

Prof. Nunzio Romano

Editor, *Hydrology and Earth System Sciences*

January 29th, 2025

Dear editor,

We thank you for your positive evaluation of our revised manuscript. We appreciate the time and effort that both you and the reviewers have dedicated to this review process. We are very grateful for the constructive comments provided by the reviewers, which have helped us to greatly improve the clarity and broader scientific significance of our study.

Below, we address Reviewer #2's additional comments and describe the associated revisions made to the manuscript.

A final proofreading of the manuscript resulted in rewriting some sentences for clarity, making minor grammatical improvements, editing of non-conform references, and updating the acknowledgments section.

Kind regards,

Elise Verstraeten, on behalf of all co-authors

Point-by-point responses to the reviewer #2 comments on the manuscript

The reviewer's remarks are summarized here for better interpretation of our answers, please refer to his review report for full remarks.

Remark 1

The reviewer recommends to emphasize more the need to combine methods, rather than only improving data-driven techniques through more data collection.

We agree with the reviewer on the potential of combining methods, and do realize this was not highlighted enough in the paper. We improved this by:

- L450-453 (perspectives) : adding “Expanding on the integration of methods, data-driven techniques could also be combined with process-based models, leveraging the strengths of both approaches. While process-based models capture the mechanisms affecting nitrate leaching, data-driven methods can harness the full potential of available data, sometimes outperforming traditional mechanistic equations.”
- L474-475 (conclusion): adding “Combining data-driven techniques with process-based models, leveraging the strengths of both approaches, could help improve model performance.”
- L21-26 (abstract): adding “One pathway is to explore integrating modelling approaches to supplement observational data with modelled data as inputs to statistical models, or to combine data-driven models and process-based models.”

Remark 2

The reviewer disagrees on the fact the study allows conclusions on the effectiveness of nitrogen management policies.

We acknowledge that distinct nitrogen management practices are not directly evaluated in this study, as the used input data does not allow it. However, our findings do allow us to draw conclusions about the broader needs for nitrogen management policies. Our results highlight the importance of tailoring policies to specific groundwater bodies, as their responses differ significantly. They emphasize the need to maintain efforts in cropland-dominated zones, which were concerningly found to correlate most strongly with concentration increases. And they show the importance of accounting for historical nitrogen loads, which may explain the observed differences in nitrate evolution between shallow and deep aquifers.

In light of this, we have removed “and nitrogen management policies” in L462 as suggested by the reviewer, and added “following the implementation of the regional sustainable nitrogen management program” in L465. Furthermore, we have rewritten the objective statement at the end of the introduction (L80–84) to avoid misconception on the study's potential outcomes.

Remark 3

The reviewer questions the effectiveness of deep-rooted crops to tackle nitrate pools in deep aquifers.

Indeed, the formulation of the sentence was misleading which explains the concern of the reviewer. We meant that the deep-rooted crop could reduce potential N leaching, and not directly to recover nitrates from aquifers. We reformulate L364-366 as follows : “Efforts to enhance the effectiveness of nitrate reduction policies should consider the incorporation of measures to accelerate the recovery of aquifers and reduce the potential nitrate leaching loss, such as the promotion of deep-rooted crops. » and added the following references :

Thorup-Kristensen, K., Halberg, N., Nicolaisen, M., Olesen, J. E., Crews, T. E., Hinsinger, P., Kirkegaard, J., Pierret, A., & Bodin Dresbøll, D. (2020). Digging Deeper for Agricultural Resources, the Value of Deep Rooting. <https://doi.org/10.1016/j.tplants.2019.12.007>

Pierret, A., Maeght, J. L., Clément, C., Montoroi, J. P., Hartmann, C., & Gonkhamdee, S. (2016). Understanding deep roots and their functions in ecosystems: an advocacy for more unconventional research. *Annals of Botany*, 118(4), 621–635. <https://doi.org/10.1093/AOB/MCW130>

Remark 4

The reviewer recommends to be less absolute concerning the unavailability of certain data, but to rather formulate opportunities.

We agree with the reviewer and reformulated certain elements :

- L430-437 (variable discussion) : removing “unavailable at the necessary spatial scale” (x2) and adding “Incorporating modelled variables as inputs, rather than relying solely on observational data, could improve certain current proxies and enable the inclusion of new critical drivers.”
- L447-448 (Perspectives) : adding “A way forward is to supplement observational data with modelled data, leveraging outputs from models like EPIC-grid, which computes nitrate recharge and precipitation surplus (Sohier et al., 2009).”
- L472-473 (Conclusion): adding “Integrating modelled data alongside observational data could also offer potential to improve the representation of controlling factors.”
- L21-22 (Abstract): changing formulation to “the challenges in defining input variables that correctly represent the controlling factors”, and removing “mainly due to lack of data”

Minor remarks

1. **L38:** we included atmospheric deposition in L42: “introduced into soils through atmospheric deposition, fertilizers and the mineralization of organic matter”
2. **L71:** we removed "can" but kept "differ" as we prefer not to make an absolute statement, especially as we do not see the need here.
3. **L348:** thank you for pointing out this sentence structure issue, this was corrected
4. **L367-369:** indeed, we added this: “Forested and green areas exhibit a negative association with nitrate pollution, showing a lesser contribution to nitrate leaching, which can be explained by lower nitrogen inputs and natural buffering effects.”
5. **L388-389:** the sentence was rewritten to add depth information : “Depth also plays a significant role, with shallow groundwater intake structures, only a few meters deep, showing greater improvement in nitrate concentrations compared to deeper structures, which can extend beyond 100 meters.”