General Assessment

This manuscript presents InSEEDS, a coupled model integrating LPJmL with agent-based modeling to simulate agricultural transitions. While the coupling represents a technical achievement, the work appears to be more of a proof-of-concept than a study reaching substantial conclusions about agricultural transitions.

We thank the reviewer for their thorough feedback, and for highlighting critical areas of improvement for us to clarify our contribution with this paper. We will provide point-by-point responses to their comments below.

Detailed Evaluation Following ESD Criteria

1. **Relevance to ESD Scope** The paper addresses human-Earth system interactions and agricultural transitions, which are clearly within the journal's scope.

We thank the reviewer for their assessment of suitability for ESD.

2. **Novel Concepts, Ideas, Tools, or Data** The coupling of LPJmL with agent-based modeling through the copan:CORE framework is technically novel. However, the novelty is primarily architectural rather than conceptual. The agent-based component itself is simplistic, using only two farmer types and omitting crucial economic factors.

We agree that the technical novelty of coupling an agent-based modeling component with LPJmL is a central contribution of the InSEEDS model. We also acknowledge that the agent-based component has room for development, which includes the integration of explicit economic factors.

As a first adjustment to the paper, we propose to better explain our design choices for this version, which touches on three main dimensions:

(1) Novelty of the modeling approach

For this first model version, we aimed to provide an agent-based component that was able to capture a first set of human dimensions considered relevant for the integrated, coevolutionary/bi-directional, social-ecological dynamics at play in the food and land use (FOLU) sector. This is where we perceive a central advance of the InSEEDS model: the ability to study certain dimensions of farmer decision-making in combination with a global gridded crop and general vegetation model. This is a completely novel approach compared to previous coupling approaches that relied on pre-processed data, often mainly encompassing yield, from LPJmL (or other crop models) and feeding these into partial equilibrium models (MAgPIE - Dietrich et al., 2019, / GLOBIOM - Krey et al., 2020) with no bi-directional interaction of decision-making and the LPJmL simulation. Other previous model coupling approaches with more nuanced decision-making representations at up-to planetary scales (Beckage…) have focused on climate instead of land system dynamics.

(2) Contribution of the ABM component

Regarding the ABM setup, we chose to focus on a combination of social norms, attitudes, two different forms of learning (social learning and learning through environmental observation) within the theory of planned behaviour and a distinction between two farmer types that represent different priorities in agriculture as a starting point. With these dimensions represented in the ABM component, we believe that our representation of decision-making processes is not necessarily simplistic, and we perceive that the integration of these components within an agent-based modeling setup coupled on up-to global levels does, therefore, also represent a conceptual advance. While we agree that there is a lot of room for development, we already regard this as a valuable starting point, that differs from other, non-ABM-based modeling approaches, like IAMs (e.g., Dietrich et al., 2019).

(3) *We think it's valuable to build such a new model step-by-step, and consciously chose to make the first step different to the standard (economics) one, for scientifically backed good reason*

In the process of choosing this starting point, we consciously decided to start building our model from a different venture than the standard economic one. Different empirical strands (Burton et al., 2020) of literature and meta synthesis studies (Swart et al., 2023) have stressed that while economic factors undoubtedly are very important for farmer decision-making, other socio-cultural factors are oftentimes of similar importance. While there are manifold models in the FOLU sector relying either on macroeconomic optimization principles or microeconomic rational choice theory, those socio-cultural factors are underrepresented in dominant modeling approaches and usually lack full bidirectional feedbacks. This is why we chose to start by shedding light on these factors as a different starting point with the explicit ambition and hope to,, provide a complementary perspective to other, more economics-centered, modeling approaches. This way, we hope to provide a tool that is able to answer complementary questions to classic "scenario modeling questions" (e.g., "how many people can we feed under climate scenario x") tackled by integrated assessment models that inevitably need economic components and optimization. There is a research gap regarding large-scale models that are able to cover topics such as societal change or social tipping points . In this gap, we deem factors like social norms and social learning to be an important foundation for further model development.

Therefore, secondly, we propose to make our future InSEEDS development plans more prominent.

Implicitly, economic factors can be considered to already be included in the farmer decision-making function in two places: (1) farmers can place a certain emphasis on their yields, and thus economic gains, and (2) the perceived behavioural control factor dampens management switches, which can also be rooted in economic considerations, like path dependencies from prior investments, as we describe in the section on page 12 (PBC). However, we clearly see the value in an extension of the model that represents such factors more explicitly in the model dynamics. As a research group, we are already working towards the inclusion of different economic and political factors into the next InSEEDS model version and will stress the importance of this for future model versions in the revised manuscript.

In a nutshell

This first version is meant to provide a first set-up that allows us to explore the coevolutionary dynamics that arise through the novel, bidirectionally coupled model structure we are working with. For this endeavour, our aim was explicitly not to already set up a complex, comprehensive structure of all dimensions of “the human” that might be relevant. We want to provide a starting point, a first foundation to expand upon, of relevant dynamics that can be expanded in future model versions. This was not clear enough in our current version. Therefore, to address the reviewer comment, we aim to make the design choices made for this model version more transparent, and also emphasize the importance of including economic factors in future model versions.

3. **Substantial Conclusions**

The contribution of this paper represents more a proof of concept than substantial conclusions.

The following paragraph, written by the authors, summarizes well their contribution: “In this paper, we have introduced the InSEEDS model, described its social, ecological components, and their interactions, and tested the model’s parameter sensitivity. We laid out first simulation results that point to distinct centrally important elements and processes in the co-evolutionary model dynamics. We zoom into certain dimensions of the co-evolutionary dynamics that can be observed at different spatial scales of simulation results, from global to cell level.”

We acknowledge that we have to clarify the substantial contribution of this paper. The paragraph singled out here is a good match for our intended contributions, but we see where we might have created confusion about our thinking.

We propose to streamline our argumentation to be clearer in the type of substantial contribution we see with this paper: We see this paper as a model description paper introducing a first prototype of a novel type of World-Earth model, which is the first of its kind built using a technically novel, coupled modeling framework (copan:LPJmL), and an in-depth exploration of its dynamics. One substantial contribution of our work is that social norms, and learning, cannot be ignored in modeling studies. This is revealed by the dynamics of the model, i.e. social networks, decision-making inertia, local context. To our knowledge, it is the first existing global-scale model in the food and land use sector taking into account factors like social norms, and learning dynamics - and capturing “the social” beyond economic factors, which we know are not the only decisive factors guiding human behaviour.

In addition to demonstrating the functionality of the technically novel modeling framework, we aim to take first steps in the journey from a “mere proof of concept” model, i.e.,that doesn’t connect to any type of psychology/cognitive science/social science theory or empirical insight, to a “highly complex model” aimed at applied, realistic studies, involving quantitative data integration for validation and calibration. In this current InSEEDS version, we explicitly build on an established psychological theory for our decision-making function and consider a first form of agent heterogeneity, which is both already novel to our knowledge for coupled, social-ecological modeling approaches at global scales.

We foresee different possible future development pathways for the InSEEDS model. We agree that for applied modeling studies aiming at behavioural realism, additions such as more social dimensions, greater agent heterogeneity, and quantitative data integration are necessary.

We envisage to address this point in the revision by emphasizing a possible development path we foresee, as well as where we perceive this current model version.

The conclusions are undermined by methodological limitations. The Paraguay case study (Section 4.2.1) is particularly concerning—the model predicts widespread adoption of conventional farming that contradicts historical trends, which the authors acknowledge but inadequately address.

In the revision we will consider two points regarding this case study: (1) clarifying (see comment above) the intended contribution / results of this paper, including the Paraguay case study, as an exploration of coevolutionary dynamics rather than a depiction of realistic behavioral patterns. (2) better discuss the dynamics we find, which point us to the need to co-develop LPJmL and InSEEDS in future modeling versions.

(1) We aim to better discuss how the results we find with this InSEEDS model version have emerged, by dissecting ecological (LPJmL component), social (ABM component) and interacting dynamics better. The results point to the fact that LPJmL simulations imply carbon legacy effects that impact the social dynamics.

    (A) These legacy effects are due to land use conversions from natural vegetation (~high SOC) to managed vegetation, mainly cropland (~med-low SOC), causing the system to strive towards a new equilibrium with LPJmL immanent long time spans, described in Herzfeld et al. 2021.
    Thus, a newly converted cell fraction from former (long-time) natural vegetation will lose carbon for a while.. RA practices can lower the difference between both equilibrium states, decreasing the carbon loss rate compared to conventional farming.

    B) The simulation dynamics make sense if we consider how decision-making is set up
    From the perspective of the agent-based component's setup, these biophysical base conditions explain why we see only a limited uptake of RA practices. The attitude component of the decision-making function is composed of a comparison of (1) performance of soil carbon and yield over time within the underlying cell (benchmark: historical state), as well as (2) comparison of these indicators between own and different management practices.
    With relatively newly converted cell fractions losing carbon over time, as in Paraguay, the historical comparison (1) does not provide farmers any clear signal towards either RA or CF as a superior practice, as none of them can halt that negative trend and

make a positive impact on SOC levels. Given the current decision-making setup, a negative evaluation of the indicators over time will make farmers more likely to adopt an alternative management practice.

(2) In the comparison to other management practices (2) they could perceive that RA slows this trend down in comparison to CF, and therefore performs better in terms of soil carbon.

However, this observation (2), in the current decision-making function, is unlikely to provide sufficient incentive for a widespread RA adoption, as it is combined by the unclear signal from the historical comparison (1), and social norms that neither incentivise RA.

Zooming into these results show that our coupled InSEEDS model behaviour behaves “correctly”, given the coecolutionary dynamics and the current decision-making model setup. The farmers’ perception cannot adequately deal with the information it gets so it makes "wrong" decisions. Better would be to calculate the trend in between the switches (e.g., SOC dynamics). If the slope is slower with conservation tillage (which it is) then they would decide against switching to conventional farming. These considerations bring us to point three:

(2) We will emphasize the necessity to co-develop InSEEDS & LPJmL for simulating regionally adapted realistic dynamics and outcomes. As demonstrated by our results, and our proposed added discussion of them, InSEEDS very much depends on sensible model responses in LPJmL that turn out only in the coupling. Vice versa, exploring the emergent adoption patterns of the agent-based model component under different ecological dynamics reveals the necessity to finetune our decision-making setup to accommodate a wide range of regionally distinct ecological patterns and dynamics that impact decision-making in distinct ways.

In a nutshell

We propose to clarify that, in the current model version, we don’t aim for behavioural realism or the *prediction* of adoption patterns, but rather *explore* the coevolutionary dynamics that arise from our model in different dimensions, such as ecological conditions as found in the Paraguay example. We suggest tracing our simulation results in terms of RA adoption to the decision-making component setup and its way of interacting with biophysical information. We further suggest discussing these results with regard to necessary future co-developments of the LPJmL and agent-based InSEEDS components to accommodate regional differences in our model studies.

1. **Scientific Methods and Assumptions**

- Meticulous description of agent-based model assumptions
- Parameter values are largely arbitrary but addressed in sensitivity analysis (Sections 3.3 & 4.1)

We plan to slightly streamline and shorten the agent-based model description sections, and specify how parameter values were reached in relation to the sensitivity analysis.

- The assumption that farmers compare current performance to historical benchmarks is overly simplistic and produces unrealistic behavior in regions with land-use legacy effects, has been addressed in limitations

We agree that behavioural patterns emerging in regions with legacy effects of recent land land conversion are currently unrealistic. As pointed out in our reply to the comment on the Paraguay case, our decision-making encompasses two distinct “performance evaluation mechanisms”: 1) comparison to historical benchmarks, and 2) comparison to different management approaches. While we chose this combination as a balance between two comparison dimensions, we agree that for regions where legacy effects become relevant, the historical benchmark comparison is not adequate. We propose that for future model versions that aim at behavioural realism and therefore work towards a regionalisation of decision-making, for regions that have relatively young, recently-converted agricultural fields, the alternative management scheme should be the central benchmark.

- No validation against real-world adoption patterns

See reply to the “substantial contributions” comment. We think that validation against real-world adoption patterns becomes relevant when aiming at application studies with behavioural realism, which is not the central goal of this paper.

1. **Results Supporting Interpretations and Conclusions**

Results largely align with interpretations and conclusions. However, some key concerns:

- Main findings show that resistance to social pressure and learning from own land (rather than neighbors') increase conventional tillage adoption more than weighing SOC over yield. However, this is evident from the model setup (w_CY and w_SOC come in as factors in A_self and A_nbr).

Thank you for this comment. It is indeed that case that w_CY and w_SOC impact the Attitude of the modelled farmer. And thus their learning from their own experiences and from their neighbours. However, what we aim to say is that a change in the weights relating to the social norms and the attitude might result in bigger differences than changes in the weights for the CY and SOC (if weights for attitude and norms are held constant). Our sensitivity analyses are set up in a way to always change one set of weights while keeping the others constant. It is thus more the question of, “how much does the overall model result change if we change specific weights?” In Figure 4 it is actually visible that some changes in the weights for CY and SOC (blue runs) have more impact than the changes in weights of attitude and norm (green runs). However, we acknowledge the interpretation of those results in the manuscript might be misleading and we propose to rewrite those sections.

- In line 566, the authors stress that their "modelling results point to the overall positive ecological performance of CT as an RA practice globally, confirming previous LPJmL work on the subject (Herzfeld et al., 2021)." This result appears to stem directly from LPJmL and its underlying assumptions, this study does not seem to provide novel insights in this respect.

As our statement says, we agree that this study does not necessarily provide novel insights with respect to the biophysical effect of CT in LPJmL simulations. However, we deem it important to highlight both the novel insights we gain about both the LPJmL and ABM components through their interaction (see the insights we gained about the decision-making setup in the Paraguay case above).

- Model is highly sensitive to initial AFT share: 100% pioneers yields 50% higher CT adoption vs. 0% pioneers -> How is spatial variance (lines 437-441) distinguished from random initialization effects of traditionalists and pioneers vs. biophysical factors?

We suggest performing a scenario ensemble with perturbations of the corresponding parameter to test the spatial variance during model initializations. We propose to add the AFT share as well as the strategy switch duration and the corresponding strategy switch time, both which are also randomly drawn in the beginning.

1. **Reproducibility**

ODD and ODD+D protocols for the agent-based model are attached. Code is made available. Model setup and parameterization are described in detail. To ensure reproducibility, the authors should additionally prepare the following:

- Report runtime benchmarks

We are happy to include a ballpark runtime penalty score, if this is the kind of benchmark the reviewer would like to see. We would be grateful for a specific hint if it is a different benchmark they are interested in.

- Clear overview of input data processing steps

We suggest providing a better set of references to clarify the input data processing steps of the LPJmL model. Several important LPJmL publications (Ostberg et al., 2023 / Schaphoff et al., 2018 / Wirth et al., 2024) have detailed the way LPJmL uses and processes different kinds of input data.

Furthermore, we propose to clarify that the InSEEDS model itself does solely use data for the initial distribution of management practices, and lay out how we use this dataset.

- the stochastic AFT allocation makes results non-deterministic -> Please provide ensemble analysis

As proposed above, we suggest adding such an analysis.

- Computational requirements are mentioned only in limitations (HPC needed) -> Please mention in Materials & Methods

Thank you for this comment. We agree that it is important to be transparent about computational requirements. We propose to provide an overview of the requirements necessary to run the InSEEDS model, and also refer to LPJmL literature for further LPJmL-specific HPC details.

1. **Credit to Related Work** Appropriate credit given to related work.

We thank the reviewer for their assessment of appropriate credits given to relevant work.

2. **Title Clarity** The paper focuses more on conservation tillage/no tillage vs. conventional farming rather than regenerative agriculture broadly (though this is addressed in introduction/discussion). "From Farm to Planet" overpromises given the model's limitations at both scales.

We will discuss a possible alteration of the title to better accommodate the contributions of our paper / the current model version.

3. **Abstract** Abstract describes contents well but lacks quantitative results. Should mention the restriction to two management practices upfront.

We aim to revise it such that it better reflects the nature of results we aim to provide with this model, as well as some of the limitations, like the two management practices, upfront.

4. **Structure and Presentation** Generally well-structured but verbose. Methods section jumps between conceptual description and technical details. See my suggestion under 13. (bullet point 2) on how to overcome this limitation.

We suggest we revise language to make sure that the message is conveyed more clearly without necessary “verbose” additions. We address the suggestion of methods section restructuring below.

5. **Language Quality** Generally clear but occasionally imprecise. Terms like "co-evolutionary" and "World-Earth" used inconsistently. Some passages unnecessarily complex (e.g., lines 69-70). RA and CT used interchangeably, and extensive use of abbreviations, making reading difficult. Throughout the paper, consistency in terms, variables and parameter names is lacking.

We agree with the reviewer’s perspective. As mentioned in previous comments, we aim to simplify language and streamline the paper to reduce unnecessary complexity. We suggest clearly defining central terms such as coevolutionary and World-Earth, also in relation to relevant literature that have coined them / they originate from. We could do so in the introduction, or possibly also provide a box/table with a small glossary of key terms and their use in our paper. We aim to revise consistency in variables and parameter names to make their use coherent.

6. **Mathematical Formulae, Symbols, Abbreviations, and Units**

Critical issues identified:

- Sigmoid normalization in Equations 5-10 lacks justification

- Equations (6) and (7): wrong indices
- Formula (15): Why "-0.25", thresholds 0.4 and 0.5, why "+0.25/t_s" (indexing of t incorrect), add option BE_i ≤ 0.4
- Inconsistent notation (indices)
- Variable/parameter names inconsistent across text, figures, tables.
- Sometimes variables are declared as parameters and vice-versa. E.g., ll. 324-325, Table 1

We thank the reviewer for their sharp identification of shortcomings in our formulae and aim to revise them according to the identified issues. We will provide a justification for the sigmoid normalization, adapt indices/notation, streamline variable/parameter names to avoid inconsistencies, and revise our variable-parameter notation. We suggest including the option of BE_i ≤ 0.4 in the mathematical formula 15, which was missing. We also suggest clarifying the reduction of PBC after a new management practice was adopted ("-0.25") in formula 15 in the text.

We use a sigmoid function to transform performance differences into attitudes because it ensures that attitudes derived from both the focal farm and neighbouring farms remain within a well-defined and bounded range. This boundedness is essential for integrating attitudes consistently into the calculation of behavioural intention and the overall decision-making process.

In our model, attitudes are based on relative performance. If the current land management practice results in lower yield and/or soil organic carbon than the previous practice, the attitude towards reverting to the previous practice is positive (i.e., there is support for change). Conversely, if the current practice performs better, the attitude towards changing back is negative.

Similarly, with respect to social influence, if the majority of neighbouring farms achieve higher yield and/or soil organic carbon under a different management practice, the attitude towards adopting that practice is positive. If the focal farm performs equally well or better, the social influence to switch remains weak or negative.

Rather than applying a sharp step function that assigns a value of 1 when an alternative practice outperforms the current one and 0 otherwise, we use a smooth sigmoid function. A step function implies an abrupt and fully rational response to even minimal performance differences. In contrast, the sigmoid function reflects bounded rationality: small performance differences lead to only modest changes in attitude, while larger differences produce stronger responses. This allows for gradual adjustment instead of all-or-nothing switching.

Moreover, the S-shaped form of the logistic (sigmoid) function captures key characteristics of behavioural adoption processes observed in empirical research: slow initial response to weak signals, rapid change once a critical threshold is approached, and saturation at high influence levels (Rogers, 1983). The logistic function is widely used in the social sciences to model binary or probabilistic decisions (Harrell, 2015) and provides a flexible representation of non-linear behavioural responses. Human decision-making is rarely proportional to stimulus size; instead, it often follows complex, non-linear patterns that are better approximated by smooth threshold functions such as the sigmoid (Kim, 2008).

Overall, the sigmoid function allows us to represent bounded, gradual, and non-linear behavioural responses while maintaining numerical stability and interpretability within the model, which we propose to clarify in the text.

Minor issues:

- Variables not consistently in cursive style
- Equation (1): define i (agent i)
- w_N and w_nbr used for same parameter
- Equation (13): consider using sigmoid instead of 0.5*(tanh(x)+1)

As mentioned above, we suggest streamlining the text, including cursive style and parameter notations. In equation 13, we will use the sigmoid notation instead of the tanh formula.

Excessive abbreviations: It is strongly recommended to reduce the number of abbreviations, where possible (e.g., SOM, WEM, SA, HLSO, CA, AB-DGVMs, …).

We suggest reducing the number of abbreviations to only use those for central terms to improve readability.

1. **Content Requiring Revision**

- L. 348: Climate is kept constant. LPJmL is used a lot for climate change projections, which is a major strength. I would expect that this is addressed in the limitation section – a business-as-usual baseline would be more realistic than keeping climate constant.

We indeed didn't discuss this model setup choice. In line with our suggestions made in the section "**Novel Concepts, Ideas, Tools, or Data"** above, we suggest clarifying our model design and setup choices. We propose to stress this current model version's aim to be a first prototype that helps foster understanding of the general model setup, explicitly without following the ambition to (a) capture a fully comprehensive set of social and ecological dynamics (b) that would be necessary for behavioral realism. A business as usual scenario would induce climate change feedbacks into the model dynamics, which would necessarily influence social dynamics, and the emerging patterns we want to analyse and understand. This would have introduced an additional level of analysis to this manuscript, which would have hindered understanding and interpretation of the basic underlying dynamics and feedbacks (which already are complex) -- our primary aim. We still agree that introducing climate forcing is a central frontier for first application studies, and suggest discussing this point.

- Condense literature review on AFTs and eliminate repetitive explanations of the TPB
    - Consider re-structuring the explanation of AFTs. Introduce choice of AFTs (pioneer vs. traditionalist), including brief literature review, before explaining model equations (before, or at top of Chapter 2.2). Then explain AFT setup and parameterization in Section 3.1.

We agree with their observation that this section should be condensed and streamlined. We propose to follow their suggestion of "fusing" the AFT introduction, which is currently split in two parts in chapter 2. Personally, we find it helpful to provide a brief (theory-based) reasoning for model equation design choices when introducing the equations, instead of separating equation and background sections. We still take the comment seriously and propose to considerably condense the background information provided with the explanations, and otherwise follow the suggested setup: choice of AFTs, including brief literature review (so, restructuring the AFT section from currently two separate, to one condense section), followed by an explanation of the model equations with condensed background information.

- Table 1: Clarify variables vs. parameters. My understanding is that Attitude (A), crop yield (CY), Soil organic carbon (SOC), Social Norm (N), and Attitudes from … (A_nbr and A_self) are the (partly dependent) variables and w[…] and pbc are the parameters. The latter are set to the values on the right in the "final" model run (only changed for the sensitivity analysis) and the former vary. Suggestion: Change "Parameter Name (Short Form)" to "Associated Variable (Short Form)" and "Wheight Variable" to "Weight parameter".

We agree that variables and parameters can be further clarified and will follow the reviewer's suggestion of novel terminology.

- Figure 1
    - Not referenced in the text.
    - It does not become clear why farming agent systems from different parts of the world are used. This suggests telecoupling, which is not addressed in this study. I suggest that two times the same farming agents (e.g., the ones from Canada) are used and in the right part, the agent's management choices are adapted.
    - For green & yellow land management types, use "conventional farming" and "conservation tillage" instead of "conventional tillage, no residue cover", "no-till, with residue cover", to be consistent with modelling practices.

Thanks, we will adjust terminology and reference Fig. 1 in the text, including your fresh perspective on its interpretation in terms of the possibility of a telecoupling. Our intention was to show that we simulate agents globally, but if that rather creates confusion, we propose following the suggestion and removing one group of farmer agents from one continent.

- Figure 2:
    - It is not easy for the reader to distinguish between management type and AFT parameterization together with a specific management type (e.g., shape next to Evaluation of social norm vs. shape next to Farmer behaviour). I suggest to delete the border from management type and increase the thickness of AFT type borders to allow better distinction.
    - Decide to either include abbreviations A, N, PBC, or not.
    - Concise and consistent with parameter and variable names (e.g., SOC=soil organic carbon vs. soil carbon, Descriptive social norm vs. social norm vs. subjective norms, …), also in text and tables

    - Stochasticity is currently not included.

We propose to follow their visual suggestions to improve clarity on AFT and management type. We suggest also streamlining the use of abbreviations and parameter/variable names in our (this and other) figures. We also thank the reviewer for spotting “stochasticity” here, which was a leftover from an older version of the illustration and will be removed to match the model setup.

- Figure 5:
    - light colored cells are hard to distinguish from NA value cells
    - -> To me it is not clear that, for the pink boxes, neighboring cells really have the opposite management practices.
    - In figure description a) lighter shade -> recent adoption. Should be distant
    - B) annual change rate: mean change rate? If yes, why not choose change since 2022, as in c)? If not specify and justify choice.
    - “Distinct ecologically heterogeneous conditions” are not marked in red

We agree that light colored cells are hard to distinguish from NA value cells, and suggest an alternative depiction, like using shading, or structures. We suggest we revise our placement of pink boxes and remove the eastern box in South Africa, which indeed creates confusion. We also suggest revising the caption, including the comment on distant adoption, which was incorrectly described by us. We suggest removing the point on distinct ecological conditions in the red area from the description, which is a leftover from an earlier figure version we decided to not illustrate to avoid the use of too many colours. We also suggest streamlining the key headers such that B) and C) align.

- Ll. 452 – 455 seem to belong to sensitivity results

We agree that this section could be better placed in the sensitivity results chapter.

- Local/cell scale: based on different scenario than global scale analysis -> not comparable

Our intention with the zoom-ins on local/cell level (Chapter 4.2.2) was not to provide insights that could be compared to the global scale analysis. Our approach of showing the different levels of analysis rather aimed to highlight social, ecological dynamics and their interaction at different scales. The cell level particularly is intended to trace distinct examples of RA adoption processes happening at the smallest possible unit of analysis. We aim to better understand the local dynamics and processes to understand how they work to then be able to understand the big picture of how these dynamics unfold. This level of analysis is about the mechanisms in place at the level of individual agents. This level of analysis shows that RA adoption can happen through very different decision-making pathways.

Sensitivity analysis: Requires major text (Chapter 3.3)/table/figure revisions. It seems that the analysis is solid, but the description is very erroneous and unclear.

We thank the reviewer for raising these important points and suggest revising/adapting the table and figures by implementing the following changes:

- Table 2: requires major revisions
    - In the text you describe that you change the pioneer share by 20% increments, in the table it says 0.25. Which is true?

Typo; we will adapt the table entry accordingly.

- Wrong parameters in line 3

We suggest streamlining parameter names throughout all figures, including this one.

- Positioning: Since Figure 3 and table 3 are related, I suggest keeping them close to each other in the manuscript

We agree and suggest placing these closer.

- Why pioneer AFT difference for second experiment +-0.05 instead of +-0.2?

We propose to clarify the difference in the parameter variations between these experiments. They stem from a different variance when comparing values on (1) one's own field/cell over time (small expected differences) vs. when comparing own (2) and neighboring fields/cells (larger expected differences). With equal weights of these two processes, the second one would overpower the first significantly. We also notice that this is a dimension that was altered during the last figure 3 edits and is therefore not represented graphically. We would of course adapt this in the revision of the figure.

- Why different numbers of simulations? Should be 5,5,4,6,?

Typo -- you are exactly right, we propose to adjust the numbers in table 2 (5,5,4,6 runs) and clearly explain why different numbers of simulations were performed: The number of simulations for each parameter depends on 1) The range of values the parameter can take (e.g., 0 to 1) and 2) Whether the parameter's variation is constrained by differences between AFTs (i.e., if the parameter must differ by a certain amount between two AFTs). Combination of both factors leads to different numbers of simulations.

So, all variations in weights were conducted with 0.2 steps, and the inclusion of one parameter of the combinations that was set to 0. For variation in weights of attitudes/norms and own land/neighbor learning, we conducted 5 runs each -- a difference of 0.2 between AFTs given the other conditions above yielded 5 runs. As the ecological weights differed with a magnitude of 0.4 between AFTs, only 4 runs were possible. For the PBC variation, we were able to conduct 6 runs, as we could just vary from 0 to 1 in 0.2 increments (no AFT difference limiting the number of simulations that could be performed).

- Figure 3: requires major revisions

We agree with the necessary major revisions in Fig. 3. We noticed that central elements of the figure were altered during the last edits, which we didn't catch. We will answer point-by-point below.

- Why do we see only three experiments?

Here, we refer to the three distinct groups of interdependent parameter variations (2 parameters that are interdependent each): (1) The variation of attitude vs norm, the variation of (2) learning from own land vs social learning from neighbors, and (3) the variation of yield vs soil organic carbon. We propose to clarify our language here.

- No thick circles in first experiment

This is part of the unintended alterations in the last round of editing, we propose to add the circles.

- Give experiments a name, so that you can refer to them in text, table and figure e.g., as in results: INTENTION, ATTITUDE, ECOL_PERF

This is a very good point. We intended to already do this (e.g., "variation of attitude sub-components" in figure 3 being connected to runs named "attitude_0" to "attitude_4", (figure 4) but we suggest making this connection even more explicit by introducing explicit naming in Figure 3.

- Description of Figure: What do circles mean? What is on x-axis? What do the numbers in brackets and in circles stand for? What about the brightness of the bars? This should all be clear from the figure description.

We propose to extend the figure description to address those points: Circles represent the exact parameter weights chosen in the given experiment (we don't do a continuous sensitivity analysis but discrete steps, which is why we don't include a gradient), the x-axis represents the weight range from 0 to 1 (we propose to add an explicit axis label), the numbers in the circle indicate the connection of the parameter combination to the run (e.g., looking at the green group varying attitudes and norms, as the subcomponents of behavioral intention: the thickly circled default run that has the number "1" in the circle corresponds to the run "intention_1" in figure 4. In this run, figure 3 shows that the parameter weights for social norm are set to 0.4 and attitudes to 0.6 for traditionalist, and 0.2 (norm) vs 0.8 (attitude) for pioneer AFTs).

- Different order of experiments

We agree and suggest ordering the three groups by their hierarchy in the decision-making model: top layer: variation of behavioral intention sub-components (norm vs attitude, green), middle layer: variation of attitude sub-components (learning from own land vs. social learning, pink), lower layer: variation of ecological sub-components (yield vs. soil, as inputs for the learning processes, blue).

- Parameter names inconsistent (w_CY and w_SOC suddenly wY and wS, …)

We suggest streamlining parameter names in this and other figures.

- In Chapter 4.1, l. 387 explain what run_intention 0, … means (ideally in chapter 3.1 already)

We agree and suggest introducing the run-names earlier in the text.

- No results on PBC variation available

Good point, we suggest adding a paragraph that lays out PBC variation results and discuss these. The variation of PBC induced drastic changes in model dynamics that were of a different magnitude than the variation of the three different other sets of parameters, so we didn't want to compare them within the same figure.

1. **References** Appropriate but slightly excessive. Some tangentially related work could be removed.
2. **Supplementary Material** Appropriate.

We thank the reviewer for their positive assessment of the references and supplementary material. We suggest revising them and being more concise with regard to where they are necessary/missing/excessive (in line with reviewer 2 suggesting that generally, they found that we needed more references).

Minor Corrections

- 318-319: "The share of the two different AFTs in a simulation run is determined by parameter S, which reflects the share of pioneers in a simulation run." -> The share of *pioneers* in a simulation run is determined by parameter S.
- 333 "6" -> "six"
- 334 following
- Chapter 1-3 check hyphen style
- Figure 4: Description: ref. to Figure 3 (l. 2)
- Figure 6: Consider using different colors for accessibility with color blindness
- 599: two times "agricultural"

We suggest implementing them these corrections. We suggest reaching out to a graphics design person to check all figures for colorblindness accessibility.

Recommendation

The coupling framework represents a technical achievement, but the model's current implementation is too simplified and poorly validated for the ambitious claims made. The authors must either:

1. Substantially enhance the behavioral model and validate against observations, or
2. Reframe the paper as a proof-of-concept with explicit limitations on applicability

The current manuscript falls between these positions, claiming transformative insights while acknowledging fundamental limitations that undermine those very claims.

We thank the reviewer for this clearly laid out options on how to frame the paper. As (hopefully) explained above, we intend to reframe it as a novel type of model prototype that allows for socio-ecological, spatially explicit simulations of farmer decision-making on up-to planetary scales – rather than to provide a comprehensive, validated, data-integrated modeling study with behavioral realism at this stage.

Literature

Burton, R. J., Forney, J., Stock, P., & Sutherland, L. A. (2020). The good farmer: Culture and identity in food and agriculture. Routledge.

Dietrich, J. P., Bodirsky, B. L., Humpenöder, F., Weindl, I., Stevanović, M., Karstens, K., ... & Popp, A. (2019). MAgPIE 4–a modular open-source framework for modeling global land systems. *Geoscientific Model Development*, *12*(4), 1299-1317.

Harrell, F. E. (2015). Regression Modeling Strategies: With Applications to Linear Models, Logistic and Ordinal Regression, and Survival Analysis. Springer Series in Statistics. Cham: Springer International Publishing. doi:10.1007/978-3-319-19425-7

Herzfeld, T., Heinke, J., Rolinski, S., & Müller, C. (2021). Soil organic carbon dynamics from agricultural management practices under climate change. *Earth System Dynamics*, *12*(4), 1037-1055.

Kim, C. N., Yang, K. H. & Kim, J. (2008). Human decision-making behavior and modeling effects. Decision Support Systems, 45 (3), 517–527. doi:10.1016/j.dss.2007.06.011

Krey, V., Havlik, P., Kishimoto, P., Fricko, O., Zilliacus, J., Gidden, M., ... & Riahi, K. (2020). Messageix-globiom documentation-2020 release.

Ostberg, S., Müller, C., Heinke, J., & Schaphoff, S. (2023). LandInG 1.0: a toolbox to derive input datasets for terrestrial ecosystem modelling at variable resolutions from heterogeneous sources. Geoscientific Model Development, 16(11), 3375-3406.

Rogers, E. M. (1983). Diffusion of innovations. New York: Free Press, 3 edn.

Schaphoff, S., von Bloh, W., Rammig, A., Thonicke, K., Biemans, H., Forkel, M., ... & Waha, K. (2018). LPJmL4–a dynamic global vegetation model with managed land–Part 1: Model description. Geoscientific Model Development, 11(4), 1343-1375.

Swart, R., Levers, C., Davis, J. T., & Verburg, P. H. (2023). Meta-analyses reveal the importance of socio-psychological factors for farmers' adoption of sustainable agricultural practices. One Earth, 6(12), 1771-1783.

Wirth, S. B., Braun, J., Heinke, J., Ostberg, S., Rolinski, S., Schaphoff, S., ... & Müller, C. (2024). Biological nitrogen fixation of natural and agricultural vegetation simulated with LPJmL 5.7. 9. Geoscientific Model Development, 17(21), 7889-7914.