Authors' responses to interactive comments on "Spatiotemporal responses in crop water footprint and benchmark under different irrigation techniques to climate change scenarios in China"

Dear Referee #2,

We appreciate very much your valuable and helpful comments and suggestions concerning our manuscript. We have studied all the comments carefully and responded as followed.

Anonymous Referee #2

The paper is interesting for the wide area it involves and the relevance of the area for corn and wheat production, despite results and methods are not totally novel

Response: We deeply appreciate your recognition of this study and valuable comment. Our research adopts the widely used method (Mekonnen and Hoekstra, 2011; Zhuo et al., 2016a, 2016b, 2019; Wang et al., 2019; Mialyk et al., 2022) to calculate the water footprint per unit crop (WF, the abbreviation of water footprint was changed from WFP to WF at Referee #1's suggestion). It does have the potential to continue to innovate. And we will also improve the research method in the follow-up study.

Meanwhile, we want to highlight the innovations in our research. Compared with existing researches, the innovative aspects are embodied in two points. The present study firstly clarifies large-scale spatiotemporal responses of WF to future climate change scenarios under different irrigation techniques. Although Wang et al. (2019) considered different irrigation techniques when calculating the large-scale WF of wheat. But he focused on only one crop, wheat, and did not consider the impact of future climate change. In addition, our research is also the first to explore large-scale changes in WF benchmarks under future climate change scenarios.

There are also some unique conclusions in our research. We find that micro irrigation and sprinkler irrigation result in the lowest increases in WF for maize and wheat, respectively. Hence, these water-saving irrigation practices effectively mitigate the negative impact of climate change. Moreover, we find that crop WF benchmarks will not change as dramatically as WF in the same area, especially the area with limited agricultural development, which also proves the stability of WF benchmarks. These conclusions also contribute to the improvement of the existing WF research field.

Specific comments:

It’s not clear how irrigation techniques scenario are managed in the analysis. Are the actual techniques implemented when baseline year was determined? And what about future scenarios? Are techniques assumed considering the actual feasibility of the territory?

Response: We are very sorry for our unclear expression and deeply appreciate your valuable comment. We obtained the planted areas of each crop under each irrigation technique at provincial level from 2000 to 2014 from the China Statistical Yearbook (NBSC, 2021). In this way, the proportion of irrigated area under different irrigation techniques in the baseline year 2013 can be calculated. Then the irrigated and rain-fed areas of maize and wheat at a 5-arc minute grid resolution from MIRCA2000 dataset (Portmann et al., 2010) were divided into different parts under various irrigation techniques. Since we mainly focus on the impact of future climate change on WF and corresponding benchmarks, the change in land use is not considered. We assumed that the crop planted areas will not change in the future compared to baseline year 2013.

Furthermore, we realized that description of different irrigation techniques settings was missing in Section 2.3 (original 2.2, since we added the Section 2.1 Research set-up at Referee #1's suggestion) Water footprint per unit crop calculation. Therefore, the following will be added at the end of Section 2.3. And the relevant table will be placed in the supplementary material.

“In the simulation, we considered different planting modes, namely rain-fed and three different irrigation techniques (furrow, micro, and sprinkler irrigation). The irrigation schedule of three irrigation techniques in model was Generation of Irrigation Schedule, namely the generation of an irrigation schedule by specifying a time and depth criterion for planning or evaluating a potential irrigation strategy. Table S6 shows the parameters of three irrigation techniques (Raes et al., 2017). We can adjust the simulated ET and Y according to the performance of the irrigation schedule.”

Table S6. Parameters of three irrigation techniques.

Irrigation technique	From day	Time criterion	Depth criterion	Water quality	Soil surface wetted
		Depleted RAW	Back to FC	Ecw	
		(%)	(+/- mm)	(dS m^{-1})	(%)
Furrow	1	50	10	1.5	80
Micro	1	20	10	0	40
Sprinkler	1	50	10	1.5	100

L. 148 “using temperature inputs and the Penman-Monteith method”. Penman-Monteith equation requires solar radiation, wind spped, relative humidity, and pressure in order to compute potential evapotranspiration (PET). Can you clarify how you computed PET?

Response: We deeply appreciate and agree with your valuable comment. We will apply the Penman-Monteith equation you mentioned to compute reference evapotranspiration (ET_o) if future climate data types are sufficient, including monthly maximum and minimum air temperature (T_{max} and T_{min}), actual vapour pressure (e_a), net radiation (R_n) and wind speed measured at 2 m (u_2). However, due to the limited future climate data obtained from the Climate Change, Agriculture and Food Security (CCAFS) database (Navarro-Racines et al., 2020; CCAFS, 2015), only monthly air temperature and precipitation data were available. Therefore, FAO Penman-Monteith method with missing data was used here to compute ET_0 (Allen et al., 1998). There are corresponding procedures to estimate missing humidity, radiation and wind speed data in this method.

1. Estimating missing humidity data

Where humidity data are lacking or are of questionable quality, an estimate of actual vapour pressure (e_a, kPa) can be obtained by assuming that dewpoint temperature (T_{dew}, °C) is near minimum air temperature (T_{min}, °C). This statement implicitly assumes that at sunrise, when the air temperature is close to T_{min}, that the air is nearly saturated with water vapour and the relative humidity is nearly 100%. If T_{min} is used to represent T_{dew} then:

$$e_a = e^0(T_{min}) = 0.611 exp\left[\frac{17.27T_{min}}{T_{min}+237.3}\right] , \tag{1}$$

2. Estimating missing radiation data

We can estimate R_n by combining elevation, latitude and longitude data and air temperature data for each grid. The net radiation (R_n, MJ m^{-2} day $^{-1}$) is the difference between the incoming net shortwave radiation (R_{ns}, MJ m^{-2} day $^{-1}$) and the outgoing net longwave radiation (R_{nl}, MJ m^{-2} day $^{-1}$):

$$R_n = R_{ns} - R_{nl} , \tag{2}$$

where R_{ns} and R_{nl} are calculated by Equations (3) and (4), respectively.

$$R_{ns} = (1-\alpha)R_s , \tag{3}$$

$$R_{nl} = \sigma\left[\frac{{T_{max,K}}^4 + {T_{min,K}}^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left[1.35\frac{R_s}{R_{so}} - 0.35\right] , \tag{4}$$

where α is the albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop, R_s (MJ m^{-2} day $^{-1}$) is the incoming solar radiation

(Equation 5), σ (4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}) is Stefan-Boltzmann constant, $T_{max,K}$ and $T_{min,K}$ (K=°C+273.6) are maximum and minimum absolute temperature during the 24-hour period, respectively, and R_{so} (MJ m^{-2} day $^{-1}$) is the clear-sky radiation (Equation 6).

Rs is estimated using Hargreaves' radiation formula based on the difference between the maximum and minimum air temperature:

$$R_s = K_{RS}\sqrt{(T_{max} - T_{min})R_a} \quad , \tag{5}$$

where K_{RS} (°$C^{-0.5}$) is the adjustment coefficient from 0.16 to 0.19, which differs for 'interior' or 'coastal' regions. For 'interior' locations, where land mass dominates and air masses are not strongly influenced by a large water body, $K_{RS} \approx 0.16$. For 'coastal' locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body, $K_{RS} \approx 0.19$. And R_a (MJ m^{-2} day $^{-1}$) is the extraterrestrial radiation (Equation 7).

R_{so} is estimated according to the elevation for each grid:

$$R_{so} = (0.75 + 210^{-5}Z)R_a \quad , \tag{6}$$

where Z (m) is the elevation above sea level.

R_a is estimated by Equation 7:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \quad , \tag{7}$$

where G_{sc} (0.0820 MJ m^{-2} min^{-1}) is the solar constant, d_r is the inverse relative distance Earth-Sun (Equation 8), ω_s (rad) is the sunset hour angle (Equation 10), φ (rad) is the latitude, and δ (rad) is the solar decimation (Equation 9).

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) \quad , \tag{8}$$

$$\delta=0.409 sin\left(\frac{2\pi}{365}J-1.39\right) , \tag{9}$$

$$\omega_s=\arccos[-tan(\varphi)\tan(\delta)] , \tag{10}$$

where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

3. Estimating missing wind speed data

Where no wind data are available within the region, a value of 2 m s^{-1} can be used as a temporary estimate for u_2. This value is the average over 2000 weather stations around the globe.

Finally, if necessary, we will provide the code scripts related to ET_0 computing.

I am not an English native speaker but I think there's need to make the manuscript be checked for English grammar.

Response: We deeply appreciate your valuable advice and apologize for our improper use of English grammar. If we are lucky enough to get a valuable chance to revise, we will carefully examine the grammar in the manuscript and ask for English native speaker's opinion to modify.

References

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M.: Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56, 300, FAO, Rome, Italy, 1998.

CCAFS: CCAFS-Climate Statistically Downscaled Delta Method data, Climate Change, Agriculture and Food Security, available at: www.ccafs-climate.org, 2015.

Mekonnen, M. M. and Hoekstra, A. Y.: The green, blue and grey water footprint of crops and derived crop products, Hydrol. Earth Syst. Sci., 15, 1577–1600, https://doi.org/10.5194/hess-15-1577-2011, 2011.

Mialyk, O., Schyns, J. F., Booij, M. J., and Hogeboom, R. J.: Historical simulation of maize water footprints with a new global gridded crop model ACEA, Hydrol. Earth Syst. Sci., 26, 923–940, https://doi.org/10.5194/hess-26-923-2022, 2022.

Navarro-Racines, C., Tarapues, J., Thornton, P., Jarvis, A., and Ramirez-Villegas, J.: High-resolution and bias-corrected CMIP5 projections for climate change impact assessments, Sci. Data, 7, 7, https://doi.org/10.1038/s41597-019-0343-8, 2020.

NBSC: National Data, China, National Bureau of Statistics, Beijing, China, available at: https://data.stats.gov.cn/, 2021.

Portmann, F. T., Siebert, S., and Döll, P.: MIRCA2000-Global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modelling, Global Biogeochem. Cy., 24, https://doi.org/10.1029/2008gb003435, 2010.

Raes, D., Steduto, P., Hsiao, T. C., and Fereres, E.: Reference manual, Chapter 2, AquaCrop model, Version 6.0, Food and Agriculture Organization of the United Nations, Rome, Italy, 2017.

Wang, W., Zhuo, L., Li, M., Liu, Y., and Wu, P.: The effect of development in water-saving irrigation techniques on spatial-temporal variations in crop water footprint and benchmarking, J. Hydrol., 577, https://doi.org/10.1016/j.jhydrol.2019.123916, 2019.

Zhuo, L., Liu, Y., Yang, H., Hoekstra, A. Y., Liu, W., Cao, X., Wang, M., and Wu, P.: Water for maize for pigs for pork: An analysis of inter-provincial trade in China, Water Res., 166, https://doi.org/10.1016/j.watres.2019.115074, 2019.

Zhuo, L., Mekonnen, M. M., and Hoekstra, A. Y.: The effect of inter-annual variability of consumption, production, trade and climate on crop-related green and blue water footprints and inter-regional virtual water trade: A study for China (1978-

2008), Water Res., 94, 73–85, https://doi.org/10.1016/j.watres.2016.02.037, 2016a.

Zhuo, L., Mekonnen, M. M., Hoekstra, A. Y., and Wada, Y.: Inter- and intra-annual variation of water footprint of crops and blue water scarcity in the Yellow River basin (1961–2009), Adv. Water Resour., 87, 29–41, https://doi.org/10.1016/j.advwatres.2015.11.002, 2016b.