Response to comments from reviewer RC3

Note that reviewer's comments are in italic black, and responses in plain blue font.

General comments:

The research on "Changing global cropping patterns to minimize blue water scarcity in the world's hotspots" used a linear optimization algorithm to assess how to change global cropping patterns to reduce blue water-scarce hotspots, with the constraints of global production per crop and current cropland areas. Below are my comments and suggestions:

We thank the reviewer for his critical comments and suggestions.

1. The linear optimization algorithm is set for an optimal reduction of blue water scarcity by changing global spatial cropping patterns. The algorithm set an upper limit of the expansion in cropland by a certain maximum rate for each crop per country (the factor ð˙IZij), and also limit total cropland to the reference extent. However, there is no lower limit of decrease in cropland area, which means cropland area (or crop production) for some crop types would decrease a lot or even disappear (as shown in results part).

Why you set an upper limit, but without a lower limit? If you also set both upper and lower limits of changes in cropland for each crop, do the results change?

The upper limit is set in order to prevent countries to unrestrictedly expand their cropland in crops where they have comparative advantage. The modest allowed changes in cropping areas of individual crops are aimed to avoid implausible expansions of crop production into cropland areas with significantly different rainfed and irrigated land productivity than where the specific crop is produced currently, due to the heterogeneity within a country (e.g. covering different agroecological zones). However, we do allow countries to decrease their cropland freely without setting a lower limit because here the plausible physical validity of the production characteristics is not compromised. In fact, moving from irrigated production to rainfed production as much as possible is directly related to maximizing the reduction of blue water use and thus blue water scarcity which links to the research objective of this paper.

We expect a significant change in the results if we do set a lower limit to the allowed change in cropland for each crop. The changes will be more apparent for the most water-scarce countries. We will implement your suggestion by performing a sensitivity study to adding lower limits to cropland per country, crop and production system. If relevant we will add some discussion and show some results in the supplementary information of the paper.

2. Blue water scarcity (BWS): BWS is defined as the total blue water footprint divided by the blue water availability in the country. Here blue water footprint only includes agriculture sector, without water footprint for domestic and industrial. Blue water availability is the natural runoff, which follows Hoekstra et al. (2012), right?

We acknowledge the validity of the point highlighted by the reviewer. Indeed, blue water has other uses than the agricultural sector (e.g. domestic and industrial). However, the share of agriculture consumptive water use is by far the largest, accounting for 92% of water consumption globally (Hoekstra and Mekonnen, 2012) (mentioned in the submitted version of the paper Line 69-70).

We also thank the reviewer for his suggestion to clarify the definitions of the terms used. We, therefore, added the following:

"Blue water footprint (BWF) refers to the volume of consumptive freshwater use for irrigation that comes from surface and groundwater. Blue water availability is taken from FAO (2015) and refers to the total renewable (internal and external resources) which is the long-term average annual flow of rivers (surface water) and groundwater (FAO, 2003).

3. L145: "A country is considered to be under low, moderate, significant or severe water scarcity when BWS is lower than 20%, in the range 20-30%, in the range 30-40% and larger than 40%, respectively (Hoekstra et al., 2012)". Hoekstra et al (2012) analysed the BWS at basin level and monthly time scale. But this study assesses water scarcity at country level and annual time scale, I think more discussion is needed to illuminate whether the index used here is suitable.

We fully agree that considering BWS at national and annual resolution may (and will) hide scarcity localised in time and space. This does limit the interpretability of results at the coarse resolution, and we acknowledge that the discussion on the suitability could be more explicit. We also note that FAO has selected the very similar indicator of Water stress (freshwater withdrawal as a proportion of available freshwater resources) at country and region level as indicator 6.4.2 in the SDG framework (UN-Water, 2018). Next, we will add a variation of the current optimization exercise, contributing to assessing the sensitivity of results to the assumed availability of total renewable freshwater at irrigation areas.

4. L148: why you choose maximum national blue water scarcity in the world as the indicator for optimization?

Within the framework of the Sustainable Development Goals, SDG 6.4.2 (Level of water stress), is used as an indicator for Goal 6. Ensure availability and sustainable management of water and sanitation for all; it is defined similar to water scarcity here, also at the resolution of countries, but based on water extractions rather than consumptive water use. Where lowering the water stress level is a goal for each country, from a global equity perspective lowering stress in countries with highest water scarcity is prioritised. This is operationalised by choosing the maximum national water scarcity as an objective function in the optimization.

5. There are too much results about the changing cropping patterns and comparative advantages. I think the authors could add more explanation on the mechanism behind the changes, especially for some typical countries.

We thank the reviewer for his suggestion. We will try to reshape our results section and bring some additional explanation on the mechanism behind the changes for some typical countries.

6. Discussion part: Previous studies have done a lot of works on the impacts of changing cropping patterns, international food trade and better water productivity on water scarcity (as list in introduction part). I think the discussion part should add more about the similarity and difference between the results in this study and previous studies.

We will highlight our results in the context of previous studies in the discussion part. For instance, we added the following in the discussion part:

"Changing cropping patterns have reduced global blue water footprint by 9%. However, not all countries benefit the same in the optimized set, India and China, for example, will have a slight increase in their blue water consumption by 5% and 4% respectively. This supports the findings of Davis et al. (2017a) who observed that water scarcity persists in many important agricultural areas (the US Midwest, northern India, Australia's Murray-Darling Basin, for example), indicating that extensive crop production in these places prohibits water sustainability, regardless of crop choice (Davis et al.2017a). In big countries such as India and China, a 4 or 5 % increase in their BWC may seem tiny. However, it could have a negative impact if it occurs in very severe regions of these countries."

7. More discussions should focus on how the results represented in this study could guide global international food trade, as well as cropping patterns to cope with global water scarcity, especially under future climate change and socioeconomic development. For example, blue water scarcity would intensify in the future as reported in previous studies. And following the results in this study, a water-scare country could reduce agriculture water scarcity by reducing cropland area for some crop types, and import crop production from other countries.

We will add discussion in the direction suggested by the reviewer. This closely links to comment 5, where we agree that the extensive result reporting took away from highlighting main patterns in findings that can feed into discussions on the role of agricultural trade in water scarcity alleviation policy.

8. L188ïijŽ" When α is equal to 1.3, 1.5 and 2.0, the maximum national blue water scarcity in the world is reduced to 6%, 4% and 2%, respectively." In my view, a larger α would result in greater global blue water scarcity reduction, but current study shows the opposite result. So I just wonder the definition of "the maximum national blue water scarcity in the world"?

Indeed, a higher alpha result in a larger water scarcity reduction. We will rephrase to better emphasize that a WS reduction to a maximum water scarcity of 2% (for alpha = 2) is a further-reaching reduction than a reduction to 6% for alpha =1.3, thus avoiding that *reduced to* is interpreted as *reduced by*.

9. Figure 4. This figure is not clear. Please give the unit and meaning of this figure.

We thank the reviewer for his suggestion. We edited the title of Figure 4 to include more information about the Figure and make it easy to understand. The title of the Figure is now the following:

"Relative change in production (production in the optimized cropping pattern divided by the production in the reference situation) per country and per crop group for the case of an optimized cropping pattern with α = 1.5 (relative change = 1: no change, relative change < 1: countries production will be reduced and relative change > 1: countries production will be expanded)".

10. Figure 5. There are only tiny differences between figures in the left and right. It's better to show the differences or relative changes.

We agree to the comment and will show the differences in absolute terms (one map for each crop groups showing the difference between the reference situation and the optimized set).

References:

FAO: Review of World Water Resources by Country, Water Reports 23, Food and Agriculture Organization of the United Nations, Rome, Italy, 2003.

UN-Water: Progress on Level of Water Stress – Global baseline for SDG indicator 6.4.2. UN-Water, Geneva, Switzerland, 2018.