In the following responses, reviewers' comments are reproduced in their entirety in black, and the authors' responses are noted in blue.

General Comments

1. Research question on modeling impacts of tile drainage on hydrology and crop yield using ecosys model is new and worthy contribution to the literature.
2. Predicting crop yield using O2 modeling is novel
3. The manuscript could be significantly strengthened with additional details on the methods and a greater emphasis on novel results fo the work.

Response: Thanks for the positive feedback and the suggestion to improve the manuscript with more clearly model illustrations and emphasizing the novelty of the paper. Please see the point-to-point response below.

Suggest that the authors consider the following points regarding their methods:

1. General observations:

- Use the past tense when referring to methods and results

  Response: Thanks for the suggestions! In the revised paper, we will check and make sure the tense is in the correct form.

- Model setup:
  - o Hydrological processes lack clarity and better description of terms and more consistent useage of terms is needed: In Fig S1, terms used are surface leaching, runoff, infiltration, discharge, subsurface leaching. What is meant by surface/subsurface leaching?
  - o No subsurface recharge is shown in Fig S1, but it is discussed in results. What is this?
  - o "Subsurface discharge" used in results. Please define.
  - o "Subsurface recharge" used in results. Please define.

  Response: Thanks for the comments and suggestions. In the revised paper, we will revise Figure S1 to make sure those concepts are well defined (Figure R1).

  In *ecosys*, the water exchange between the simulated field and the surrounding environment is conceptualized as water exchange between the field and an external water body, which defines the subsurface boundary conditions with a specific external water table depth and lateral distance to the external water table. Subsurface discharge refers to the below-ground water flux that leaves the field to the external water body, which happens when the field water table is higher than the external water table. Subsurface recharge refers to the below-ground water flux that enters the field from the external water body, which happens when the field water table is below the external water table. We will use surface runoff to refer to the water fluxes leaving the system on the surface. Infiltration refers to the water flux from the surface to the subsurface. We will use surface nitrogen loss and subsurface loss to replace surface leaching and subsurface leaching to represent nitrogen loss through surface and subsurface loss paths.

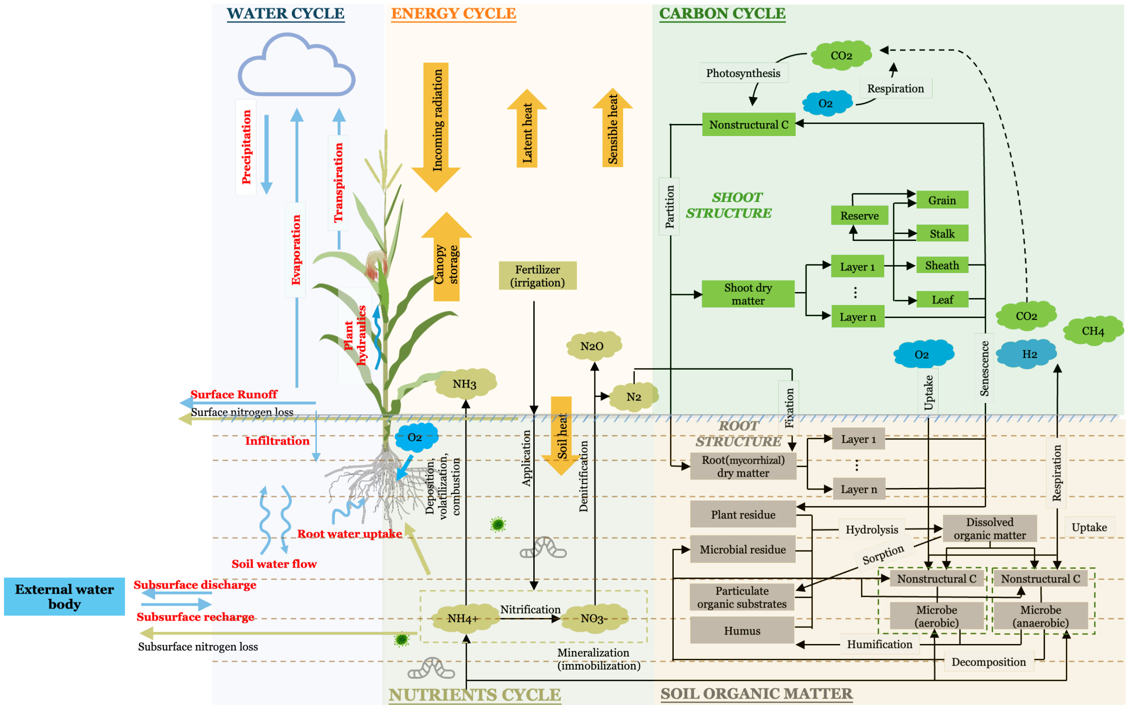

Figure R1. **Schematic of the processes in *ecosys***. Hydrological processes are highlighted with bold red fonts (draft).

- What is the scale of the model, and what are the boundaries of the setup?

Response: Thanks for the comment here and the details in the supplement materials. In the revised manuscript, we will specify that *ecosys* is a 3D ecosystem model. This paper performs a diagnostic analysis at an experimental site in the Iowa State University Southeast Research and Demonstration Farm in Washington County. Accordingly, we have revised Figure S5 to show the geological information of the experiment site as follows:

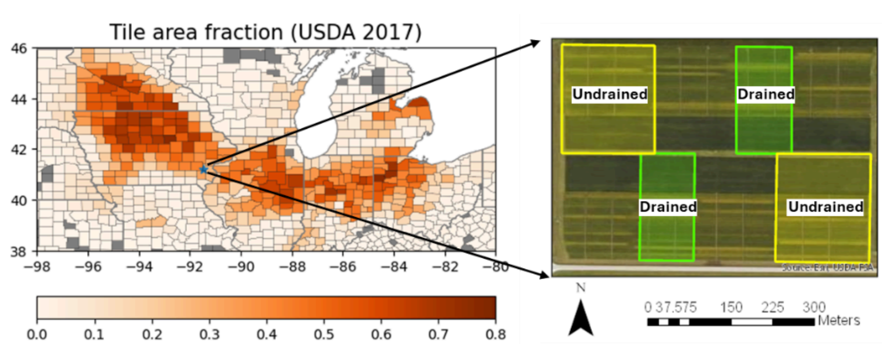

Figure R2. Tile fractions over the U.S. Midwest region, and the location and layout of the selected experiment field. Yellow boxes represent sub-fields without tile drainage, and green boxes represent sub-fields with conventional drainage.

- Calibration/Validation:

- More detail is needed here. Why use undrained for calibration and drained for validation? State reasons for doing so.

  Response: Thanks for the comment and suggestion. There are three reasons we are doing so: 1) To extend the validation and calibration period length. There are only 11-year yield observations with corn-soybean rotation (2007-2018). If we split the calibration and validation in the time domain, the calibration period and validation period would be too short, for instance, 6 years (3 corn years and 3 soybean years) for calibration and 5 years (2 corn years and 3 soybean years) for validation. By splitting the calibration and validation on the tile-drained and no-drained field, we have 11 years in total for validation and calibration. 2) to keep parameters the same for the tile-drained field and the undrained field. Except for tile drainage settings, we do not expect to see other differences between tile-drained fields and undrained fields. 3) To ensure the model correctly captures the impact of tile drainage on crop yield. As we only calibrate the related parameters in the undrained condition, we could validate whether the model could capture the impact of tile drainage on crop yield.

- List all parameters used in calibration, along with beginning and final values

  Response: Thanks for the suggestion. We will include the updated table (Table R1) with calibration range and final values in the revised paper.

Table R1. Calibrated plant parameters in ecosys

Crop	Parameters	Explanation	Range	calibrated values
Corn	GroupX	Plant maturity group: Node number required to start floral initiation (-)	[13,17]	15
	Chl4	Fraction of leaf protein in mesophyll chlorophyll for C4 plants (-)	[0.015,0.055]	0.025
	Gfill	Maximum rate of kernel filling (g seed-1 h-1)	[0.0004, 0.0008]	0.0004
	RCS	Shape parameter for stomatal resistance vs leaf turgor potential (-)	[4, 8]	6
	XKCO2	Rate constant for Rubisco Carboxylation (uM)	[20, 30, 40]	40
soybean	GroupX	Plant maturity group: Node number required to start floral initiation (-)	[13, 19]	17
	VCMX	Specific rubisco carboxylase activity (umol g-1 s-1)	[35 ,50]	45
	Gfill	Maximum rate of kernel filling (g seed-1 h-1)	[0.0002, 0.0006]	0.0006
	RCS	Shape parameter for stomatal resistance vs leaf turgor potential (-)	[-8,4]	-5
	XKCO2	Rate constant for Rubisco Carboxylation (uM)	[8, 16]	12.5

- Why is precipitation different in tile vs no-tile treatments (Fig. 6)?

Response: Sorry for the confusion. The precipitation under tile and no tile conditions is the same. We will update the figure (Figure R3). Note, tile flow is a type of subsurface discharge.

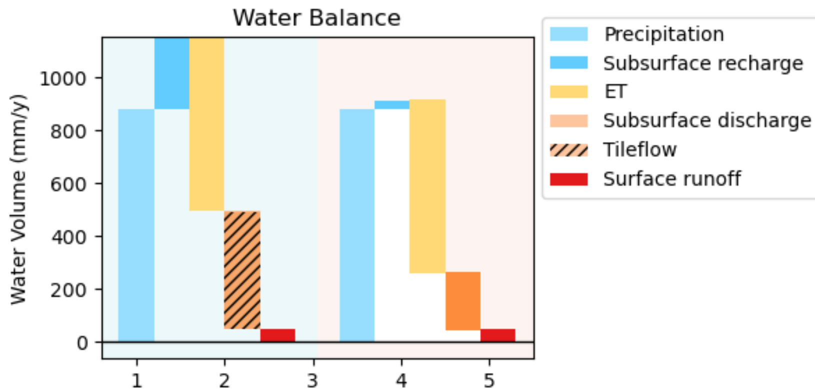

Figure R3: Ecosys-simulated annual water balance under tile and no-tile conditions. Overall, tile drainage increases both subsurface discharge (water coming out of the field) and subsurface recharge (water going into the field), and ET and surface runoff are similar under tile and no-tile conditions. The imbalance between influxes and outfluxes is subject to storage change.

- Increased precipitation experiment:
  - Why stop at 30% increased precipitation? Why not go further?

    Response: A 30% increase is already a large change. Based on the National Climate Assessment, the mean precipitation in the winter and spring may increase around 10% by the end of the century in the U.S. Midwest region (Climate Assessment 2018), and the IPCC estimates a 7% increase in precipitation for each degree of warming (UCAR Center for Science Education 2025). Thus, varying precipitation for -10% to 30% should capture those cases.

  - How was additional precipitation distributed? The seasonal/daily/hourly distribution of rainfall is important. Please comment on this.

    Response: Thanks for the comment. We acknowledge that the way additional rainfall is apportioned across seasons, days, or hours can strongly influence flood dynamics and, consequently, crop responses. In our experiments, we did not alter the seasonality or the intra-daily/hourly structure of precipitation; instead, we applied a uniform scaling factor to each time step of the original precipitation record so that the total seasonal (or annual) rainfall increases by the specified amount, while the relative variability at all timescales is preserved, as shown in Figure S7. We will make it clearer in the revised paper. Though the extreme rainfall might happen more frequently in the future, there is no standard way to distribute additional precipitation, and the uncertainty in distributing additional precipitation might outweigh the signal we aim to study.

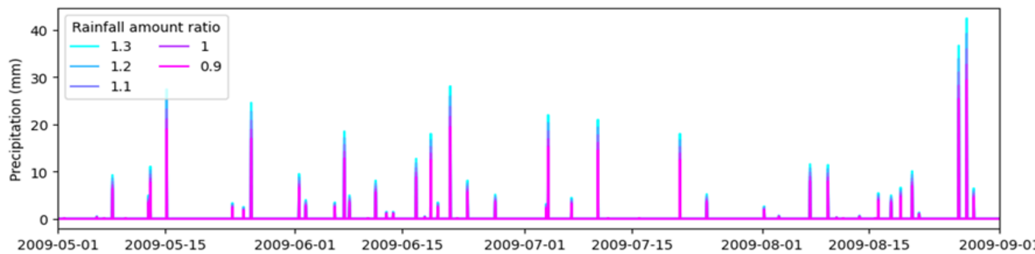

Figure R4. Example of precipitation inputs in the numerical experiments. Basically, we changed the precipitation on each time step with a scaling factor (i.e., 0.9, 1, 1.1, 1.2, and 1.3) to account for the increased rainfall amount.

Results:

1. Predicted *no impact* or *increase* of surface runoff in the tiled scenario (Fig S10 and line 385)—what is the explanation for this unusual result (normally, surface runoff decreases with tile drainage)?

   Response: Thank you for your comments. We have analyzed the model setups and identified factors influencing the simulated runoff. The surface runoff primarily occurs during significant rainfall events, indicating that the infiltration-excessive mechanism dominates surface generation (Figure R6). The model estimates the infiltration rate based on soil water content, as shown in Figure R7 across different soil layers. While tile drainage generally lowers soil water content, its impact is more significant in deeper soil layers. Our simplified 1-D column representation of the field reduced surface water holding capacity, diminishing the role of tile drainage in managing surface water. This rapid removal of surface water likely underestimates tile drainage's influence on surface runoff regulation, potentially explaining the lack of impact in the scenario. Upon reviewing the model's internal processes, we identified potential numerical issues. Initially, drier soil conditions under tile drainage led to substantial infiltration fluxes, saturating the topsoil. Once saturated, infiltration decreased to zero, resulting in a slight overestimation of surface runoff. In the revised manuscript, we will further elaborate on the simplification that underestimates tile drainage's role in surface runoff estimation and address the identified numerical issues.

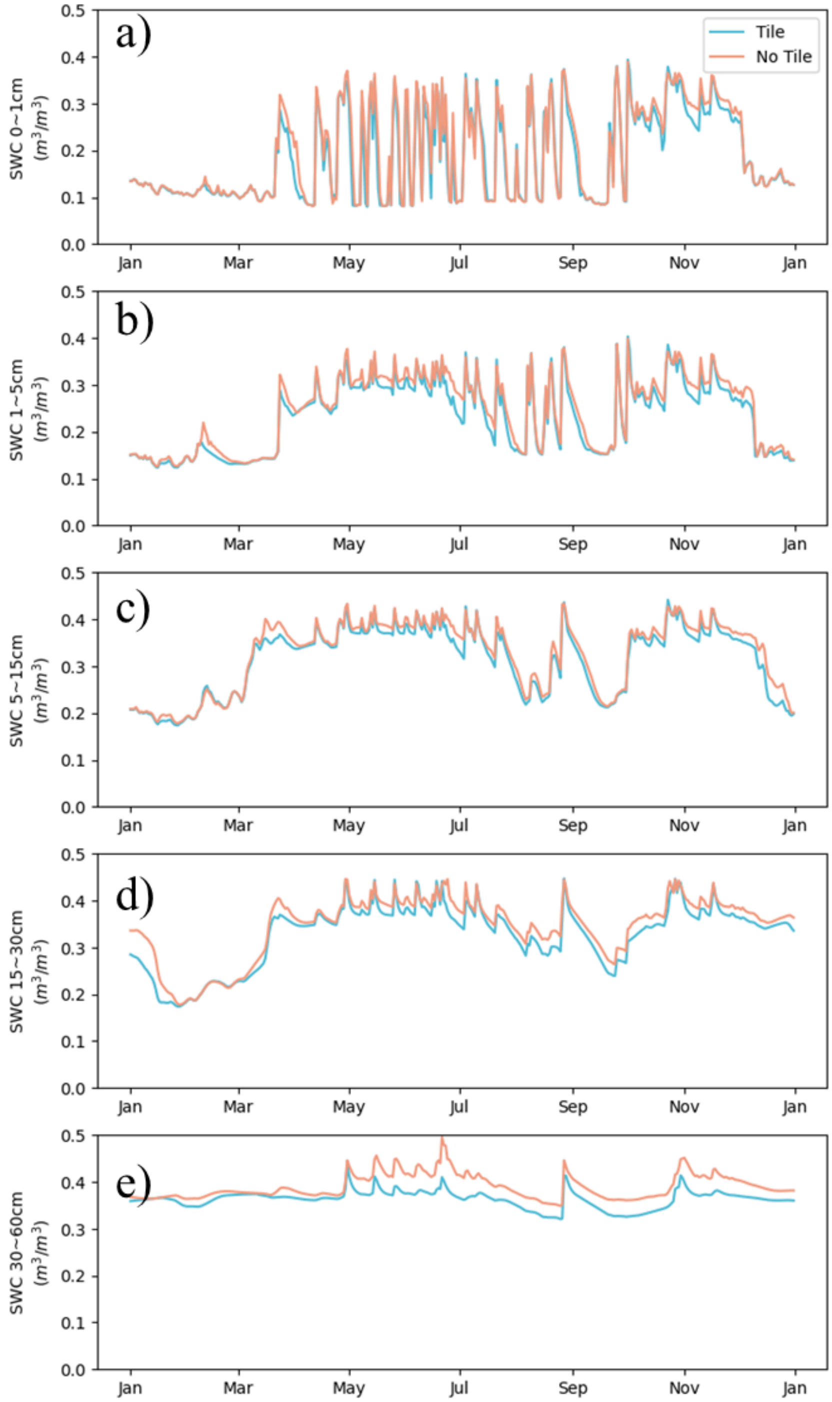

Figure R5. Ecosys-simulated soil water content (SWC) in 2009. Soil water content in a) 0~1 cm soil layer, b) 1~5 cm soil layer, c) 5~15cm soil layer, d) 15~30cm soil layer, e) 30~60 cm soil layer.

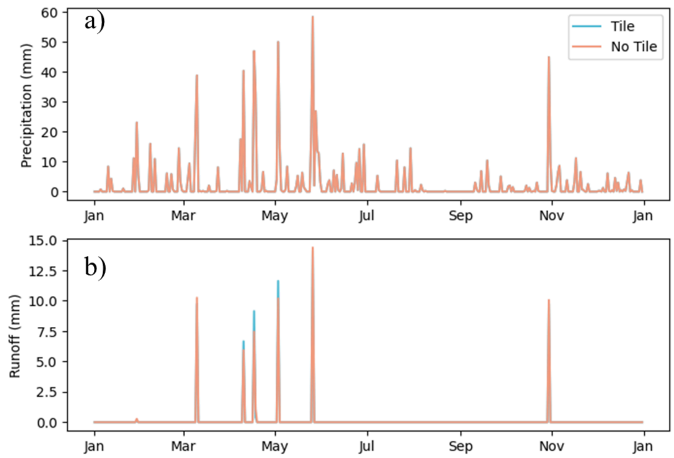

Figure R6.Precipitation and ecosys simulated runoff time series. a) The time of precipitation. b) the time series of the runoff.

2. What is the mechanism for tile drainage increasing ET in the summer months?

   Response: We hypothesized that tile drainage increases ET in the summer months through promoting crop transpiration via stronger roots developed in the early growing season. Figure R7 shows the modeled profile of soil water, soil oxygen concentration, and root density on August 17th, 2013 (a dry summer). The results indicate that tile drainage reduces soil water content while promoting root growth. Though the reduced soil water content might expose the crop more to water stress, the developed root offsets the water stress induced by reduced soil water content in our case, which ultimately increases crop evaporation (Figure R8).

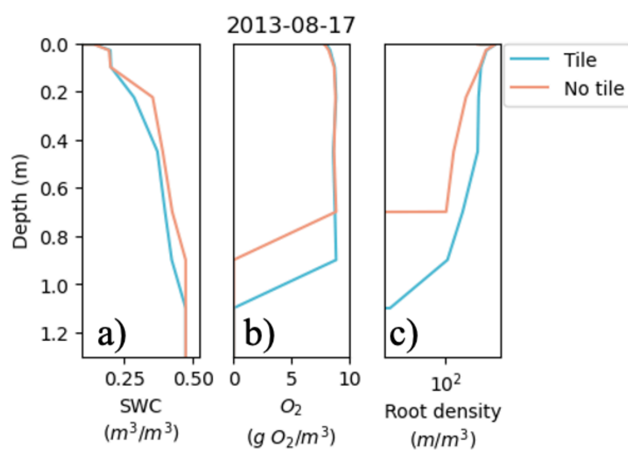

Figure R7. Ecosys-simulated soil profile of a typical dry soybean year. The profile of a) Soil water content, b) soil oxygen concentration, and c) root density in the soil column on June 17th, 2013.

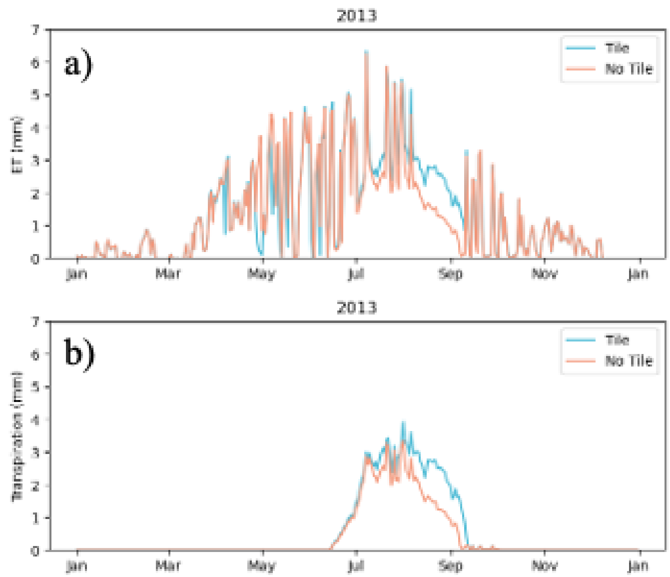

Figure R8. Ecosys-simulated evapotranspiration in 2013. a) Ecosys simulated crop transpiration in 2009. b) Ecosys simulated crop transpiration in 2013.

3. Fig 6 - keep tile drainage volume separate.

   Response: Thanks for the comments. We will update Figure 6 in the revised paper.

4. Fig 6 - Is subsurface recharge ("water going into the field") flow from adjacent fields? Please define this parameter?

   Response: Sorry for the confusion. As shown in Figure S21, the amount of precipitation is smaller than the sum of the field evapotranspiration and tile flow, and additional water fluxes from the surrounding environment, including the adjacent field, are required. In the *ecosys* model, the surrounding environment is conceptualized as an external water table, and subsurface recharge is defined as the water flux from the external water table to the field through subsurface paths. The external water table is characterized by a specific external water table depth and lateral distance to the external water table. We will clearly define it and revise Figure 3 accordingly.

Conclusions

1. Conclusions drawn by the authors do not really challenge or go beyond what we already know about the impacts of tile drainage on soils and crop growth--but I think there is a potential to do so. This seems like a missed opportunity with the novel approach taken by this study. Recommend reevaluating the discussion and conclusions to focus on unique aspects of this study.

   We appreciate the reviewer's comments and suggestions. While we acknowledge the extensive existing literature on the impacts of tile drainage on hydrology and crop growth, we will revise the discussion, conclusions, and introduction to more clearly articulate the novel contributions of this research.

   We assert that this study is distinguished by two key aspects. Firstly, we adopt an integrated systems perspective, examining the complex interactions and feedbacks among natural/climatic/hydrological, ecological and agricultural, and social processes within the tile drainage system. Secondly, we move beyond a black-box approach by employing the Ecosys model, which captures critical ecological and biogeochemical processes. Unlike previous studies, our model explicitly simulates oxygen dynamics and the root system, thereby enhancing our understanding of the tile drainage system. The incorporation of plant hydraulics representation (Zhang et al. 2021) further allows us to evaluate the system under intricate scenarios, such as the combined occurrence of a wet spring followed by a dry summer. Consequently, this study represents a distinct and comprehensive examination of the effects of tile drains, diverging significantly from prior research. The insights derived from this investigation can inform the development of simplified, coupled models tailored to this specific region.

Other comments in the supplement files:

Response: Many thanks for the detailed checking of our manuscript, and we will correct the grammar and revise the concepts accordingly.

1. Line 25, "in the U.S. Midwest". Tile drainage is not only used in the U.S. Midwest but also throughout the world.

   Response: Thanks for the correction. We will correct it in the revised paper.

2. Line 27, "their connections are poorly understood and highly uncertain". This is not the case, so further justification and reference are needed for the authors to make this assertion.

   Response: Thanks for the comment. We will change the statement accordingly.

3. Line 35, "Model results show that tile drainage reduces soil water content and enhances soil oxygenation. It additionally increases subsurface discharge and elevates inorganic nitrogen leaching, with seasonal variations influenced by climate and crop phenology." These impacts are well-known. Perhaps the authors can make a more specific statement that alludes to the unique findings of this work.

   Response: Thanks for the comments. We revise the statement to stress the novelty of involving oxygen dynamics to link the impacts of tile drainage on hydrology, soil biogeochemistry, and crop yield.

4. Line 41, "The model reveals the inherent connections of tile drainage's impacts on hydrology, soil biogeochemistry, and plant growth." Same comments as before--well-understood effects of tile drainage

   Response: Thanks for the comments. We will revise accordingly

5. Line53-56, Recommend finishing this thought by saying that the practice of tile drainage will become even more important and thus, understanding the impacts .....

   Response: Thanks for the correction. We will correct it in the revised paper.

6. Line56, remove "the".

   Response: Thanks for the correction. We will correct it in the revised paper.

7. Line64, “These local-scale changes additionally alter watershed hydrology”. Need a reference.

   Response: Thanks for the correction. We will add citations to show the tile drainage across different scales.
   Example of the impact of tile drainage at the field scale: (Woo and Kumar 2019)
   Example of the impact of tile drainage at a relatively small scale: (Hansen et al. 2013)
   Example of the impact of tile drainage at the regional scale: (Miller and Lyon 2021)

8. Line 67, “For instance, tile drainage would either” to “For instance, tile drainage may either”

   Response: Thanks for the correction. We will correct it in the revised paper.

9. Line 83, “The development of tile drainage modules has recently attracted lots of”, These have been developed over the last 50 years!

   Response: Thanks for the correction. We will correct it in the revised paper. The idea here is that the development of the tile drainage module is still active in the hydrology and land surface model.

10. Line 116, “grow” to “growth”

    Response: Thanks for the correction. We will correct it in the revised paper.

11. Line 117, “2) how do those impacts on the three aspects are interrelated?” to “how are those impacts on the three aspects interrelated?”

    Response: Thanks for the correction. We will correct it in the revised paper.

12. Line 118-121, “We hypothesize that tile drainage alters in-field hydrology and soil biogeochemical processes in ways that positively influence crop growth (Fig. 1). We further hypothesize that tile drainage could bolster agricultural production and potentially serve as an efficient adaptation strategy in the context of climate change.” Suggest proposing more specific hypotheses. These hypotheses are already well-proven--no need for additional research to address them. Perhaps reword the hypothesis to address your approach of looking at O2.

    Response: Thanks for the comments and suggestions. We will revise the hypotheses accordingly to stress the novelty of involving oxygen dynamics to link the impacts of tile drainage on hydrology, soil biogeochemistry, and crop yield.

13. Line 137, Please mention whether Ecosys is a 1- 2- or 3-dimentional model.

    Response: We will specify that ecosys is a 3-dimensional model in the revised paper.

14. Line 156, “uptaked” to “uptoken”

    Response: Thanks for the correction. We will correct it in the revised paper.

15. Line 165, “Besides” to “In addition”

Response: Thanks for the correction. We will correct it in the revised paper.

16. Line 170, remove “here”.

    Response: Thanks for the correction. We will correct it in the revised paper.

17. Line 261, should be “Fig 3b”.

    Response: Thanks for the correction. We will correct it in the revised paper.

18. Line 266, “Tile flow only occurs in soil layers above the tile pipes”. Please provide more detail here. When saturation above the depth of the drains occurs, flow is present both above and below the drains (the flow field involves saturated zone both above, and below the tile). The authors' statement seems to not recognize this. Also, use "tile drains" instead of "tile pipes".

    Response: Thanks for the correction. We will provide more details about the model process in the updated Figure 3 and Figure S1-3.

19. In Figure 3, What are the black vertical dots representing in the figure?

    Response: Sorry for the confusion. The vertical dots present there are multiple soil layers not shown in the figure. We will make it clear in the revised paper.

20. Line 279, I think you are hinting at spatial scale here, but not stating it, specifically. What is your spatial scale--the entire US Midwest? If so, what are the boundaries of your system?

    Response: This paper performs a diagnostic analysis at an experimental site in the Iowa State University Southeast Research and Demonstration Farm in Washington County (Figure R1).

21. Line 288, this figure (Fig S5) should be improved and placed in the main paper. There is no scale or dimensions and the text in the figure is not very clear. As this is key to the calibration & validation, it should be described more clearly.

    Response: We will revise Figure S5 (see above responses) to show the geological information of the experiment site.

22. Line 290, Provide more detail on these soils--at least giving the soil types. Even better to show soil properties with depth.

    Response: We will provide the detailed soil information used in the revised paper.

23. Line 293, “Tile pipes” to “tile drains”

    Response: Thanks for the correction. We will correct it in the revised paper.

24. Line 295, use “cm” or “mm”.

    Response: Thanks for the correction. We will correct it in the revised paper.

25. Line 305, “we simply assumed that precipitation is uniformly distributed over two distinct hours”. Why do this, when other techniques for distributing rainfall, exist?

    Response: Thanks for the comment. Although techniques exist to downscale precipitation, these approaches primarily rely on the probability distribution of known high-resolution precipitation information, such as the AWE-GEN method. It lacks the reference at the study site, and it also introduces uncertainty by referring to other stations far from the study site. We think the current downscaling method could satisfy our needs to reveal the mechanisms of how tile drainage affects the system.

26. Line 306, “The soil information was obtained from The Gridded Soil Survey Geographic Database”. The research site did not have soil characterization data? Explain why gSSURGO data was used instead of site data.

    Response: The research site has some measured soil data. However, not all the soil data required to drive the model are provided. Thus, we used gSSURGO to drive the model. We will clarify it in the revised paper.

27. Line 307, “External water table depth”. Please explain what "external water table depth" is, and how it is used.

    Response: As stated above, we will clearly define the external water table depth in the revised manuscript.

28. Line 310, “Half of 310 the tile spacing is 9.15 m.” Preferable to list the tile spacing.

    Response: Thanks for the suggestion. We will change accordingly in the revised version.

29. Line 315, Need to provide details on precisely what parameters were used for calibration and the range of values used.

    Response: Thanks for the suggestion. We will list the parameters, their definition, ranges, and final values in the revised version.

30. Line 330, "mimic the change of precipitation" to "evaluate wetter conditions"

    Response: Thanks for the correction. We will correct it in the revised paper.

31. Line 335, "We found that ecosys is promising in estimating both crop yield and tile drained flow in the tile." You are stating results before you have presented any results. Please present results first, discuss them, and then make conclusions later.

    Response: Thanks for the suggestion. We will revise accordingly in the revised version.

32. Line 340, use Metric units!

    Response: Thanks for the correction. We will correct it in the revised paper.

33. Table 2, label the calibration and validation

    Response: Thanks for the correction. We will state it explicitly in the revised paper.

34. Line 365, "Besides, tile drainage has been" to "Tile drainage was"

    Response: Thanks for the correction. We will correct it in the revised paper.

35. Line 397, "the annual mean total inorganic nitrogen (IN) loss from surface runoff and subsurface discharge is 2.72 $gg\ NNmm{-}2$ and 1.89 $gg\ NNmm{-}2$ for tile and no-tile". Fig 8 does not show annual mean. Please add to figure.

    Response: Thanks for the suggestions. We will add the boxplot at the annual scale in the revised paper.

36. Line 399, "Tile drainage primarily increases subsurface inorganic nitrogen leaching," The word "leaching" is a poor choice. Surface losses are not typically referred to as "leaching" and subsurface losses are either losses, or transport of N. If deep percolation to groundwater is mentioned, then the term "leaching" is appropriate, in this instance.

    Response: Thanks for the correction. We will correct it in the revised paper.

37. Line 407, "Furthermore, model results show that nitrogen leaching increases with the total precipitation (Fig. S12)." Why not plot annual N loss vs precipitation?

    Response: Thanks for the correction. We incorporate the plot in the revised version.

38. Line 425, “to increase soybean yield this year” to “to increase soybean yield during 2009”

    Response: Thanks for the correction. We will correct it in the revised paper.

39. Line 439, remove “a mere”

    Response: Thanks for the correction. We will correct it in the revised paper.

40. Line 440, “Besides, the precipitation in May reached 230.61 mm, which might saturate the soil” to “Precipitation in May reached 230.61 mm, which may have saturated the soil”

    Response: Thanks for the correction. We will correct it in the revised paper.

Reference

Assessment, Climate. 2018. “Fourth National Climate Assessment.” https://nca2018.globalchange.gov/downloads/NCA4_Ch00_Front-Matter.pdf.

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Ivanov, Valeriy Y., Rafael L. Bras, and David C. Curtis. 2007. “A Weather Generator for Hydrological, Ecological, and Agricultural Applications.” Water Resources Research 43 (10). https://doi.org/10.1029/2006wr005364.

Miller, Samuel A., and Steve W. Lyon. 2021. “Tile Drainage Causes Flashy Streamflow Response in Ohio Watersheds.” Hydrological Processes 35 (8). https://doi.org/10.1002/hyp.14326.

UCAR Center for Science Education. 2025. “Predictions of Future Global Climate.” 2025. https://scied.ucar.edu/learning-zone/climate-change-impacts/predictions-future-global-climate.

Woo, D. K., and P. Kumar. 2019. “Impacts of Subsurface Tile Drainage on Age—Concentration Dynamics of Inorganic Nitrogen in Soil.” Water Resources Research. https://doi.org/10.1029/2018WR024139.

Zhang, Jingwen, Kaiyu Guan, Bin Peng, Ming Pan, Wang Zhou, Chongya Jiang, Hyungsuk Kimm, et al. 2021. “Sustainable Irrigation Based on Co-Regulation of Soil Water Supply and Atmospheric Evaporative Demand.” *Nature Communications* 12 (1): 5549.