

Response to Referee #2

Recommendation: Accept with minor revision.

This study describes the usefulness of the WRF-Crop model in capturing vegetation and irrigation patterns in the North China Plain (NCP), by incorporating double-cropping with interactive irrigation. The authors modified the crop model in terms of the vegetation fraction (FVEG) and the planting/harvesting dates and improved the irrigation model in calculating the irrigation amount. The authors validated their model results in terms of various irrigation and crop growth aspects and concluded that coupling of the enhanced crop and irrigation models significantly improved the performance in estimating crop stages and yields, field biomass, and leaf area index. This manuscript can be a valuable report to the scientific community for better prediction of double cropping and irrigation aspects in NCP; however, some issues need to be clarified or discussed in more detail.

► We appreciate the reviewer's positive feedback and helpful comments. Please find our detailed responses to each comment below.

1. The authors need to specify major differences in their methods and results compared with those of Yu et al. (2022).

► Thank you for your insightful comment. Yu et al. (2022) focus on northeast China, which predominantly practices single-cropping and rainfed cultivation. They utilize the original single-cropping model without irrigation. However, our study focus on the irrigated North China Plain (NCP), where both single and double cropping systems are prevalent, with double cropping being more dominant. Thus, we implement a double-cropping function with activated irrigation to better represent the NCP's agricultural practices. Detailed comparison are listed as follows:

Calibration Process: While Yu et al. (2022) mainly calibrate the specific leaf area (BIO2LAI) for one-year corn or soybean that already present in WRF4.2, we develop almost a full set of parameters for winter wheat and recalibrate the carbon allocation for summer corn, which differs significantly from one-year corn.

Phenology Input: Yu et al. (2022) use unified planting and harvesting dates across their study domain. In contrast, we adopt spatially varied dates to better capture the diverse agricultural practices within our study area.

Results: Yu et al. (2022) evaluate the performance of their dynamic crop model at a fine resolution (10 km) in northeast China, showing variability in results with different parameters and comparing vegetation predictions from crop and dynamic vegetation models. Our study, on the other hand, aims to develop an irrigated crop model applicable to irrigation studies. Thus, we use a 25 km resolution across eastern China, focusing on the model's ability to capture the general patterns of both water and vegetation, particularly the vegetation's sensitivity to water forcing (i.e., comparing irrigation and non-irrigation scenarios).

Due to the adoption of different study domains, it is challenging to conduct a result comparison quantitatively. However, we believe that distinctions mentioned above already highlight the unique contributions of our study in advancing the understanding of irrigated cropping systems in the NCP. In

conclusion, we only adopted the method of calibrating BIO2LAI and utilized the default planting and harvesting dates (for a few grids that are not covered by the crop calendar dataset) from Yu et al. (2022). Thus, it's difficult to incorporate a detailed comparison into our manuscript, as the primary improvements we have made, mainly the implementation of double-cropping rotation and spatially-varied interactive irrigation, are not addressed in Yu et al. (2022). Nevertheless, we have added a reference to Yu et al. (2022) in the introduction section to acknowledge the similar parameter calibration process carried out in their study.

Yu, L., Liu, Y., Liu, T., Yu, E., Bu, K., Jia, Q., Shen, L., Zheng, X., and Zhang, S.: Coupling localized Noah-MP-Crop model with the WRF model improved dynamic crop growth simulation across Northeast China, *Comput. Electron. Agric.*, 201, 107323, <https://doi.org/10.1016/j.compag.2022.107323>, 2022.

2. Abstract: Delete the last sentence describing the future research. Just include more details and focus on the current research.

► Thanks for the comment. We have deleted it accordingly, and put some implications of the study instead.

3. Plain Language Summary: This part should have more scientific information, including more details in results and their implications.

► Thanks for the comment. We have improved it in the revised manuscripts.

4. L 53 & L 78–79: Remove the commas in front of ‘but alo’. Note that ‘not only . . . but also’ requires a comma only when two independent clauses are linked. No comma is required in linking nouns or noun phrases.

► They have been updated accordingly.

5. L55: “while others incorporate irrigation with fixed amount (Vira et al., 2019) or dynamically based on daily soil conditions” → Hard to understand: Rewrite. Should ‘dynamically’ be replaced with ‘dynamically varying amount’ or something else?

► Yes, ‘dynamically’ implies the irrigation amount is varied dynamically with the soil conditions instead of a fixed value. We have updated it to “..., some models simply assume no irrigation, while others incorporate irrigation with fixed amount or dynamically adjust the irrigation amount based on daily soil conditions...”

6. L 69: “regionalizing the algorithms” → How can the algorithms be regionalized? In general, one develops new parameterization schemes or improves the existing parameterization schemes and/or tunes/calibrates/optimizes the parameter values in the schemes, making the schemes and/or parameter values work well in a specific region of interest. The authors need to explain more explicitly on ‘regionalization of algorithms’.

► In this study, the process of regionalization not only includes parameter calibration but also some specific modifications on the algorithms. For example, we introduced a temperature check for irrigation to avoid harmful irrigation during freezing periods. This modification may not be necessary in other regions where double cropping is not dominant (i.e., winter is not a cropping period for them). Thus, we also consider these modifications as part of the regionalization process, as they mainly aim to improve the model’s suitability for the targeted region. We have included some additional explanations in the revised manuscript to avoid confusion.

7. L 71: Include a paragraph that provides examples of ‘regionalizing algorithms’, e.g., developing new algorithms for a specific region and tuning/calibrating/optimizing parameter values that fits observations well in a specific region. Some examples of developing parameterization schemes at regional scales, in chronological order, include

Bou-Zeid, E., Parlange, M. B., and Meneveau, C.: On the Parameterization of Surface Roughness at Regional Scales. *J. Atmos. Sci.*, 64, 216–227, <https://doi.org/10.1175/JAS3826.1>, 2007.

Liu, J., Ding, Y., Zhou, X., Li, Y.: A Parameterization Scheme for Regional Average Runoff over Heterogeneous Land Surface Under Climatic Rainfall Forcing, *J. Meteorol. Res.*, 24, 116–122, 2010.

Song, W., Tang, H., Sun, X., Xiang, Y., Ma, X., Zhang, H.: Developing a New Parameterization Scheme of Temperature Lapse Rate for the Hydrological Simulation in a Glacierized Basin Based on Remote Sensing. *Remote Sens.*, 14, 4973, <https://doi.org/10.3390/rs14194973>, 2022.

Asmus, C., Hoffmann, P., Pietikainen, J.-P., Böhner, J., and Rechid, D.: Modeling and evaluating the effects of irrigation on land–atmosphere interaction in southwestern Europe with the regional climate model REMO2020–iMOVE using a newly developed parameterization, *Geosci. Model Dev.*, 16, 7311–7337, <https://doi.org/10.5194/gmd-16-7311-2023>, 2023.

and some examples of regional parameter estimations, in chronological order, include

Xie, Z., Yuan, F., Duan, Q., Zheng, J., Liang, M., and Chen, F.: Regional Parameter Estimation of the VIC Land Surface Model: Methodology and Application to River Basins in China. *J. Hydrometeorol.*, 8, 447–468, <https://doi.org/10.1175/JHM568.1>, 2007.

Livneh, B., and Lettenmaier, D. P.: Regional parameter estimation for the unified land model, *Water Resour. Res.*, 49, <https://doi.org/10.1029/2012WR012220>, 2013.

Hong, S., Park, S. K., and Yu, X.: Scheme-Based Optimization of Land Surface Model Using a Micro-Genetic Algorithm: Assessment of Its Performance and Usability for Regional Applications, SOLA, 11, 129-133, <https://doi.org/10.2151/sola.2015-030>, 2015.

Park, S. and Park, S. K.: A micro-genetic algorithm (GA v1.7.1a) for combinatorial optimization of physics parameterizations in the Weather Research and Forecasting model (v4.0.3) for quantitative precipitation forecast in Korea, Geosci. Model Dev., 14, 6241–6255, <https://doi.org/10.5194/gmd-14-6241-2021>, 2021.

► We sincerely appreciate the constructive comments and the detailed references provided by the reviewer. While these references are applicable to the context of the general regionalization process, some of them appear to be less relevant to our focus on irrigation and crop simulations. Therefore, we incorporate these references in the beginning of the paragraph when addressing the general aspects of regionalization, and then provide more detailed explanations for the studies that are pertinent to our research. The revised paragraph is highlighted in red text below. Once again, we extend our gratitude to the reviewer for the thorough suggestions on potential references.

“Previous studies have shown that the regionalization process significantly improves the model performance. This process includes not only parameter calibration (Hong et al., 2015; Liu et al., 2010; Park and Park, 2021; Xie et al., 2007) but also algorithm modifications to enhance the model's applicability to different regions (Bou-Zeid et al., 2007; Livneh and Lettenmaier, 2013; Song et al., 2022). For instance, recalibration has been shown to significantly enhance crop prediction accuracy in Northeast China and southwestern Europe (Asmus et al., 2023; Yu et al., 2022). Introducing new tuning factors into the default equation can aid in simulating unique vegetation patterns within specific study domains (Wu et al., 2018b). Upgrading a variable such as the irrigation threshold from a single constant to a spatially varied 2D variable can better capture the spatial variability of irrigation application (Xu et al., 2019; Zhang et al., 2020). Additionally, incorporating new irrigation methods for paddy cropland improved irrigation predictions for southern Asia (Yao et al., 2022). These enhancements underscore the importance and efficacy of regionalization in improving the simulation in irrigated agriculture.”

8. L 84: The acronym ‘LSM’ should be replaced with ‘LSMs’.

► It has been updated accordingly.

9. L 89–90: “Noah-Multiparameterization (Noah-MP)” → Give the full original words “Noah land surface model with multiparameterization options (Noah-MP)”, and provide a proper reference for it, i.e., Niu et al. (2011).

► It has been updated accordingly.

10. L 92–93: “Weather Research Forecast (WRF)” ⇒ “Weather Research and Forecasting (WRF) model”, i.e., provide the correct original words for WRF. And cite a proper reference.

► It has been updated accordingly.

11. Figure 1: Modify the caption to “(a) Annual precipitation (mm/day) and basic geostatic variables applied in this project, including (b) topography (m), (c) cropland fraction (%), and (d) irrigated land fraction (%)”

► The caption of Figure 1 has been updated.

12. L 120: Provide the proper reference of WRF version 4.3. Please also check if this version number is correct because your title says it is WRF4.5.

► Thanks for pointing out the typo. The correct version should indeed be WRF 4.5. We have made the necessary correction to ensure accuracy in our paper.

13. L 127: “ERA5-Interim” → There is no ERA5-Interim reanalysis data. It should be either “ERA5” or “ERA-Interim”. Based on the cited reference, Hersbach et al. (2020), it should be “ERA5”.

► We conducted preliminary tests using both ERA5 and ERA-Interim datasets, and based on our evaluation, ERA-Interim performed better. Thus, it should be ERA-Interim. The name and the reference have been corrected.

14. L 143: There exists only one Liu et al. (2016) and only one Zhang et al. (2020) in the References; thus, the authors do not need to put the first names’ initials. Replace “X. Liu et al. (2016)” with “Liu et al. (2016)” and “Z. Zhang et al. (2020)” with “Zhang et al. (2020)”. Please do it throughout the manuscript.

► It has been updated accordingly.

15. L 175: There exists only one Wu et al. (2018b) in the References; thus, replace “L. Wu et al. (2018b)” with “Wu et al. (2018b)”.

► It has been updated accordingly.

16. L 194: “crop growth.” ⇒ “crop growth. Equations (1) and (2) below represent the original FVEG equation by Niu et al. (2011) and the adjusted FVEG suggested in this study, respectively.”

► It has been updated accordingly.

17. L 196, Eq. (1): “Niu et al. (2011) FVEG” ⇒ “Original FVEG”

► It has been updated accordingly.

18. L 222–223: Describe explicitly ‘Yucheng’ and ‘Shenyang’ in Fig. 3a. In Fig. 3a, two red circles may represent these two locations, but the authors needs to put the location names in the map. Most readers around the world are not familiar with the location names.

► Thanks for the comment. It has been updated accordingly.

19. L 225: The double-cropping area is quite large: Would Yucheng be considered to represent well the large area, especially the southern part of the area? Isn't there any station near the southern edge of the area? If another station exists with long-term observation at the southern part of the area, including it will make this study more valuable. Otherwise, add a sentence that Yucheng, located at the northern part of the double-cropping area, can well represent the characteristics of the southern part of the area, with some scientific evidences.

► Thanks for the question. We did calibration first in the Yucheng site (shown in Fig. 7), and then we applied it to the whole domain. Thus, the performance of adopting Yucheng in other area can be examined by validating the spatial pattern of crop calendar, grain mass, LAI and FVEG (Fig. 8 and 9 and S2). Please refer to the response to comment #59 for a detailed explanation regarding the choice of Yucheng over other stations in the southern region.

20. L 231: The authors used 'Vcmx25' and 'BIO2LAI' without any definition or explanation. If they are acronyms, please provide the original words; otherwise, explain what they are.

► The original words are provided inline. "For instance, large regional uncertainties may exist in the maximum carboxylation rate (Vcmx25) and the leaf area per living leaf biomass (BIO2LAI) for summer maize..." More detailed information is available in the supplementary table.

21. L 237: "Table S1 provides . . . with the supporting scientific references and recalibration procedures." ⇒ "Table S1 provides . . . with the supporting scientific references." Then, from Supplementary, please move the 2 paragraphs below "The recalibration process:" to the end of Section 2.3.3.

► It has been updated accordingly.

22. Figure 3: In the caption of Fig. 3, explain what the two red circles in Fig. 3a means.

► It has been updated accordingly.

23. Figure 3: Figures 3b-e are never cited in the manuscript. The authors need to properly cite each subfigure in the text, probably in the paragraph in L 210–219.

► Thanks for the comment. The corresponding explanation to Figure 3b-e has been added in section 2.3.3, after the definition of cropping area.

24. L 249: Use consistent tense: "the crop emerges" vs. "the crop matured".

► It has been updated to the present tense.

25. L 254: Is there any reason that 'irrigation' should be expressed in capital ("The default Irrigation")?

► It's just a typo. We have corrected it accordingly.

26. L 267: What does the number '2005' mean? Is it the year 2005?

► Yes. We have updated it to ‘year 2005’ to avoid confusion.

27. Equations 3 & 4: Define SMCLIM and SMCAVL immediately following the equations.

► We have made updates accordingly.

28. L 264–269: It is recommended to modify this part as below: The default daily irrigation amount is resolved as follows, based on the soil moisture and vegetation fraction which is fixed to be 0.95:

$$\int (\text{SMCLIM} - \text{SMCAVL}) * 0.95$$

where SMCLIM is ... and SMCAVL is When adopting it to large-scale irrigation, we improve the irrigation amount by replacing the constant 0.95 with IRRFRA, i.e., the irrigation land fraction map around 2005 from the Food Agriculture Organization database (Siebert et al., 2013) as follows

$$\int (\text{SMCLIM} - \text{SMCAVL}) * \text{IRRFRA}$$

► We have made updates accordingly. However, we moved the explanation of SMCLIM and SMCAVL before the equations for better explanation.

29. L 272–273: Definition of SMCLIM and SMCAVL should appear immediately following Equations 3 & 4.

► We moved the explanation of SMCLIM and SMCAVL before the equations for better explanation.

30. L 284: “which not only comprises irrigation, but also husbandry, forestry, and fishery consumption”
⇒ “which comprises not only irrigation but also husbandry, forestry, and fishery consumption”

► It has been updated accordingly.

31. L 285–287: Figures 4b and 4c are cited before Fig. 4a is cited. It is recommended to switch the order of subfigures in the order that they appear in the explanation.

► It has been updated accordingly.

32. L 296–297: “NCP (i.e., Beijing, Tianjin, Hebei, Shandong, and Henan, follows D. Wu et al., 2018) is coupled” ⇒ “NCP—Beijing, Tianjin, Hebei, Shandong and Henan that follow Wu et al. (2018)—is coupled”

► It has been updated accordingly.

33. L 307: “Figure 4(j)” ⇒ “Figure 4j”

► It has been updated accordingly.

34. L 307–315: Figure 4j is cited before Figure 4i is cited: Switch the order of these two subfigures in Fig. 4.

► It has been updated accordingly.

35. Figure 4, Caption: “(IRRnew), and (i) irrigation range among 10 ensemble members using different initial conditions (j) MAD” \Rightarrow “(IRRnew), (i) irrigation range among 10 ensemble members using different initial conditions, and (j) MAD”

► It has been updated accordingly.

36. Figure 5 and L 319–329: The authors just compared the results between two models—IRRdef vs. IRRnew. To verify that IRRnew is better, the authors should also show the observations. Although the authors showed that IRRnew had better results than IRRdef in terms of spatial distributions in Fig. 4, the authors should also validate the model results in terms of temporal variations.

► Thanks for the constructive comments. We totally agree that temporal validation is also important, but the statistical data is provided annually but not monthly. Thus, we only assess the inter-annual variability of irrigation prediction in Figure 10.

37. L 337: “(first two lines in Fig. 6)” \Rightarrow “(top and middle panels in Fig. 6)”

► It has been updated accordingly.

38. L 338: “we considered the entering the initial reproductive stage as the heading date” \Rightarrow “we regarded the start of the initial reproductive stage as the heading date”

► It has been updated accordingly.

39. L 340: “is considered as the maturity date” \Rightarrow “is considered the maturity date” or “is regarded as the maturity date”

► It has been updated accordingly.

40. L 341: “can be considered as rough indicators” \Rightarrow “can be considered rough indicators” or “can be regarded as rough indicators”

► It has been updated accordingly.

41. L 351: “time is not” \Rightarrow “time is not”

► It has been updated accordingly.

42. L 356: “(third row in Fig. 6)” \Rightarrow “(bottom panels in Fig. 6)”

► It has been updated accordingly.

43. L 365: “each of the following factors, implementation ... irrigation, holds” \Rightarrow “each of the following factors—implementation ... irrigation— holds”

► It has been updated accordingly.

44. L 368: “Yucheng and Shenyang station” \Rightarrow “Yucheng and Shenyang” (We already know that Yucheng and Shenyang are stations.)

► It has been updated accordingly.

45. L 369: “The station-based biomass is adopted for calibration (Fig. 7ad).” \Rightarrow “The station-based biomass in a specific year is adopted for calibration in both stations (Figs. 7a-d).”

► It has been updated as “The station-based biomass in year 2005 is adopted for calibration in both stations (Figs. 7a-d).”

46. L 369 & 373: “Yucheng station” \Rightarrow “Yucheng”

► It has been updated accordingly.

47. L 376: “Shenyang Station” \Rightarrow “Shenyang”

► It has been updated accordingly.

48. L 376: “(Fig. 7b and 7d)” \Rightarrow “(Figs. 7b and 7d)”

► It has been updated accordingly.

49. L 377: “Fig. 7e-g” \Rightarrow “Figs. 7e-g”

► It has been updated accordingly.

50. Figure S1: The bottom panels of Fig. S1 show “GWBnew”, which is never defined either in the main text or in the Supplementary. Define “GWBnew”.

► GWBnew is a redundant experiment of IRRnew. It has been removed in the updated supplementary.

51. Figure 8: The caption can be better described as follows: “Monthly LAI patterns of the satellite observation (OBS), simulation with default crop model only (CROPdef), and simulation with improved crop and improved irrigation (IRRnew) from March (MAR) to October (OCT).”

► It has been updated accordingly.

52. L 417–418: “in the NCP, Shandong, Henan and Hebei, are depicted” \Rightarrow “in the NCP—Shandong, Henan and Hebei—are depicted”

▶ It has been updated accordingly.

53. L 418–419: “with horizontal and vertical error bars showing the interannual variability of both observation and simulation” \Rightarrow “with horizontal and vertical error bars showing the inter-annual variability of observation and simulation, respectively” (Please check if this modification gives correct interpretation.)

▶ Yes, it does. It has been updated accordingly.

54. L 419: “Most of the dots especially the red dots, are” \Rightarrow “Most of the dots, especially the red dots, are”

▶ It has been updated accordingly.

55. L 421: “the uncertainties associated with the observation and simulation are” \Rightarrow “the uncertainties associated with the observation and simulation, respectively, are”

▶ It has been updated accordingly.

56. Figure 9, Caption: “the horizontal and vertical error bars depict the inter-annual variability observed in both the simulations and actual measurements” \Rightarrow “the horizontal and vertical error bars depict the inter-annual variability observed in the simulations and the actual measurements, respectively”

▶ It has been updated as “horizontal and vertical error bars showing the inter-annual variability of observation and simulation, respectively”

57. L 430–431: “the model design restricts the simulation of only one crop type per grid” \Rightarrow “the model design restricts the simulation to only one crop type per grid”

▶ It has been updated accordingly.

58. L 432 & 433: “the Yucheng Station” \Rightarrow “Yucheng”

▶ It has been updated accordingly.

59. L 447: “It is important to acknowledge that the model performance may be less satisfactory in southern NCP.” \rightarrow This may be because the authors did not include an observation station in the southern part of NCP for calibration (see the comment in #19). It will be great if the authors can include one station in the southern NCP for calibration and compare the results.

▶ Thanks for the comment. The reviewer highlighted an important issue. Yes, the model cannot simulate both the northern and southern regions well since they are sharing the same set of parameters, while certain parameters (such as specific leaf area) should differ regionally. This limitation, however, arises from model design that each crop type can only utilize one set of parameters for each crop type across the entire region.

While there are other stations available in the southern NCP, the data collected from those stations indeed differ significantly from the Yucheng station. As a result, we were only able to choose one station for the calibration process, and we finally chose Yucheng due to the more intense irrigation in the northern NCP. We have explicitly mentioned this as the limitation of our study.

60. L 453–454: This part should not be itemized, i.e., it should be rewritten as To enhance our understanding of the irrigation impact on regional climate, our study focuses on simulating irrigated crop growth in the NCP region using the WRF-Crop model. In order to improve the model’s capabilities, we have implemented the following enhancements:

- Incorporating ...
- Establishing ...
- ...
- Calibrating ...

► It has been updated accordingly.

61. L 471: “potential application of it” \Rightarrow “potential application of this study” (Please describe ‘it’ explicitly. Please check if ‘it’ can be replaced with ‘this study’; otherwise, please describe it adequately.)

► It represents the WRF-Crop model that this study adopts. It has been updated as “potential application of the WRF-Crop” in the revised manuscript.

62. L 472: “adopting it” \rightarrow Again, describe ‘it’ explicitly.

► Similarly, “it” has been updated as “this model”.