Authors' responses to Interactive comments on "Physical versus economic water footprints in crop production: a case study for China"

Dear Referee #1,

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

Anonymous Referee #1

The study assesses the WF of 14 crops from 2001 to 2016 in both physical and economic terms for 31 provinces of China. It also analyzes the spatial agglomeration and the temporal trends of the WFs. This provides valuable information as to which crops have a higher economic return per unit of water consumed. However, it is not clear why some of the analyzes are needed and there is a lack of in-depth discussion on the interpretation of the outcome. I suggest that the authors address the following comments before the paper got accepted:

Response: We deeply appreciate your positive words and valuable comments.

#1 Subsection 2.2: The authors modeled crop yield using the AquaCrop model but used statistical output. The question is, why didn't you use the modeled yield? Don't you trust the outcome of your modeling? It is understandable that yield modeling has large uncertainty and may require a rigorous calibration of the model. Modeled ET and yield are consistent as both derive from the model, but to what degree is the ET consistent with the statistical yield? How reliable is the statistical yield?

On line 88, I see that the modeled yield was checked against the provincial statistical yield. How good was the modeled yield compared to the statistical yield? I suggest that you plot the modeled vs. statistical yield to show the fitting between the two results. You can add the graph for each crop as additional information. Please explain if you did some manipulation on the modeled yield so it matches the statistical yield.

Response: We are very sorry for our unclear expression and use of incorrect word.

The current calculation of water footprint is based on both the modeled ET and yield. Being consistent with the existing calibration method which has been widely applied (Mekonnen and Hoekstra, 2011; Zhuo et al., 2016a; Zhuo et al., 2016b; Wang et al., 2019; Zhuo et al., 2019), the modeled crop yield was calibrated at provincial level according to the statistics (NBSC, 2019). Within a province, we calibrated the average level of the modeled yields among station points to match the provincial statistics. Therefore, we kept the spatial variation in crop yields, so that in associated water footprints simulated by AquaCrop model. For sure, the calibrated yield was consistent with the modeled ET.

#2. Line 179 — 183: The interpretation of the SI is confusing. It seems to suggest larger SI to be better as province with larger SI are deemed to have "... (less water consumption per yield and higher economic benefits per water consumption unit). The SI is derived by comparing provincial WF and national average values. The result would thus mean, the province performs better in terms of generating higher economic benefits per unit of water. I would expect the SI value would be different if you compare two high performing provinces or evaluate the SI against a benchmark value instead of the national average value.

Response: We strongly agree with you that a reasonable reference value should be used for synergy evaluation between crop PWF and EWF. The choice of reference value is based on the purpose of the evaluation. In the current study, the SI measures, considering the spatial heterogeneities in crop WFs among provinces, the synergy levels between the current PWF and EWF. The synergy (both the PWF and EWF are lower than the national averages), trade-off (one is higher than the national average while the other is lower), or lose-lose (both are higher than the national averages) situation can be identified. The most optimized situation means high economic value generated by low water consumption. If the reference value is set by the WF benchmark (Mekonnen and Hoekstra, 2014), then the SI will show information on efficiency. The meaning is totally different from the current one. But we believe it will be a nice study for the future that we like to carry out. We will add the discussion on the possible recommendations on further studies and wider applications of the proposed SI approach in the revised manuscript.

#3. Please provide for each crop the yield, CWU, PWF, EWF for the irrigated and rainfed systems separately. This will help to see if there is difference in the economic WP of rainfed and irrigated systems.

Response: Yes, we will add a table consisting of the suggested information in the revised manuscript.

#4. The purpose of some the analyses are not clear e.g. Mann-Kendall. For the current study we don't need this analysis as the positive trend is visually clear from the figures. The authors themselves have used the test result on only one sentence (line 218-219).

Response: Thank you very much for your valuable comments. We realize that the description of Mann-Kendall (M-K) test results is too little, so we will add the explanation of M-K in the relevant paragraphs.

For example, as for line 218-219: "The M-K test results of each crop's PWF in table 2 further confirm the above views.", we can visually see the downward trend of PWF and upward trend of yield for both grain and cash crops at the national average level from Figure 2. However, the grain crop here was the weighted average result of six different crops (winter wheat, spring wheat, spring maize, summer maize, rice and soybean) and the cash crop was the weighted average result of eight different crops (cotton, groundnut, rapeseed, sugar beet, sugarcane, citrus, apple, and tobacco). The main cultivated crops in different provinces were different, and the PWF and yield of different crops had different time evolution trends, and the time evolution trends of the PWF_b and PWF_g of the same crop were also different. Therefore, we used M-K test for 14 crops to show more details. In Table 2, among grain crops, winter wheat had the lowest M-K statistical value in PWF (-4.547) showing an obvious downward trend, while the M-K statistic value of soybean was only -0.675, which meant that the PWF of soybean had almost no significant change.

We will improve the interpretation in relative places also including line 301-302: "The M-K test results in Table 7 further confirmed the above results, as the M-K statistical values of all crops' EWF passed the significance level test of $p<0.05$."

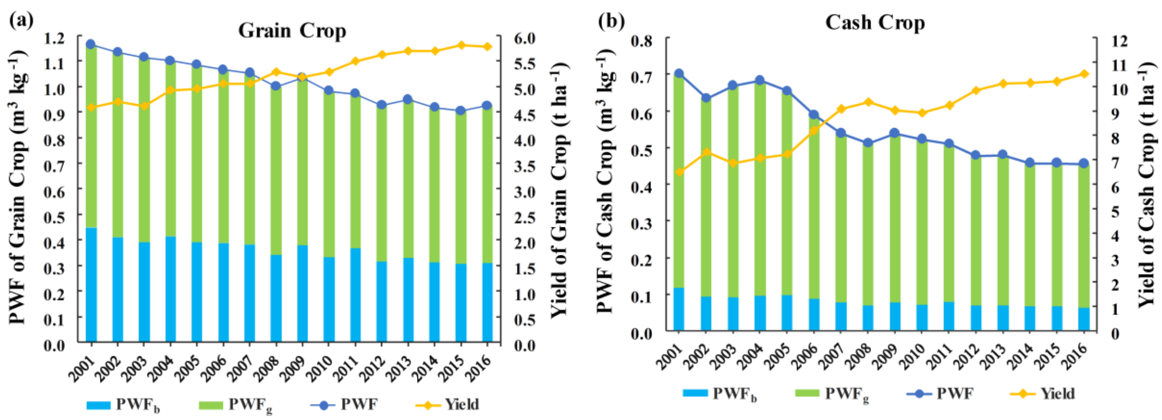

Figure 2: Interannual variability of national average production-based water footprint (PWF) of (a) grain and (b) cash crops in China over 2001-2016.

Table 2. M-K analysis of production-based water footprint (PWF) of the 14 crops.

		PWF ($m^3 kg^{-1}$)	PWF_b ($m^3 kg^{-1}$)	PWF_g ($m^3 kg^{-1}$)	Yield ($t ha^{-1}$)
Winter Wheat	Z_c	-4.547	-3.737	-4.547	5.178
	Signific	**	**	**	**
Spring Wheat	Z_c	-2.476	-0.135	-3.107	4.457
	Signific	*		**	**
Spring Maize	Z_c	-4.097	-4.097	-2.476	3.647
	Signific	**	**	*	**
Summer Maize	Z_c	-3.287	-3.647	-3.197	4.277
	Signific	**	**	**	**
Rice	Z_c	-3.377	-3.107	-3.017	4.637
	Signific	**	**	**	**
Soybean	Z_c	-0.675	1.846	-1.396	1.126
	Signific				
Groundnut	Z_c	-3.917	-3.467	-3.287	4.547
	Signific	**	**	**	**
Rapeseed	Z_c	-2.476	2.386	-2.476	4.097
	Signific	*	*	*	**
Cotton	Zc	-4.007	0	-4.187	4.277
	Signific	**		**	**
Sugarcane	Z_c	-2.476	-3.377	-2.116	3.467
	Signific	*	**	*	**
Sugar beet	Z_c	-4.457	-0.045	-4.457	4.727

	Signific	**		**	**
Apple	Z_c	-4.997	-4.907	-5.088	5.358
	Signific	**	**	**	**
Citrus	Z_c	-4.997	-4.997	-4.817	5.178
	Signific	**	**	**	**
Tobacco	Z_c	-2.746	-0.855	-2.836	2.926
	Signific	**		**	**

* Significant at $p < 0.05$, ** significant at $p < 0.01$

#5. The discussion is more on comparing the WF of the provinces and saying this WF is larger here and there (Line 226-247 and 371-400). The reader can read this fact from the figures. Please expand the discussion of the result and explain why the WF is large in one province and small in another. Is it climate, crop varieties, or what? Substantiate your argument with some references.

Response: Thank you very much for your suggestions. We recognize that the current description on results does not go far enough. Also, as Referee #2 pointed out, we should give more explanation about results not just the statement of the numbers. We will identify the main reasons behind these results in terms of variations in possible impacting factors including climate, cultivation scales, agricultural productivities, or cultivation distribution via substantiation by existing references. We will revise and shorten the current lengthy and inefficient sentences and expand the discussion focusing on explanation how the results came from in the revised manuscript.

#6. Please explain why there is spatial agglomeration of the EWP for the grain crops while none for the cash crops? What are the reasons for spatial agglomeration and what does it explain? Generally, provinces in the same climate region will have more or less similar WF. The price of the crops may also be dependent on the total production volume, demand for the crop, availability of market. Or are there other factors that play? Please discuss.

Response: Yes, for a same crop, the spatial variations of its PWF are defined by climate and productivity. The price is one of the main factors defining the EWF. While in related to the cluster maps shown in the current results for grain and cash crops, the main factor is the cultivation distribution. Regarding the grain crops, the cultivation distributions of major grain crops in China show obvious spatial agglomeration characteristics. For instance, rice is mainly distributed in central and southern China (Hubei, Hunan, Jiangxi, Guangdong and Guangxi). Winter wheat is concentrated in Huang-Huai-Hai Plain (Shandong, Henan, Jiangsu, Anhui and Hebei). Whereas regarding the cash crops, the dominant crop differs among provinces which resulted in obvious scattered characteristics in related WFs. For example, in the northwest regions, there is only Xinjiang where cotton is planted on a large scale, and almost no cotton is planted in the surrounding provinces.

In addition, crop prices in the main producing provinces are generally lower, while vary affected by the regional economic level. For example, both Henan and Shandong are the main producing areas of winter wheat, but the price

(0.21 USD/kg in 2016) in Shandong, which has a more developed economy, was higher than that in Henan (0.17 USD/kg).

We will carefully analyze further the displayed results and add discussion on the reasons behind to improve the manuscript.

#7. Line 442-443: the statement seems to suggest that to improve the green water, rain water harvesting and storage should be improved. Is rainwater harvested green water or blue water? You need to be clear what you mean by the rainwater harvesting. If the farmer builds small retention pond to collect rainwater, the farmer is collecting blue water not green. But if a farmer manages his field to increase the water retention through tillage system and mulching, this is increasing the green water. Please clarify your suggestions.

Response: Yes, we should clarify the green and blue water in statements. Sure, water supplied by rainwater harvesting is blue water (Hoekstra, 2019).Therefore, we will rewrite the pointed sentence like "Therefore, the utilisation efficiency of green water resources should be improved through water retention by tillage system and mulching. Meanwhile, more blue water can be generated through rainwater harvesting (Hoekstra, 2019). ".

#8. Line 444-445: the statement "As for northern China, green water (rain water) should be converted into blue water (irrigation water) as far as possible, so as to reduce blue water consumption while ensuring and increasing economic benefits." is not clear. What do you mean the green should be converted to blue? How do you convert green to blue? Do you mean, we need to increase irrigation?

Response: We are sorry for the confusion because of unclear writing. Specifically, we mean two measures to increase the blue water efficiency in northern China. One is the rainwater harvesting in rainy season, especially for the short-time heavy rain which cannot effectively used by crops but easily cause soil erosion. It is the process of transferring green to blue water. The other one is reducing blue water consumption and loss at field by popularizing water-saving irrigation techniques and mulching practices. Such measure is helpful to improve the utilisation efficiency of both blue and green water.

We will clarify the relative discussion in the revised manuscript.

#9. Line 446-448: the statement is an empty statement: " The necessary way to alleviate the contradiction between water resource consumption and economic value creation is to adjust the agricultural production mode and the irrigation method according to local conditions." What do you find from your study and what practical ways do you suggest? How do farmers or policy makers adjust the agricultural production mode?

Response: Thank you very much for your comments. Based on the current results, we recommend the government to improve agricultural water use efficiency through the application of water-saving irrigation techniques and better management of all agricultural inputs, especially in northwest China. High water consumption and low economic value crops' acreages in non-primary production areas should be reduced. For the southern regions with abundant rainwater resources, the economic benefits of irrigation are very limited, on the contrary, rain-fed agriculture has obvious advantages and the potential to increase economic benefits. Therefore, farmers should improve the water conservation rate and the utilization efficiency of green water through farming system and coverage to reduce the amount of water used for irrigation. The government should also give financial subsidies for agricultural production to those provinces where there were lose-lose relationships between reducing the water resources input for harvesting crop yields and optimizing the economic benefits per unit of water consumption. Finally, it is necessary to improve the field managements especially in utilization rate of chemical fertilizers and pesticides to increase agricultural productivity further. Previous studies have shown that less than 50% of the fertilizer applied to fields actually fertilizes the crops for which it was intended, with the rest leaching into the environment (Zhang et al., 2013).

We will think more deeply and add more references to come up with more realistic proposals in the revised manuscript.

#10. There is a statement in a number of places (lines 186, 371, 447, 468, 492) that reads, "contradiction between water consumption and economic value creation". There is no contradiction between water consumption and value creation. You cannot create value without water consumption. The issue should be how we optimize the value creation per unit of consumed water. Please rephrase your sentences.

Response: We are very sorry for the loose expression. It is also pointed by Referee#2. In the revision, we will check through the text and correct the word "contradiction" into "trade-off" or "lose-lose" accordingly.

#11. On Table 4, the $EWP_{g,ir}$ is almost half of the $EWP_{g,rf}$. Why is that? Is the equivalent rainfed yield under the irrigated condition double that of the rainfed yield? Or the $CWU_{g,ir}$ is half of the $CWU_{g,rf}$? Generally, $CWU_{g,ir}$ is slightly lower than $CWU_{g,rf}$ but cannot be close to half. Please explain.

Response: Table R1 lists the average annual blue and green CWU and yield under irrigated and rain-fed condition by crops in China from 2001 to 2016. It can be seen that for all the crops, $CWU_{g,ir}$ was 23% (sugarcane) -51% (spring wheat) smaller than $CWU_{g,rf}$. Therefore, it is possible to result in $EWF_{g,ir}$ being much smaller than $EWF_{g,rf}$. We will add explanation on such results in the revised manuscript.

Table R1. The average annual blue (CWU_b) and green crop water use (CWU_g) and yield (Y) at irrigated and rain-fed fields by crops in China from 2001 to 2016.

	Irrigated			Rain-fed	
	$CWU_{b,ir}$ (m^3 ha^{-1})	$CWU_{g,ir}$ (m^3 ha^{-1})	Y_{IR} (t ha^{-1})	$CWU_{g,rf}$ (m^3 ha^{-1})	Y_{RF} (t ha^{-1})
Winter Wheat	3559	2694	5.13	4675	3.98
Spring Wheat	4448	1795	3.91	3661	2.60

Spring Maize	4022	2454	6.85	4504	5.22
Summer Maize	2543	2810	5.30	4605	4.99
Rice	2768	2705	6.64	4444	5.85
Soybean	3141	2721	2.10	4562	1.57
Groundnut	3466	2793	3.43	4662	3.23
Rapeseed				2122	1.81
Cotton	4920	3007	1.50	5099	1.19
Sugarcane	4244	5534	123.71	7178	63.15
Sugar beet				3818	39.64
Apple	4278	3439	16.68	5235	14.70
Citrus	3612	5073	12.39	7764	11.74
Tobacco	2204	2552	2.23	3622	1.99

Minor comments

Please provide the spatial scale of the analysis in the last paragraph of the introduction section. I see in the discussion section that the analysis was done at a meteorological station level. How many stations per province?

Response: Yes, we will add a table showing the number of meteorological stations per province in the revised manuscript.

Please provide the definition of "synergy evaluation index", what it does and how to interpret the result.

Response: We will add the following definition in the revised manuscript at the start of section 2.4.

The synergy evaluation index (SI) in the current study is the measure of the synergy levels between the PWF and EWP of crops, by summing up their corresponding difference between the water footprint and the base value divided by the range (the maximum minus the minimum) of the water footprint. Here, we adopt the national average level water footprint value as the reference for comparison.

Line 30-31: change occupation to consumption on the following sentence

"The water footprint (WF) (Hoekstra, 2003) reveals the occupation and pollution of water in the process of production or consumption and ...."

Response: We will correct the word in the revision.

Lin 52: the sentence is not clear - what do you mean by “WF coordination”?

Response: The WF coordination in current study indicates that the PWF and EWF of one province are both lower than the national averages, then it shows a good synergy in reducing the water resources input for harvesting crop yields and optimizing the economic benefits per unit of water consumption, compared with national average level.

Lin 57: Remove the period before (Tilman et al., 201 I;Gao and Bryan, 2017;Cui et al., 2018)

Response: We will do the correction in the revision.

Line 100: add reference to Hoekstra (2019)

Response: We will add the reference in proper places in the revision.

Reference

Hoekstra A Y (2019) Green-blue water accounting in a soil water balance. AdWR 129:112-117. doi: https://doi.org/10.1016/j.advwatres.2019.05.012

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