"Impact of environmental changes and land-management practices on wheat production in India" by Gahlot et al. submitted to Earth System Dynamics

RESPONSE TO COMMENTS BY THE REVIEWERS

Reviewers' comments are in blue and our responses are in black font

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Response to Reviewer 1

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Based on a dynamic land model, the authors developed the growth processes for spring wheat using field experiments and studied the effects of different environmental factors and land management practices on the spring wheat production in India. The authors have shown that both the increase in CO2 concentration, availability of water through irrigation and additional nitrogen fertilizer enhance the annual wheat production, while the elevated temperature reduces total wheat productions. The authors also investigate the impact of the above factors on wheat production at five spring wheat environment (SWE) regions. The paper is written in a very decent way and the results contribute to our understandings of the impact of induvial environmental factors on wheat production in India.

We thank the reviewer for such encouraging comments.

I have only some minor points to make. First, in the Results section, you discussed changes in the overall wheat production. It might be interesting to also include changes in its components, like gross production and respiration in a table.

This is a very important point. The research work on the development of the spring wheat module was conducted in two parts. This paper deals with the first part where we focus on crop growth features like LAI, biomass and production. Adding GPP and respiration as a table can be done but will not do justice to such a complex issue. We are currently working on the second paper where we study carbon dynamics in spring wheat agroecosystems in a comprehensive manner. That paper will include evaluation of variables like GPP, respiration, NEP etc. against field observations, trends in these variables and how they are affected by environmental and anthropogenic forcings. Adding all these elements will make the current paper unfocussed, unwieldly and long. That is why we prefer not to add carbon fluxes so we can focus on wheat growth and production.

Second, in section 3.3, you analyzed the wheat productions in five SWE regions and their associations with different environmental factors based on the control simulation results. You can also do a similar calculation as done at the country-scale, by comparing results between the control simulation and four sensitivity simulations (that is, you set a constant value to each environmental factor one at a time). In this way, you can probably see the impact of different factors on wheat production at different regions and quantify their overall contributions to the country-scale changes.

We thank the reviewer for this suggestion. This is a valuable suggestion that will add to the understanding of SWEs. We will do the analysis for SWE-specific impact of each external driver on wheat production and add the results in the form of a new table in the paper. Details of this analysis will also be added in the Results and Discussions section. The knowledge added by this additional text will contribute to a comprehensive understanding of wheat production patterns in India.

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Response to Reviewer 2

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This study uses the land surface model, ISAM, to examine the effect of different environmental factors, including atmospheric CO2, temperature, nitrogen fertilization, and irrigation on spring wheat production in India. First, the authors implemented spring wheat processes in ISAM by updating C3 crop parameterizations. After calibrating and validating the updated model against available observations, ISAM is applied to explore environmental and land management factors on Indian wheat production. It is found that during the last 30 years, increasing atmospheric CO2, addition of nitrogen fertilizer, and irrigation act to increase the production of spring wheat, but increased growing season temperature causes a loss of wheat production due to increased heat stress. Regional scale analysis of environmental factors and land management practice shows that Indo-Gangetic plain is the best region for growing spring wheat in India, C1 ESDD Interactive comment Printer-friendly version Discussion paper and Northwestern India is the least productive region for wheat growth. This study makes a useful contribution to boost our general understanding in the effect of environmental change and land management on crop yields and production. The manuscript is in general clearly written. I recommend its publication after the following issues are addressed.

We thank the reviewer for the encouraging comments

Lines 61-63: This sentence is hard to read. Please rephrase.

We will modify the following lines in the current paper text:

61 Studies that cover the impact of land management practices of irrigation and addition of
62 nitrogen input on crop production aid in giving an overall understanding of the scope of
63 improvement in planting and managing the crop to enhance production (Tack et al. 2017).

to:

Quantification of the impact of land management practices on crop production helps in understanding how the croplands can be managed to improve production (Tack et al. 2017).

Line 105: How big is the wheat experimental site?

The experimental plots are approximately 650 sq m. We will add this information to the text.

Lines 139-140: What are these major plant functional types?

There are 30 PFTs in ISAM. These include different types of forests (e.g., evergreen needleaf deciduous broadleaf, etc.), savannah, croplands, pastures and urban areas. Providing a full list of PFTs is not necessary for this paper because we are focusing only on the croplands area. For brevity, we have provided details that are directly relevant for this study. of the An interested reader can find descriptions of the PFTs and other details in Barman et al. 2014a, 2014b; Song et al. 2013, 2015, 2016; that are cited in the text.

Line 179: Where 'the climate driver' data come from? Also, the reference of Meinshausen et al., 2011 is missing.

The climate data is taken from Climate Research Unit (CRU)-National Centre for Environment Prediction reanalysis (Viovy et al. 2018). The citation for CO_2 data will be corrected to Le Quéré et al. 2017 in the text which was previously mentioned as Meinshausen et al., 2011.

Line 179 will be changed to:

The model is spun-up by recycling the climate data (CRU data, Viovy et al. 2018), [CO_2] (Le Quéré et al. 2017) and airborne nitrogen deposition (Lamarque et al. 2011) data for 2015-16 until the soil temperature, soil moisture, the soil carbon pool and the soil nitrogen pool reaches a steady state.

Line 225: Section 3.2 Here the effect of a single factor (CO_2, temperature, etc.) is obtained by subtracting the simulation that includes the effect of all factors (CTRL) from the simulation that excludes the effect of a certain factor. Thus, the effect includes interactions with other factors. How would it compare with the sole effect of a certain factor by keeping other factors constant? (For example, suppose a simulation in which only atmospheric CO_2 changes to represent the CO_2 effect). Some discussion on this issue would be helpful.

The current experiment design accounts for how the different input drivers have contributed to the wheat production as we see it today. Since the interactions between the input drivers are non-linear, and process-based models allow for such interactions, the current experiment design accounts for such non-linearities and interactions. The alternate experiment design, in which only one factor is varied, does not allow such interactions since all other inputs will be kept constant. Such experiment design can be used to study how each input driver can contribute to wheat production, but the results will not be able to match with the actual production numbers in the country because of lack of representation of interactions and feedbacks in the experiment design.

Also, what are the nonlinear interactions among different factors? Does the sum of individual effects add linearly to the combined effect? The authors stated that changes in atmospheric CO_2, irrigation, fertilizers, and temperature led to 39%, 15%, 20% and -16% changes in countrywide production. So, what explains the residual change in wheat production that are not attributed to these factors? Some discussions should be added.

The Earth System is a nonlinear system where different components interact with each other. We used a process-based model that includes such interactions including interactions between different drivers. For instance, higher temperatures increase the crop water demand. Higher [CO2] increases photosynthesis that also affects nutrient and water demand. Because of these interactions, the sum of the effects will not add up to 100%. Moreover, the experiments are not exhaustive; there are other factors like relative humidity etc. that affect production. We will add a discussion to this effect in the revised manuscript.

Lines 256-257: ‘2’ -> ‘two’

The suggested change will be implemented.

Lines 431-432: This sentence lacks a context. How does this study imply that ISAM will likely provide better estimate of terrestrial carbon flux?

Currently ISAM uses a generic crop model to simulate all the agroecosystems of India. Using crop-specific models like the spring wheat model developed in this study will improve the simulation of crop phenology over wheat agroecosystems. This will likely lead to better simulations of the spatio-temporal variability in carbon dynamics. We will add this discussion to the Conclusions and Discussions section of the paper.

Table 1: For the experiment S_{TEMP} that assumes no temperature change, I assume other climate fields such as precipitation and humidity change with time. If so, to what extent changes in other climate fields such as precipitation and soil moisture contribute to the ‘direct’ heat stress effect? Some discussions should be provided.

The effects of climate variables of temperature and precipitation have been studied separately in the runs S_{TEMP} and S_{WATER} respectively. The S_{WATER} run, as described in Table 1, allows for no precipitation change and no irrigation. Other climatic variables like humidity are allowed to change with time in all simulations. Soil moisture is calculated in the model based on soil water balance with inputs of precipitation, irrigation, soil type etc.

Table 3: statistic test should be done on the trends shown here.

We will add statistical significance of the results presented in this table.

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Response to Reviewer 3

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Comments on the MS The manuscript entitled "Impact of environmental changes and land-management practices on wheat production in India" is a very good study to quantify the role of various environmental factors and agricultural management practices on spring wheat production in India during 1980-2016 by Integrated Science Assessment Model (ISAM). Elevated atmospheric CO2 and rising temperature are considered in environmental factors while nitrogen fertilizers applications and water availability through irrigation practices are considered in land management factors. The author's effort is commendable however some minor corrections needed in the draft.

We thank the reviewer for the positive comment.

1) From 1980-2016 for every ppm rise in [CO2] level total wheat production of the country has increased by 0.37 Mt and 39% increase in production compared to the 1980-84 period (Fig. 6a; R2 0.97 while described in the draft R2 0.93) and thus a strong positive correlation has observed. While during the same period total wheat production increased at the rate of 0.10Mt for every kg nitrogen fertilizer-N/ha applied to the farm and 20% increase in production compared to the 1980-84 period (Fig. 6c; R2 0.39), a decrease of 8.38 Mt (_10% reduction) of wheat per degree Celsius increase in the average growing season temperature (Fig. 6b; R2 0.26) and 15% increase in production compared to the 1980-84 period due to increased irrigation. (Fig. 6d; R2 0.13). These factors have not shown a strong correlation that needs to improve.

If we understand correctly, the reviewer is asking us to improve the correlation between some of the forcings and the corresponding impact. This cannot be done because the correlations are outcomes of numerical modelling experiments. We cannot improve the values but can provide an explanation. Figure 6 plots the forcings and the impacts at the country-scale. The CO_2 forcing is uniform across the country but the others forcings are not. There is strong spatial variability in the temperature, fertilizer and water demand forcings and their impacts. This is why we have developed the SWE approach to explore the forcings at regional scale. These patterns will be clearer when we analyse the data further as suggested by Reviewer 1.

The r2 values mentioned in Fig. 6a is correct. The text will be corrected accordingly. We apologize for this oversight.

2) In the draft different equations of the models are not shown e.g. Eq. A1, A2, A3 (line no. 170), Eq. A4, A5 (197); Eq. A6, A7, A8 (205); Eq. A9 (207), Eq. 10 (233), Eq. 11 (259) or may be included in the additional/supplement materials.

All the equations are already included in the supplementary material.

3) Data for the actual amount of water used for irrigation is not available. So in the SCON simulation, every grid cell is considered 100% irrigated and crops do not undergo water stress at any point in the growing season and all the regions are 100% irrigated. Since wheat is a non-monsoon crop, is highly dependent on the availability of irrigation. The development of irrigation water use datasets could reduce the uncertainty in simulating the effect of water stress on crop production.

We agree with the reviewer's comment that irrigation water use datasets can help in reducing the uncertainty in simulating the effect of water stress on crop production. We have already mentioned this in the Conclusions and Discussions sections (lines 438-444). Developing such a dataset is a huge task that is beyond the scope of this study.

4) Variation in wheat productivity in different regions as well as in different years of the study period (1980-2016) depends not only on environmental factors and management practices but also on the genetic factors, multiple cropping's, insect pests and diseases. Since 1980 various hybrids and high yielding wheat varieties were cultivated to increase the input use efficiency and higher economic yield. Similarly, in different climatic zones, area-specific resistant wheat varieties were also grown to enhance wheat productivity. The addition of new processes accounting for the effects of pests, multiple cropping and genotypes will make the simulations more representative of the Indian situation.

We agree with the reviewer's comment that accounting for additional effects like pests, multiple cropping and modelling more genotypes will ensure better representation of the actual scenario in the simulations. We have already discussed this in the Conclusions and Discussions sections (lines 435-438). Because the model developed and used in this study is a process-based model, implementation of every process requires data. We do not have adequate data in the public domain from Indian wheat ecosystems that can be used for this purpose.

5) The study is more generalized for different climatic zones/spring wheat environment (SWE) while there is a need for more focused regional-scale studies. However, the study is an attempt to work in the similar direction with a focus on wheat in India.

We appreciate the reviewer's comment. We decided to introduce the concept of SWEs to address the spatial variability in the forcings and impacts.

6) In the draft multiple citations should be arranged in descending order of the publication year (line no. 54, 58-59, 68-69, 76, 79-80, 83, 137, 145, 212, 270-271, 277-278, 303) and citation of line no. 76, 212, 213 needs to correct as per the formatting guidelines of the journal.

We apologize for these oversights. We will make corrections in the manuscript to ensure proper citation of the references.

7) References missing for some of the citations in the draft e.g. FAO Statistic 2014 (line no. 43-44), Leaky et al. 2009 (58-59), Bondeau et al., 2007 (76, 80), Drewniak et al. 2012 (79-80), Lu et al. 2017 (80), Zhao et al. 2007 (168), Meinshausen et al. 2011 (179), Lamarque et al. 2011 (180), Ren et al. 2015 (197), Harris et al., 2014 (212), Viovy, 2016 (212), Meinshausen et al., 2011 (213), Lamarque et al. 2011 (214).

We apologize for these oversights. We will re-check and correct the reference list and the citations in the text.

8) Some listed references have missing citation in the draft e.g. Ball & Berry 1987 (line no. 470-472), Chen 1992 (479-480), Drewniak et al. 2013 (488-490), Farquhar et al 1980 (500-501), Gill et al 2014 (505-507), Jonckheere et al. 2004 (508-510), Rajaram et al. 1993 (558-560), Xiaolin R. Weitzel et al. 2013 (595-598). 9) Some word formatting error needs to be corrected e.g. in line no. 110, 111, 382, and 511. 10) In the reference list prescribed journal format should be followed. As the reference of line no. 462-466, 542-545, and 569-571 seems out of the format.

We apologize for these oversights. We will re-check and correct the reference list and the citations in the text.