Authors' Response to Reviews of

Shifting water scarcities: Irrigation alleviates agricultural green water deficits while increasing blue water scarcity

Review #3

The study leverages two indicators: green water scarcity (GWS) and blue water scarcity (BWS), to quantify and examine the interconnectedness of green and blue water resources for irrigation. They show that while irrigation alleviates GWS, it simultaneously exacerbates BWS at the expense of environmental flow supply. The paper successfully addresses the research gap with clear narration and consistent structure throughout. Given that the results hinge on several salient parameters (E_{max}, threshold values), I recommend that authors consider conducting a sensitivity analysis to strengthen their analysis and to enable both themselves and the readers to better gauge the robustness of the results.

We cordially thank Reviewer 3 for taking the time to review our manuscript and for providing valuable and constructive feedback. Below, we provide detailed responses to all comments, including proposals to address the suggested improvements.

Major comments:

- There is still room to further improve the transparency of the modelling process. This could include making assumptions more explicit and providing justification or citations for modelling decisions so that readers can trace and assess their epistemic quality/reasoning. Such steps would also support future scholars in replicating the work based solely on the provided documentation. Please see the following details:
    - **L. 90**: Could you expand on the parameterisation of irrigation efficiency? Since CFTs may be suitable to more than one irrigation method (see Jagermeyr et al 2015), how did you determine which method to apply? Was the efficiency value based on an area- or grid-cell-weighted average?

Thank you very much for raising this point. We acknowledge that the description of the modelling process and decisions can be improved. In the revised manuscript, we will explain steps more clearly, and justify our methodological choices in greater detail.

To determine which irrigation method to apply to each CFT, decision rules have been developed by Jägermeyr et al., 2015 (based on Brouwer et al., 1988; Sauer et al., 2010; Fischer, 2012). These rules specify the suitability of surface, sprinkler, and drip systems for each CFT (summarized in Jägermeyr et al., 2015, Table 2). For all CFTs that may be suitable for more than one irrigation method, a structured allocation algorithm was applied: First, for each country, all grid cells with drip-suitable CFTs were identified, and CFT fractions were randomly sampled until the national target area for drip irrigation was met. This procedure was repeated 1000 times, and the iteration best matching the national target was selected. Second, sprinkler irrigation was assigned following the same logic, and the remaining irrigated area was allocated to surface systems (see Jägermeyr et al., 2015 (Supplementary Material)). In this way, the method selection is not based solely on CFT suitability but also constrained by observed national irrigation system shares. As a result, each CFT in each grid cell is allocated to one of the three irrigation systems.

The parameterisation of irrigation efficiency depends on the irrigation systems as well as soil conditions. For pressurized systems (sprinkler and drip irrigation), the conveyance efficiency is set to 0:95 while for surface irrigation conveyance efficiency is connected to different soil saturated hydraulic conductivities (see Jägermeyr et al., 2015 (Table 1)). The irrigation efficiency values are based on the area-weighted shares of irrigation systems at the grid-cell level.

- **L. 120**: Could you provide a rationale for using E_{max} = 8 mm/day? Earlier studies suggest lower values (e.g., Gerten et al 2004 report 5-7 mm/day, while Rost et al, 2008 used 5 mm/day). If more recent studies support your chosen value, it would be helpful to cite them.

In our study, we used the revised maximum daily transpiration rate (E_{max} = 8 mm day^{-1}) from Fader et al. (2010). We will include this reference in the revised manuscript and seek additional supporting literature.

- **L. 129**: The statement "*If S > D, we set S = D to ensure the result remains within [0,1]*" could benefit from clearer justification. For example: "When S>D, we set S = D, because plants cannot take up more water than their transpiration demand allows." This framing preserves the rationale while adding a physiological explanation.

Thank you very much for this suggestion which we adopted.

- **L. 143**: Could you elaborate on the rationale for selecting 0.4 as the threshold to delineate highly water-scarce conditions? Since this assumption conditions the characterisation of scarcity across regions, you may consider conducting a sensitivity analysis to assess the soundness of your results to alternative threshold values.

We acknowledge that the choice of the threshold levels 0.2 and 0.4 was not robustly tested in the original manuscript. With the new threshold approach - building on actual yield declines of specific CFTs due to green water stress (as described in the general response to all reviewers) - we propose reframing the GWS categories to sequential steps of 0.2, in order to show a graduality in the GWS exposure. We will define the categories as following:

0-20 % yield decline = low GWS
20-40% yield decline = moderate GWS
40-60% yield decline = high GWS
60-80% yield decline = severe GWS
80-100% yield decline = extreme GWS

We will adjust the text accordingly.

- **L. 256:** It may be helpful to mention the non-representation of multiple cropping already in the methodology, rather than only in the discussion, as this limitation (as you argued) could underestimate your results.

Thank you for the suggestion, we will adjust the Method section accordingly.

- Given that the results are highly contingent on several parameterisations, it may be beneficial for the authors to conduct a sensitivity analysis to strengthen their conclusions and to allow stakeholders to better gauge the robustness of the findings. For example, sensitivity runs on influential elements such as E_{max} values (5-8 mm/day) and different thresholds (0.2, 0.3, 0.4, 0.6) may be informative and also support your choice of values.

In the revised analysis, we will use sequential steps as GWS thresholds and we will provide a sensitivity analysis showing how the threshold definition can influence the results of the area affected. We will furthermore compare the new threshold results to our original assumptions (0.2 and 0.4).

We acknowledge that E_{max} values usually range between 5-8 mm (as noted above). We already validated the evaporation rates of this study with evaporation rates measured at eddy flux towers (in the Supplementary Material) and will point to this more clearly. In addition, we propose to include global ET values in Table 1 to facilitate better comparison.

Minor comments:

- For consistency with previous LPJmL studies, please consider standardising the equation symbols:
    - **L. 124**: a_m should be written as α_m
    - **L. 124**: adjust the fraction form of g_m/g_c for clarity

Will do.

- The authors may consider aligning the numbering of supplementary materials with the order in which they are first referenced in the manuscript. Additionally, there are several information and figures included in the supplementary material that are not explicitly mentioned in the main text. Without such references, readers may overlook these potentially important resources.

Thank you for this helpful comment. We will align the numbering of the supplementary materials accordingly and ensure that all supplementary figures and tables are properly referenced in the manuscript.

Technical comments:

- When citing, if applicable, it may be helpful to specify that exact page, figure or table for the reader's reference. For example, **L. 90**: (Table 5, Jagermeyr et al. 2015)

We will adjust that.

- **L. 156**: Please consider removing the comma following "*overuse*"

Will do.

- **L. 156**: It may improve readability to elaborate on the meaning of transgression: clarifying what it implies when a threshold has been transgressed.

Thank you for this comment. In the revised manuscript, we have clarified what transgressions of EFRs would imply.

- **L. 264-266**: The sentence "*While irrigation reduces GWS (below the threshold of 0.2) on 13% of the global agricultural area, it thereby leads to an increase in areas experiencing moderate BWS as well as high BWS by 6%, respectively.*" may be confusing, as "respectively" suggests a missing distinction between moderate and high BWS. Consider rephrasing for clarity, e.g., "…by 6% and 6%, respectively" or "…both by 6%"

Thank you for this valuable remark. We will adjust the text to make the distinction between moderate and high BWS clearer in the revised version of the manuscript.

References

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