Authors' response to Interactive comments on "Benchmark levels for the consumptive water footprint of crop production for different environmental conditions: a case study for winter wheat in China"

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Dear Referee #1,

Thank you very much for your valuable comments and suggestions on our manuscript. We have provided our responses directly below the comments.

Anonymous Referee #1

The study presents an attempt to estimate benchmark levels for the consumptive water footprint of winter wheat in China by applying the crop model AquaCrop. Water footprints simulated for the period 1961-2008 are compared between dry and wet years, between warm and cold years, across soil types and between irrigated and rainfed wheat. Such an analysis is interesting in general and fits also well to the scope of the journal. However, I think that the manuscript requires substantial improvement before it may be considered for publication in HESS. May main points of criticism are:

1.) I completely miss a discussion on the relevance of the water footprints obtained in the present study. Why is this information needed? Farmers, for example, are not interested in optimizing water footprints; they are more interested in optimizing their economic return. The attempt to optimize the water footprint to benchmark levels provided in this study may also be misleading from an environmental or ecological perspective because these water footprints can only be achieved when nutrients are not limiting, thus require high nutrient inputs and consequently high nutrient losses. Currently, over-fertilization is another burning environmental problem in many cropping regions of China. Finally, from a hydrological perspective, it also sounds not logical to minimize the water footprint in humid regions (e.g. in Southern China) where water does not limit wheat yields and where water scarcity is not a problem for the society nor the environment. What I'm questioning here is the one dimensional focus on water productivity in the current study which makes it impossible to draw useful conclusions from the results.

Response: The purpose of developing water footprint (WF) benchmarks of a product is to provide an incentive for producers to reduce the WF of their products toward reasonable levels and thus use water as efficiently as possible (Hoekstra, 2013; 2014). In crop production, we agree with Referee #1 that farmers are more interested in optimizing their economic return. As water is one of the most fundamental resources for crop production and becoming increasingly limited for agriculture (Huang et al., 2002), undoubtedly, how to minimize the investment in water resources as well as water resources management and to maximum the production output at the same time (i.e. minimize the WF) are important issues in not only individual farmers' but also water governors' consideration for reaching their highest economic return. Therefore, setting WF benchmarks in crop production is necessary and essential for both water users and managers.

The magnitude of consumptive (green and blue) WF per tonne of a crop is determined by ET over the cropping period and crop yield. Therefore, reducing consumptive WF can be achieved by reducing ET or increasing crop yield. Mekonnen and Hoekstra (2014) summarized technology and practices to reduce the WF in crop production, which include three aspects: (i) increasing yield, (ii) reducing non-beneficial ET and (iii) enhancing effective use of rainfall. Evidently, it does not have to cost higher nutrient to increasing crop yield. Other than the simplest and direct way of increasing fertilization, wise soil and water management (e.g. appropriate tillage) and high technology improvement (e.g. breeding technology, plant biotechnology technology to improving crops' adaptation to natural stresses and diseases) (Huang et al., 2002) can also contribute to increasing crop yield.

The current results show that there is high potential to decrease consumptive WF of winter wheat in South China. South China has 81% of national blue water resources (Jiang et al., 2015). However, the risk of water shortage is increasing in the wet South with the operation of the South-to-North Water Transfer Project and the increasingly competition on the water resources by different sectors (Barnnet et al., 2015). Therefore, water saving and benchmarking WF for the South China are as equally important as for the drier North.

The current study, as an explorative study by taking winter wheat in China as the study case, aims to explore which environmental factors should be distinguished when determining benchmark levels for the consumptive WF of crops. We believe that the reported conclusions can serve as reference information for water managers and water scholars when estimating and setting WF benchmarks of crop production.

2.) The authors use a crop model to calculate water footprints but they completely miss to describe the model, its parametrization and its calibration. Therefore the results are not reproducible by external scientists. For example, the authors compare water footprints for warm and cold years. Temperature affects many different processes and to interpret the results of the study it is essential to know which effects have been considered in the model used here. How much is the difference in simulated evapotranspiration between cold and warm years and are the changes mainly an effect of different temperature or of associated differences in other variables, e.g. radiation or humidity? How is the effect of different temperature on crop yields? In general, higher temperature results in faster crop development and shortening of the period between sowing and maturity and therefore, in most cases, in lower yield. However, this effect can only be reflected in the model when the harvest date is considered dynamic. As far as I know AquaCrop offers two options: simulation with fix sowing and harvest dates and simulation with fix temperature sums. The shortening of the growing period can only be simulated when the second option is used. Therefore, description of the model parameterization and associated assumptions is essential. Furthermore, there is no information whether the model was calibrated, for which target variables the calibration was performed and which parameters were adjusted in the calibration process.

Response: We will add detailed content on model description, parameterization and calibration of the AquaCrop in the revised paper. In addition, we will discuss uncertainties from underling assumptions when modelling in the revised manuscript.

The core of methodology in the current study is to explore to which environmental factor the level of consumptive WF benchmark of crops most sensitive by making use of crop water productivity modelling. Therefore, we did not calibrate the simulated crop yield according to real statistics. We calibrated input crop parameters including crop calendar, reference harvest index, and maximum root depth for China's winter wheat. We validated the simulated WFs of winter wheat by comparing to available database with similar assumptions under similar hypothetical conditions, as shown in Section 3.7.

In order to be more clear, as suggested by Referee #1, we will add all the detailed information on the parameter calibration and improve the content on result validation in the revised manuscript.

3.) The target variable for the study is the consumptive water footprint which requires simulation of evapotranspiration and crop yield. Previous research (e.g. all these recent model inter-comparison studies) indicated a high uncertainty in present model results for both variables. Since only one specific crop model has been used for the present study it is a challenge to prove the reliability of the results, in particular when considering that the reported differences shown between cold and warm years, irrigated and rainfed wheat, humid and arid regions are relatively low (Tables 2-6). How did the authors validate their results? The comparison of simulated yield to yields simulated with a another model (Figure 8) and the comparison of province level yields reported for one specific year with potential yield simulated by the authors provide little evidence that spatial patterns and temporal dynamics in water footprints simulated for this study are reliable. Therefore, the section describing the model validation needs to be extended and improved.

Response: The current study goal is exploring which *environmental factors* should be distinguished when determining consumptive WF of crop production. As an explorative study, we make use of modelling results under a kind of hypothetical condition by only considering water stress impacts in crop growth, which is aiming to avoid effects of non-environmental factors (e.g. technology, fertilization). Therefore, it is not possible to calibrate or validate the result according to real statistics. What the best we can do and we have done is comparing the current simulated crop yields to available few data based on similar hypothetical modelling or simulations, as we described in the Section 3.7 Discussion. In addition, the performance of AquaCrop on crop water use and yield simulation has been widely tested and evaluated for variety of crop types under different conditions (e.g. Kumar et al., 2014; Jin et al., 2014; Katerji et al., 2013; Abedinpour et al., 2012; Mkhabela and Bullock, 2012; Andarzian et al., 2011; Stricevic et al., 2011; Heng et al., 2009; Farahani et al., 2009; García-vila et al., 2009). Furthermore, the core result reported in the current study is the relative differences between the consumptive WFs for different level of certain input variables that diminishes the uncertainties in the absolute magnitude of simulated results on crop ET, yield and finally consumptive WF. Therefore, we believe that the current reported results are valid and comparable to the results carried out by different crop models and can serve as useful referential information for water managers when setting WF benchmarks.

As suggested, we will improve the content on model and result validation by summarizing available relative information on the model performance in previous studies in the revised manuscript.

Specific comments:

- Which process explains differences in the water footprint across soil classes for the irrigated winter wheat? If drought is the only stress factor considered in the study, the soil class should not have an effect for the irrigated winter wheat.

Response: For the irrigated winter wheat, the different levels of ET defined the differences in the consumptive WF across soil classes. As we interpreted in the line 20-23 in page 7, the WF benchmarks for irrigated winter wheat in sandy soils are about 15% smaller than the WF benchmarks for the other three soil classes, due to relatively low ET. The low ET of sandy soil was resulted from the fast percolation of water below the root zoon.

-Tables 2-6: Do you really show averages in the last column or is it the median (50^{th} percentile)?

Response: We show the weighted averages in the last column in Tables 2-6.

References:

Abedinpour, M., Sarangi, A., Rajput, T.B.S., Singh, M., Pathak, H. and Ahmad, T.: Performance evaluation of AquaCrop model for maize crop in a semi-arid environment, Agricultural Water Management, 110, 55-66, doi: 10.1016/j.agwat.2012.04.001, 2012.

Andarzian, B., Bannayan, M., Steduto, P., Mazraeh, H., Barati, M.E., Barati, M.A. and Rahnama, A.: Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran, Agricultural Water Management, 100(1), 1-8, doi: 10.1016/j.agwat.2011.08.023, 2011.

Barnett, J., Rogers, S., Webber, M., Finlayson, B. and Wang, M.: Sustainability: Transfer project cannot meet China's water needs, Nature, 527 (7578), 295-297, doi: 10.1038/527295a, 2015.

Farahani, H., Izzi, G. and Oweis, T.Y.: Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton, Agronomy Journal, 101(3), 469-476, doi: 10.2134/agronj2008.0182s, 2009.

García-vila, M., Fereres, E., Mateos, L., Orgaz, F. and Steduto, P.: Deficit irrigation optimization of cotton with AquaCrop, Agronomy Journal, 101(3), 477-487, doi:10.2134/agronj2008.0179s, 2009.

Heng, L.K., Hsiao, T.C., Evett, S., Howell, T. and Steduto, P.: Validating the FAO AquaCrop model for irrigated and water deficient field maize, Agronomy Journal, 101(3), 488-498, doi: 10.2134/agronj2008.0029xs, 2009.

Hoekstra, A. Y.: The water footprint of modern consumer society, Routledge, London, UK, 2013.

Hoekstra, A. Y.: Sustainable, efficient, and equitable water use: the three pillars under wise freshwater allocation, Wiley Interdisciplinary Reviews: Water, 1, 31-40, doi: 10.1002/wat2.1000, 2014.

Huang, J., Pray, C. and Rozelle, S.: Enhancing the crops to feed the poor, Nature, 418 (6898), 678-684, doi:10.1038/nature01015, 2002.

Jiang, Y.: China's water security: Current status, emerging challenges and future prospects, Environmental Science & Policy, 54, 106-125, doi:10.1016/j.envsci.2015.06.006, 2015.

Jin, X. L., Feng, H. K., Zhu, X. K., Li, Z. H., Song-S. N., Song, X. Y., Yang, G. J., Xu, X. G. and Guo, W. S.: Assessment of the AquaCrop model for use in simulation of irrigated winter wheat canopy cover, biomass, and grain yield in the North China Plain, PLoS ONE, 9(1), e86938, doi: 10.1371/journal.pone.0086938, 2014.

Kumar, P., Sarangi, A., Singh, D.K. and Parihar, S.S.: Evaluation of AquaCrop model in predicting wheat yield and water productivity under irrigated saline regimes, Irrigation and Drainage, 63(4), 474-487, doi: 10.1002/ird.1841, 2014.

Mekonnen, M. M., and Hoekstra, A. Y.: Water footprint benchmarks for crop production: A first global assessment, Ecol Indic, 46, 214-223, doi: 10.1016/j.ecolind.2014.06.013, 2014.

Mkhabela, M.S. and Bullock, P.R.: Performance of the FAO AquaCrop model for wheat grain yield and soil moisture simulation in Western Canada, Agricultural Water Management, 110, 16-24, doi: 10.1016/j.agwat.2012.03.009, 2012.

Stricevic, R., Cosic, M., Djurovic, N., Pejic, B. and Maksimovic, L.: Assessment of the FAO AquaCrop model in the simulation of rainfed and supplementally irrigated maize, sugar beet and sunflower, Agricultural Water Management, 98(10),1615-1621, doi: 10.1016/j.agwat.2011.05.011, 2011.