aspect in Section 2.2 Case study when revising the manuscript.

*The research also has implications for water management in spelling out the relative benefits and limitations of irrigation used specifically for cooling during heat waves. This was lacking previously (e.g. Van der Velde et al., 2009).*

In Section 4.3 (Irrigation reduces but does not cancel the risk of heat stress), we had briefly explained the benefits and limitations of irrigation as a way to reduce the occurrence of heat stress in crops, but also its costs and implications in terms of water requirements and negative environmental consequences. In a revised manuscript, we plan to deepen this discussion by completing Section 4.3 explicitly mentioning the effects of extensive irrigation at the regional scale; and the corresponding effects of a change in temperature regime mentioned by the Referee in the previous comment. Altogether, these direct and indirect effects can significantly alter the final crop yield, as for example clearly shown in the article suggested by the Referee.

*One point of clarification needs to be made with regard to soil water balance and effective rooting depth. Research has shown that deeper rooting vegetation and thus access to soil moisture can lead to contrasting responses of vegetation and canopy temperature to heatwaves (e.g. see work of Teuling et al., 2010, but also Zaitchik et al., 2007). Have you done sensitively test of your model with respect to effective rooting depth parameter (now 0.3 m)? While not necessary to consider for this manuscript, you may detail this a bit further by referring to your previous work.*

As long as the effective rooting zone remains far from the water table, its depth, $\boldsymbol{Z_r}$, has multiple effects on plant water availability (and hence canopy temperature; see Fig. 2 in the original submission). These effects depend on precipitation regime (see e.g. Fig. 8 and 10 in Laio et al., 2001, for the combined effects of rooting depth and climatic conditions on the probability distribution of soil moisture and the averaged soil water balance), as well as plant water use strategy. Assuming the same plant water use strategy (i.e., response to decreasing soil water potential), deeper roots are expected to reduce losses by runoff and deep percolation and stabilize soil moisture.

Nevertheless, by considering a range of $\boldsymbol{Z_r}$ compatible with rooting depths for wheat (and annual crops in general; Jackson et al., 1996), we found rooting depth had no appreciable effect on mean canopy temperatures, for the baseline and more intermittent rainfall scenarios (Figure 2.1). The small difference in $\boldsymbol{Z_r}$ and the fact that this was the only parameter changed in this sensitivity analysis likely explain why these results are in contrast with those reported in the papers suggested by the Referee. There, different land uses are associated not only to likely differences in rooting depth, with forests having deeper roots than grasslands and croplands, but also with different water use strategies, with forests generally having a more conservative water use, i.e., a stronger regulation of stomatal conductance in response to temperature, solar radiation, and vapor pressure deficit, or different coupling to the atmosphere (see, e.g., the interpretation proposed by Teuling et al., 2010). Indeed, in three wheat varieties, cooler canopies at anthesis were correlated with deeper roots, but also higher canopies (Li et al., 2019), making it difficult to disentangle the effect of rooting depth alone based on experimental observations. The number and timing of processes and feedbacks involved in defining the differential response of forests and grasslands in the face of climatic conditions could also explain the contrasting results emerging from the two papers suggested by the Referee.

Given the negligible effect of $\boldsymbol{Z_r}$ in isolation when focusing on realistic ranges for wheat and considering that the manuscript is currently focusing on the effects of changes in the pedoclimatic conditions (i.e., assuming a set crop and its features), we would prefer not to add this dimension to a revised manuscript. Yet, we will briefly touch upon this in Section 3. Results, with reference to previous results.

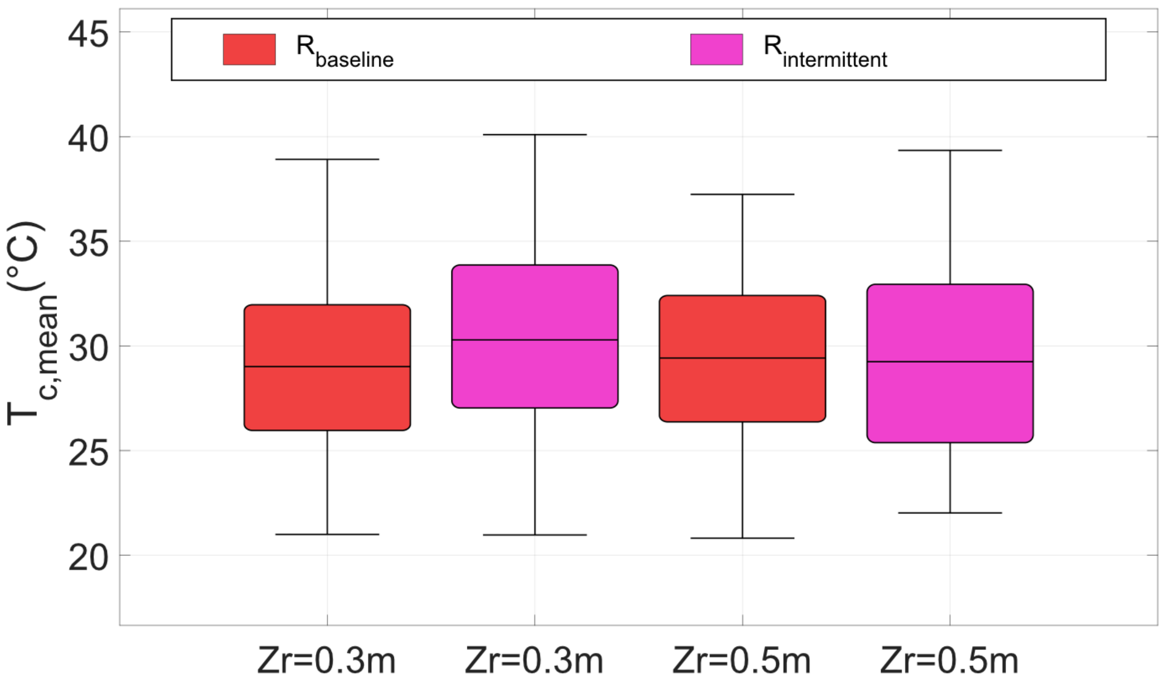


**Figure 2.1: Mean canopy temperature during anthesis ($T_{c,mean}$), for two effective rooting depths $Z_r$ (x-axis) and different precipitation (colors). $R_{baseline}$ and $R_{intermittent}$ represent rainfed cropping, respectively under baseline precipitation ($\alpha_p$=8.2 mm; $\lambda_p$=0.2 $d^{-1}$) and more intermittent precipitation ($\alpha_p$=23.5 mm; $\lambda_p$=0.07 $d^{-1}$). For each climatic and rooting depth scenario, 100 21-day simulations were run. The horizontal black lines are the median values; the boxes extend from the first to the third quartile; whiskers cover the whole range.**

*L298 Reference missing*

A reference to Table 1 should have appeared here but the link got corrupted. It will be added in the revised manuscript.

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*L298: Reference missing.*

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