Responses to the comments of Reviewer #1:

We would like to thank reviewer 1 for his extensive and thoughtful comments. In this document we give a detailed response to all comments. Below we cite first the comment, this is followed by our response and often by a section how the text will be revised in the manuscript. The text in blue are changes and additions in the original text. For clarity we do not show any of the removed text.

Thank you so much.

Zailin, Tammo and Zhongyi

Major comments:

Comment 1. The title mentions the optimum performance of irrigated crop. Optimization is how- ever NOT a topic covered by the analysis, and optimum crop performances are neither reached nor explored. I agree that the simulation model can support irrigation management, and I suggest to re-phrase the title accordingly.

Response: Thanks for your suggestion. We agree that the title of the manuscript does not represents its content. In the revised manuscript, the title was changed as:

> "A FIELD VALIDATED SURROGATE CROP MODEL FOR PREDICTING ROOTZONE MOISTURE AND SALT CONTENT IN REGIONS WITH SHALLOW GROUNDWATER"

Comment 2. Overall, the authors present too much information about the important role of irrigation, and too little and confused regarding the tradeoff between irrigation and salinity.

Response: Thanks for your suggestion. As we know, irrigation practices are main method to leach salt and weaken the influence for irrigated agriculture, and many researchers analyzed the tradeoff between irrigation and soil salinity (Letey et al., 2011; Hanson et al., 2oo8; Pereira et al., 2002; Minhas et al., 2020). In the section 4.1.4, we analyzed

> "… The soil salinity concentration was decreasing during an irrigation event due to dilution and then gradually increasing partly due to evaporation of the water. Some of the soil salt was transported to the layers below during irrigation and some salt was moving upward with the evaporation from the surface. As expected, after the harvest, the autumn irrigation decreased the salt concentration from fall 2017 to spring 2018."

The detailed mechanism between irrigation and soil salinity was not explored in this manuscript. Therefore, much more information about the tradeoff between irrigation and soil salinity was not analyzed. We add some studies about the tradeoff between irrigation and soil salinity in the introduction section of the revised manuscript as follows:

"… However, at the same time, capillary upward moving water carries salt from the groundwater increasing the salt in the upper layers of the soil leading to soil degradation and possibly decreasing yields and change of crop patterns to more salt tolerant crops (Guo et al., 2018; Huang et al., 2018). The leaching of salts with irrigation water is necessary and useful for irrigated agriculture (Letey et al., 2011). In north China, the fields are commonly irrigated in the autumn before soil freezing to leach salts and provide water for first growth after deeding in the following year (Feng et al., 2005; Pereira et al., 2007).

Tradeoffs between irrigation practices and soil salinity were studied by a lot of researchers (Hanson et al., 2008; Pereira et al., 2002, 2009; Minhas et al., 2020). Minhas et al. (2020) give a brief review of crop evapotranspiration and water management issues when coping with salinity in irrigated agriculture. Phogat et al. (2020) assessed the effects of long-term irrigation on salt build-up in the soil under unheated greenhouse conditions by the UNSA-TCHEM and HYDRUS-1D (Phogat et al., 2020)."

Comment 3. More information on the current status of surrogate modelling in shallow aquifers is needed since it is not clear how the proposed approach contributes with respect to the current status.

Response: Thanks for your suggestion. Actually studies about the surrogate model in shallow aquifers are relatively rare compared with studies in deep groundwater depth. Here we analyzed the necessary of building surrogate models for areas with shallow aquifer.

> "Simple surrogate models are abundant in China for areas where the groundwater is deeper than approximately 10 m (Kendy et al., 2003; Chen et al., 2010; Ma et al., 2013; Li et al., 2017; Wu et al., 2016), but are limited and relatively scarce for areas where the groundwater is near the surface in the arid to semi-arid areas (Xue et al., 2018; Gao et al., 2017; Liu et al., 2019). In these areas with shallow aquifer, the upward groundwater flux from groundwater is an important factor in meeting the evapotranspiration demand of the crop (Babajimopoulos et al., 2007; Yeh and Famiglietti, 2009). The advantage of applying surrogate models in areas with shallow aquifer is that they can simulate the hydrological process with fewer parameters using simpler and computationally less demanding mathematical relationships than the traditional finite element or difference models (Wu et al., 2016; Razavi et al., 2012)."

Comment 4. The methodology is quite clear and thorough, even though it can be lighter if some textbook material is simplified and properly referred to.

Response: We are aware that the text is pretty basic. However, soil physics is not being taught in many universities especially in the USA and we prefer therefore to explain it well so that a wider audience might understand why shallow groundwater can modeled with considering the conductivity.

Comment 5. It would be interesting to present, at the beginning of the methodology, a methodological framework which includes all the experimental steps and summarizes the field and modelling effort, highlighting the interdependences between the two components.

Response: Thank you for your suggestion. The experimental steps are discussed in the section after the model description. We added the following in the last paragraph of introduction section of the revised manuscript:

> "In the following section we present first the theoretical background of the surrogate model. The model consists of crop growth module and a vadose zone module. This is followed by detailed description of the two-year field experiments staring in 2017 in the Hetao irrigation district where maize and sunflower were irrigated by flooding the field. The experimental results consisting of climate data, irrigation application, crop growth parameters, moisture and salt content and groundwater depth are used to calibrate and validate the model."

Comment 6. The results could be structured differently (some simulation results appear to be presented beforehand)

Response: We are grateful for your suggestion. In the results section, the experimental data was analyzed first in order to avoid showing the observed experimental data at the time when it is compared with model simulation results. This is not ideal but we found this the least confusing.

Minor comments:

Comment 1. L59: Add this information in a separate sentence, providing context on the total extension of the basin.

Response: Thanks for your suggestion and we moved this sentence to Section 3.1.

> **"**The groundwater depth is between 0.5-3 m. Regional exchange of groundwater is minimal due to low gradient of 0.01-0.025 (Xu et al., 2010). Thus, the groundwater flows mainly vertically with minimum lateral flow in the regional scale. Over 50% of the total irrigated cropland, 5250 km^2 in the Hetao irrigation district in the Yellow River basin, is affected by salinity (Feng et al., 2005).**"**

Comment 2. L 97: I recognize that the objective here is to introduce the need for more surrogate models for irrigation areas with shallow aquifers. However, this sentence appears not connected with what stated before.

Response: Thank you for your suggestion. This sentence is used to stress the importance of matric potential in the area with shallow groundwater. In the revise manuscript, it was revised as

"The change in matric potential is often ignored in these surrogate models for soils with a deep groundwater table. However, for areas with shallow aquifers (i.e., less than approximately 3 m), the matric potential cannot be ignored. The flow of water is upward when the absolute value of matric potential is greater than the groundwater depth or downward when it is less than the groundwater depth (Gardner, 1958; Gardner et al., 1970a; b; Steenhuis et al., 1988). The field capacity in these soils is reached when the hydraulic gradient is constant (i.e., the constant value of sum of matric potential and gravity potential). In this case, the soil water is in equilibrium and no flow occurs.

Xue et al. (2018) and Gao et al. (2017), developed models for the shallow groundwater, but used field capacities and drainable porosities that were calibrated and independent of the depth of the groundwater. This is inexact when the groundwater is close to the surface. Liu et al. (2019), used for simulating shallow groundwater the same type of model as described in this pater but calibrated crop evaporation and did not simulate the salt concentrations in the soil. This made their model less useful for practical application."

Comment 3. L 98-104: I believe the flow of thoughts here should be: 1- There are limited modelling resources when GW is near the surface. 2- Shallow aquifers areas are in fact different from their physical. characterization perspective (i.e. explain better lines 94-104). 3- If any modelling has been performed, it is necessary to provide some context (what did Xue et al., 2018; Gao et al., 2017; Liu et al., 2019 do? what were the shortcomings of their modelling experience?). How the current manuscript contributes towards implementing a more reliable-simple-tailored model in the specific application?

Response: Thank you for your suggestion. In the revised manuscript, we added some information in the next paragraph

"The change in matric potential is often ignored in these surrogate models for soils with a deep groundwater table. However, for areas with shallow aquifers (i.e., less than approximately 3 m), the matric potential cannot be ignored. The flow of water is upward when the absolute value of matric potential is greater than the groundwater depth or downward when it is less than the groundwater depth (Gardner, 1958; Gardner et al., 1970a; b; Steenhuis et al., 1988). The field capacity in these soils is reached when the hydraulic gradient is constant (i.e., the constant value of sum of matric potential and gravity potential). In this case, the soil water is in equilibrium and no flow occurs.

Xue et al. (2018) and Gao et al. (2017), developed models for the shallow groundwater, but used field capacities and drainable porosities that were calibrated and independent of the depth of the groundwater. This is inexact when the groundwater is close to the surface. Liu et al. (2019), used for simulating shallow groundwater the same type of model as described in this pater but calibrated crop evaporation and did not simulate the salt concentrations in the soil. This made their model less useful for practical application.

Because of the shortcomings of in the above complex models, we avoided the use of a constant drainable porosity and considered the crop growth and thus improved the surrogate model in our last study (Liu et al., 2019). The objective of this research was to develop a field validated surrogate model that could be used to simulate the water and salt movement and crop growth in irrigated areas with shallow groundwater and salinized soil with a minimum of input parameters. To validate the surrogate model, we performed a 2-year field experiment in the Hetao irrigation district that investigated the change in soil salinity, moisture content, groundwater depth and maize and sunflower growth during the growing season."

Comment 4. L189: Not clear. Do you mean: j is the exogenous variable on which the term before the parenthesis depends?

Response: Apologies for the unclear expression. In this study, j is the number of soil layer and t is the day number. We add this information in the revised manuscript

"where j is the number of soil layer and t is the day number, $T_p(t)$ is the total potential transpiration….."

Comment 5. L 339: Groundwater?

Response: It is "water". Here we tried to introduce the movement of soil water and groundwater, not just groundwater.

Comment 6. L 466: I would specify that the SA used in this experiment is a qualitative one

Response: Yes, as this reviewer point out, this simple parameter sensitivity analysis method only produces the qualitative results to show which parameters are important to output of the model. This is useful to determine related parameters to use the model. We have explained these in the 3.4 section.

Comment 7. L467: outputs?

Response: Apologies for this vague expression. It was revise as

> "Each parameter was varied over a range of -30% to 30% to derive the corresponding impact on the model output of soil moisture, groundwater depth, soil salinity, leaf area index and actual evapotranspiration."

Comment 8. L472: I wonder if experimental data should be presented in the case-study characterization, and not in the result section.

Response: Thanks for your suggestion. It is always difficult to decide how to structure a paper. The field experiment was carried out by us and therefore we believe that it should be in the results section. If the experiment was not carried out by the authors, it should certainly be in the case study characterization.

Comment 9. L473: calibration and validation results

Response: Thanks for your suggestion. It was revised as

"The 2017 and 2018 experimental data of the Shahaoqu farmers' fields in the Hetao irrigation district (Fig.3) are presented first, followed by the calibration and validation results of the CROP and VADOSE modules of EPICS model."

Comment 10. L595: There is no red line

Response: Apologies for the mistake. It was revised as

"The pink line is the fit with the Brooks-Corey equation."

Comment 11. L626: However, information on calibrated and simulated trajectories of those variables are already shown (see for example fig 7). I would re-name the current section or (even better), restructure the results to complement the above discussion with error statistics.

Response: We are grateful for your suggestion. The simulation results were shown with the experimental results because we analyzed the experimental data first. And this section is about the comparison of simulation results and experimental results and the model results error analysis. It was revised as "4.4 Model calibration and validation with field data".

References

Babajimopoulos, C., Panoras, A., Georgoussis, H., Arampatzis, G., Hatzigiannakis, E., Papamichail, D.: Contribution to irrigation from shallow water table under field conditions. Agr. Water Manage. 92:2015-210. https://doi.org/ 10.1016/j.agwat.2007.05.009

Chen, C., Wang, E., and Yu, Q.: Modelling the effects of climate variability and water management on crop water productivity and water balance in the North China Plain. Agr. Water Manage.97:1175-1184.https://doi.org/10.1016/j.agwat.2008.11. 012. 2010.

Feng, Z., Wang, X., Feng, Z.: Soil N and salinity leaching after the autumn irrigation and its impact on groundwater in Hetao

Irrigation District, China. Agr Water Manage, 71(2): 131-143. https:// doi.org/10.1016/j.agwat.2004.07.001. 2005.

Gao, X., Huo, Z., Qu, Z., Xu, X., Huang, G., and Steenhuis, T.S.: Modeling contribution of shallow groundwater to evapotranspiration and yield of maize in an arid area. Sci. Rep-UK 7. https:// doi.org/10.1038/srep43122. 2017.

Gardner, W.: Some study-state solutions of the unsaturated moisture flow equation with application to evaporation from a water table. Soil Sci., 85:228-232. 1958.

Gardner, W., Hillel, D., and Benyamini, Y.: Post-Irrigation Movement Soil Water 1. Redistribution. Water Resour Res., 6:851-860. https:// doi.org/ 10.1029/WR006i003p00851. 1970a.

Gardner, W., Hillel, D., and Benyamini, Y.: Post-Irrigation Movement of Soil Water 2. Simultaneous Redistribution and Evaporation. Water Resour Res., 6:1148-1153. https:// doi.org/ 10.1029/WR006i004p01148. 1970b.

Guo, S., Ruan, B., Chen, H., Guan, X., Wang, S., Xu, N. and Li, Y.: Characterizing the spatiotemporal evolution of soil salinization in Hetao Irrigation District (China) using a remote sensing approach. Int J Remote Sens 39: 6805-6825. https:// doi.org/10.1080/01431161.2018.1466076. 2018.

Hanson, B., Hopmans, J., Šimůnek, J.: Leaching with Subsurface Drip Irrigation under Saline, Shallow Groundwater Conditions. Vadose Zone J. 7, 810-818. http://doi.org/10.2136/vzj2007.005 32008. 2008.

Huang, Q., Xu, X., Lu, L., Ren, D., Ke, J., Xiong,Y., Huo, Z. and Huang, G.: Soil salinity distribution based on remote sensing and its effect on crop growth in Hetao Irrigation District. Transactions of the Chinese Society of Agricultural Engineering, 34:102-109. 2018.

Kendy, E., Gérard-Marchant, P., Walter, M. T., Zhang, Y., Liu, C., and Steenhuis, T.S.: A soil-water-balance approach to quantify groundwater recharge from irrigated cropland in the North China Plain. Hydrol. Process., 17:2011-2031. https:// doi.org/10.1002/hyp.1240. 2003

Letey, J., Hoffman, G.J., Hopmans, J.W., Grattan, S.R., Suarez, D., Corwin, D.L., Oster, J.D., Wu, L., Amrhein, C., 2011. Evaluation of soil salinity leaching requirement guidelines. Agric. Water Manag. 98, 502–506. https://doi.org/10.1016/j.agwat.2010.08.009.

Li, X., Zhao, Y., Xiao, W., Yang, M., Shen, Y., Min, L.: Soil moisture dynamics and implications for irrigation of farmland with a deep groundwater table. Agr. Water Manage.,192:138-148. https:// doi.org/ 10.1016/j.agwat.2017.07.003.2017.

Liu, Z., Wang, X., Huo, Z, Steenhuis, T.S.: A unique vadose zone model for shallow aquifers: the Hetao irrigation district, China. Hydrol Earth Syst Sc. 23(7):3097-3115. https:// doi.org/ 10.5194/hess-23-3097-2019. 2019.

Ma, Y., Feng, S., and Song, X.: A root zone model for estimating soil water balance and crop yield responsesto deficit irrigation in the North China Plain. Agr. Water Manage., 127:13-24. https:// doi.org/10.1016/j.agwat.2013.05.011. 2013.

Minhas, P., Ramos, T., Ben-Gal., A., Pereira, L.: Coping with salinity in irrigated agriculture: Crop evapotranspiration and water management issues. Agr Water Manage, 227, 105832. https://doi.org/ 10.1016/j.agwat.2019.105832. 2020.

Phogat, V., Mallants, D., Cox, J., Šimůnek, J., Oliver, D., Awad, J.: Management of soil salinity associated with irrigation of protected crops. Agr. Water Mange., 227:105845. https://doi.org/10.1016/j.agwat.2019.105845.2020.

Steenhuis, T., Richard, T., Parlange, M., Aburime, S., Geohring, L., PArlange, J.: Preferential Flow Influences on Drainage of Shallow Sloping Soils. Agr Water Manage., 14(1-4):137-151. https:// doi.org/ 10.1016/0378-3774(88)90069-8. 1988.

Wu, X., Zheng, Y., Wu, B., Tian, Y., Han, F., Zheng, C.: Optimizing conjunctive use of surface water and groundwater for irrigation to address human-nature water conflicts: A surrogate modeling approach. Agr Water Manage, 163(1): 380-392. https:// doi.org/10.1016/j.agwat.2015.08.022. 2016.

Xue, J., Huo, Z., Wang, F., Kang, S., and Huang, G.: Untangling the effects of shallow groundwater and deficit irrigation on irrigation water productivity in arid region: New conceptual model. Sci. Total Environ., 619:1170-1182. https:// doi.org/10.1016/j.scitotenv.2017.11.145 2018.

Yeh, Pat J-F., Famiglietti, J.: Regional Groundwater Evapotranspiration in Illinois. J. Hydrometeorol., 10:464-478. https:// doi.org/10.1175/2008JHM1018.1. 2009