Interactive comment on "Marginal cost curves for water footprint reduction in irrigated agriculture: guiding a cost-effective reduction of crop water consumption to a benchmark or permit level" by Abebe D. Chukalla et al.

Reply to Anonymous Referee #4

We thank Referee #4 for the comments; below we give the reply to the comments.

Comment

The paper tries to derive marginal costs curves for water footprint reductions. In summary, the paper calculates costs and savings of standard practices using the standard tool Aquacrop for 3 european locations plus Israel. The concept is straightforward and therefore of limited originality. The author claim to be the first doing this type of analysis, while later in the paper they admit it has been done previously in the same context but slightly different condition. The difference is relation to water footprint, which is in this context very specifically defined (and only late in the paper). The definition deviates from international standards and should be introduced early in the paper (acknowledge the different definitions and provide rationale for the chosen approach). Additionally, the scope is very narrow (selecting 4 locations) but not having actual case study data and thus being theoretically. However, the topic as such is not novel and might be suitable for an irrigation journal.

Reply:

We agree with the referee comment that the definition of water footprint (WF) is introduced later in the paper. In the introduction part of the revised paper, we will add the WF definition and the rationale on the chosen approach: "*Reducing the non-beneficial consumptive water loss is a means of demand management to increase water use efficiency and thus reduce water scarcity (Mekonnen and Hoekstra, 2016). In crop production, reducing the non-beneficial consumptive water use is possible by decreasing the ratio of evapotranspiration (ET) over the growing period to the crop yield (Y) or increasing the inverse ratio (Y to ET). The first ratio is called the water footprint of crop production (Hoekstra et al., 2011); the inverse ratio is called water productivity (Molden et al., 2010).*"

There are model-driven and expert-based approaches to develop the MCC; the two approaches have been applied extensively in *carbon footprint* reduction. In the area of WF reduction, the expert-based approach has been applied only once, in a case for the industrial sector (Tata-Group, 2013). The current paper pioneers by introducing a *model-driven MCC* in the area of WF reduction and by applying a MCC for water footprint reduction in *irrigated agriculture*. In addition to MCCs, we show the plausible WF reduction pathways, which requires insight in the agronomic plausibility of successive implementation of field scale measures. The approach is highly original and much needed, filling the gap of existing literature on water footprint reduction which generally lacks the practical and economic component: what are the subsequent steps and associated costs to achieve increasing levels of water footprint reduction.

The referee is right we did not use field measured data for validating the simulated result. This limitation puts a disclaimer to the simulated results of our study, but we believe that the results of this study provide a useful reference for similar future studies with other models. Basically we develop an advanced method to develop MCCs and WF reduction pathways for irrigated agriculture.

Comment

All regions are high income countries and therefore this needs to be stressed in the title (add in high income regions). Also cost data is partially only representative of EU conditions.

Reply:

We will add the description of the case study areas in the abstract and introduction section of the revised version of the paper.

Comment

One major flaw in the analysis is the lack of accounting of important costs such as fertilizer and land, which is completely omitted but highly important, since land is typically limited and therefore deficit irrigation has a yield reduction (which is a land cost increase). The results are therefore to be reconsidered.

Reply:

The study is not a full cost benefit analysis of crop production. The study is a cost-effectiveness study to achieve a certain water footprint reduction. We include marginal costs and benefits associated with changing different components in the overall management practice. Costs of fertilizers are a highly relevant element of cost for a farmer, but we don’t change fertilizer application practice, so there are no changes in this respect. The costs of land are also relevant, but we consider a fixed field, which means no change in land costs. Moving from full irrigation to deficit irrigation indeed involves yield reduction, but in our study yield reduction from deficit irrigation is kept under 2%.

Comment

L 14 The authors write about water footprint permit per hectare, which needs to have a rationale

Reply:

With the overall increasing demand for water and effect of climate on water availability (Hanjra and Qureshi, 2010), there is fierce competition among various water using sectors. The rationale behind a WF permit per hectare is that the water availability per catchment is limited to runoff minus environmental flow requirement. When dividing the maximum amount of water available in a catchment over the croplands that need irrigation, one finds a maximum volume of water available per hectare of cropland. This could be translated in water allocation policy into a max WF permit per hectare. This is just one way of promoting water footprint reduction in areas where that is needed. Another way is to create incentives to reduce the WF per unit of production to a certain benchmark level. The MCCs we develop can be used for analysing cost-effective WF reduction given either a target level for WF per unit of crop or a target level for WF per hectare.

Comment

Introduction in general: The authors mainly cite their own work, while it is important to give a broader overview, especially in a diverse field such as water footprint, where many different water footprint concepts have been published and the reader needs to be informed what is done here and how this relates to other work.

Reply:

We are aware as there are debates on water footprint concepts and methodological assessment phases between the life cycle assessment (LCA) and water footprint assessment (WFA) approaches (Chenoweth et al., 2014;Pfister et al., 2017;Hoekstra, 2016). The two approaches differ in their impact/sustainability assessment stage, not in the way they account water consumption in their inventory/accounting stage (Boulay et al., 2013). The current study focuses on cost-effective reduction of water consumption from a field, whereby it does not make a difference on whether we take a WFA or LCA perspective.

Comment

L100: here it is important to talk about land use costs too

Reply:

The study is on MCC for reducing WF per hectare, which informs us about cost of saving water per ha, and on MCC for reducing WF per tonne, which informs us about cost of increasing water use efficiency. We do not aim to represent an agro-economic cost-benefit analysis with inclusion of the costs of all input factors and all revenues. We make sure that yields remain within 2% of the max yield, so that is why we left out reduced revenue at the cost side. We will better highlight this in the paper (now this remark is hidden in method section 2.2).

Comment

Section 2.2 is basically directly summarizing Aquacrop and might be moved to Appendix as it does not provide important additional information (at least it can be summarized).

Reply:

In Section 2.2 we don't really summarize Aquacrop, but highlight the way we implement the different measures in Aquacrop, just to be fully transparent about our analysis.

Comment

L188ff: The authors talk about green water and differentiating it form blue water. However, there is no way this can be properly done nor is there any hydrological definition of green waster vs. blue water. However, if the concept is used, literature refers to green water as soil moisture (see Falkenmark et al) and thus this is in conflict with previous research. I suggest to omit as it does not add meaningful information.

Reply:

We follow the broadly agreed interpretation that blue water in the soil refers to irrigation water (derived from groundwater or surface water) and that green water in the soil stems from rainwater (Falkenmark and Rockström, 2006). The green and blue fractions in total ET are calculated based on the green to blue water ratio in the soil moisture, which in turn is kept track of over time by accounting for how much green and blue water enter the soil moisture, following the accounting procedure as reported in Chukalla et al. (2015).

Comment

L204-206: What about fertilizer use? Is this assumed to be optimal? What are the cost related to it?

Reply:

Yes, we assumed optimal fertilizer. The cost of fertilizer is not considered as it is not required to develop the objective of the paper, developing MCCs for reducing WF.

Comment

L208. The authors define water footprint cutting supply chain (which is commonly included even by the author's own references on water footprint). E.g. seedling and fertilizer water use should at least be mentioned.

Reply:

The WF of a *product* is equal to the WF of the *processes* to produce the product, considering all processes over the supply chain (Hoekstra et al., 2011). In the current study we just focus on the process of crop growing, hence we just look at the WF at field level, not the WF of inputs to the process. We will highlight that in the paper.

Comment

Section 2.4. Since major aspects (land and fertilizer costs) are omitted the analysis is very theroetical and not covering the full picture. Additionally the author mix data form global sources and European, while it is used for the European context. Adjustments to price levels needs to be discussed. Some data is really old (1992)

Reply:

Using up-to-date cost data that reflect the market value of the technologies would have been our interest, but we notice that getting such data is difficult. For our purpose, showing a method rather than evaluate a specific case, the data we used suffice. We will advise readers to use the paper as a guide to develop MCCs for WF reduction rather than take all data for granted. Each specific case will require its own data.

Comment

L260. Where is the StDev presented?

Reply:

We indicate the uncertainty around the cost using whiskers in Fig. 3, 4, 7 and 8.

Comment

L293: the scope of the study (locations etx) should be presented at the beginning,
since up to this point the reader supposes it is a globally relevant study.

Reply:

We will add the location of the study both in the abstract and introduction section of the revised paper.

Comment

Results: the results must be revised after inclusion of the additional costs. Also they should report uncertainties. this also applies to the discussion. **Especially the main finding that deficit irrigation is useful (even win-win based on this study) the authors should also discuss why there is still potential for it and why it has not been done already (what are the constraints etc).**

Reply:

We will reflect on the cost uncertainties and why deficit is not practiced yet in the discussion and conclusion section of the revised version of the paper.

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