**Response to Editor and cover letter**

**Overall response**

Dear Jagadish,

Thank you very much for your thorough and very constructive review of our manuscript “Risk-based evaluations of competing agronomic climate adaptation strategies: The case of rice planting strategies in the Indo Gangetic Plains” with the manuscript number “AGSY-D-23-01429”.

Based on these feedbacks, we have thoroughly revised the manuscript and provide a detailed point by point response to your comments and the reviewers’ comments below. Overall we believe that this new manuscript is substantially improved and addressing many of the issues of the previous version of the manuscript.

Most importantly, we would like to emphasize that the novelty of this manuscript lies in methods innovation. As of our knowledge, there are no other spatial approaches for evaluating the riskiness of different agricultural strategies. To demonstrate our approach – we use the results of a peer-reviewed gridded crop simulations that have been extensively calibrated with ground data and evaluated vis a vis reported data on phenology and yield across the simulation period. All of this is well described in the original peer-reviewed publication by Urfels et al. (2022) and published in Environmental Research Letters. We fully agree that having longitudinal farmer field trials across the many varying micro-climate in the Indo-Gangetic Plains would be very useful – but these are very expensive and using well calibrated crop models that are evaluated with respect to reported and remotely sensed crop production information provides a solid foundation for an initial ex-ante study. With our results, future research may guide the selection of study sites for longitudinal climate resilience trials and thus add substantial value to the literature not only for the methods innovation but also for cost-effective designs of future field data collection campaigns. As you suggested, we also further discuss our work with respect to other results that have been published on this topic to crystallize the novel contributions of our work within the emerging literature of this important topic.

We spent a lot of time revising the manuscript to further clarify these points and hope that these are now very clear and adequately delineate the novelty and practical relevance of our work while providing the reader adequate information the empirical foundations of this piece of work.

We sincerely believe that this manuscript is now ready for publication in AgSys and kindly ask for your consideration to publish this research article.

Please find below our more detailed point-by-point response to all of your and the reviewers’ comments with excerpts from our revisions indented and in italics.

Thank you very much and we look forward to receiving your response.

Best regards,

Anton.

Comments from the editor:

Q1. As pointed out by the third reviewer, the main weakness of the manuscript is lack of calibration and validation and ground-level data and dependence on simulated data only.

Response: We thank you for re-emphasizing the reviewer’s comment. The basis of our contribution in this paper is a crop growth model already published in Urfels et al (2022). The calibration, validation and groundtruth assessments were conducted in those previous papers and we do not repeat these in the current manuscript but we now more clearly describe these in manuscript and point the reader to the existing publication in more detail. As mentioned above, our contribution in the current paper regards the risk-based assessment of the different agricultural practices under climate variability. We could have used any other crop growth model reviewer 3 believes is relevant for the region to showcase this important contribution. Through out the paper, we have pointed the risk based evaluation approach as the key contribution.

For example see the introduction section edits below:

*We specifically follow the approach proposed by Hurley et al. (2018) to estimate willingness to pay bounds for a risk averse farmer to likely adopt an alternative rice planting date strategy. The key idea of the willingness to pay bounds is that there is an amount of economic gain that will make one choose a new strategy in the sense of second order stochastically dominating the base strategy. Similarly, there is an amount that would make them indifferent. The algorithm uses a golden section search optimization approach to select the maximum and minimum numbers that satisfy these conditions. We depart from their approach in three substantial ways. First, instead of fertilizers and improved varieties, we consider multiple management changes including sowing dates, irrigation amounts, and varieties differing on duration to maturity. This allows a more realistic comparisons of the benefits of the interrelated crop management decisions rather than a piecemeal and partial analysis of specific decisions. Second, we consider a rice-wheat multi-crop system unlike Hurley et al. (2018) who focus on maize only. This has the added value that the optimal decision in one crop may be suboptimal for the next season there providing the trade-offs that farmers make when making adjustments in one crop. Third, we do not only consider pairwise comparisons but also use the willingness to pay bounds to select the best strategy among multiple competing options. This has the advantage that we can select one optimal strategy among the many to recommend for risk averse farmers. Our application shows how this risk-assessment framework can handle increasingly complex decisions.*

*The rest of the paper is organized as follows. We present next the methods focusing on the computational risk assessments. In section 3 we present results and discussion of the yield and economic benefits of alternative planting date strategies. We finally conclude in section 4.*

Q2. Also, the manuscript lacks a discussion which requires comparison of the results with those of others' works and not merely with by authors' own works. Otherwise, there arises a question of novelty.

**Response:** We have added a discussion section which revisits the literature that looks at rice sowing optimization in the area of interest as well as those papers that try to include risk-based assessments. We do not find any work that does spatial risk-based assessments as we have provided. Some recent work AgSy journal recently by Wang et al 2024 uses EPIC crop model to make planting date assessments and we now discuss these works. We have included this work in the references including adding other literature with authors not associated with our work or within our networks and provide a discussion of how we embellish this emerging field.

The graphical abstract is incomplete; it should capture the entire paper giving objectives, results, conclusions and significance. You can see examples of good graphical abstracts under relevant section in Guide to Authors in journal website, or in the recently published papers in this journal.

Response: We have revised the graphical abstract as advised.

Any resubmission should address above issues in addition to the reviewers' comments.

Response: We thank the editor for giving us the chance to revise the paper in line with reviewers’ comments. We have comprehensively addressed all the comments and these suggestions have improved the quality of the revised paper.

**Response to reviewer 1 comments**

Reviewer #1:

This paper demonstrates a risk-based evaluation of six agronomy decisions for rice and wheat planting strategy in Indo Gangetic Plains. The spatial representation of the result is interesting. However, more details on the reasoning behind key decisions need to be added. The introduction needs to be re-organized and the research objectives need to be clearly described. Also, an entire discussion section is not included. Especially, the authors need to discuss how their suggested approach is compared with the existing ones and what their limitations are.

Response: We thank the reviewer for the comments.

On re-organization and objectives, we have added an objective statement in the first paragraph.

We have now included a separate discussion section rather than the combined results and discussion section. This discussion now includes a discussion of the limitations of the proposed approach and future research.

We have also compared our approach to the mean-variance and conditional value at risk approaches which are the competing outcome-based risk analysis methods.

Please see below edits:

*4. Discussion*

*4.1. Spatial variation in recommended rice planting date strategies*

*The results of the adapted have provided climatic risk proof rice planting strategies such that even a risk averse farmer would find it profitable to adopt the proposed strategies. Importantly and in addition to the findings of Urfels et al. (2022) and Montes et al (2023), our framework shows that in parts of the Eastern Gangetic Plains providing only supplemental irrigation rather than full irrigation is economically beneficial from a risk perspective. The same is true for some areas in the northern parts of the Middle and Western IGP – indicating importance of climatic and soil variability. However, in the Northern and Southern parts of the Western and Middle IGP, we get substantially different outcomes – but also indicating that in these areas multiple rice planting strategies perform equally well and farmers have more flexibility to choose amongst various options for similar results.*

*In addition to cited prior works (Urfels et al 2022 and Montes et al 2023) which formed the basis of our analysis and used APSIM crop growth model, our results can be compared to two recent studies (Wang 2022, 2024) which rely on regionally calibrated Environmental Policy Integrated Climate (EPIC) agronomic model.*

*4.2. Value of a risk-based evaluation approach in face of climatic risks*

*The IGP is a hotspot of climate change impacts in that though it supports the most intensive crop production, it also suffers from frequent droughts, volatile monsoon onsets, and heat stress. Farmers delay rice planting in dealing with these environmental and climatic impacts (McDonald et al 2022) thereby suffering substantial yield penalties. Without affordable irrigation infrastructure, timely rice planting becomes very risky for the farmers as evidenced by the recent El Nino event and late monsoon – causing farmers to fallow and reduce rice area. Similar issues of importance of timing and precipitation variability affect other farming systems elsewhere. Recommendations therefore require to consider riskiness evaluation and will need to include also field evaluation of riskiness after the first pass model ex-ante simulations as we do in this paper.*

*Climate variability and change has prompted a rethinking of how the agricultural research and development community can develop climatic risk proof innovations. These are innovations that are expected to be resilient to present and future climatic shocks. In that regard, crop modelling has become the key approach of assessing how different agronomic innovations perform under varying historical realizations of weather. In this paper, we have demonstrated that a nuanced understanding of risk in evaluating such crop model results can generate insights and provide a basis for making climate risk proof recommendations to smallholder farmers. This approach then allows researchers and farmers to understand the plausible strategies they can follow in order to maximize profits even in years when the weather is extreme.*

*Besides the farmers and researchers, our approach provides policy decision makers with a prioritization and targeting framework for extension support services that advances only the strategies that are more likely to be accepted by all the farmers in the location. This then reduces wastage of resources especially when risk neutral and profitable technologies are promoted in locations where most farmers are risk averse. The task of figuring out the risk aversion preferences of the farmers in non-trivial and not possible for each of the individual pixels. The approach we use innovatively circumvents this challenge by placing conditions and extent under which any risk averse farmer will still find the proposed strategy beneficial.*

*4.3. Limitations and future research*

*There are several key limitations to our approach. First, it is computationally heavy especially if the gridded analysis is conducted for larger spatial scales. This challenge can be resolved by reducing the number of pixels in each analysis because the approach uses each pixel separately such that the optimal strategies will not differ based on number of pixels. Second, it requires many years of data to characterize the empirical cumulative distribution function. Our analyses use the period 1982-2015 data which covers enough variation of climatic variability. In the context of long-term trials and surveys, it is difficult to find such longitudinal datasets at scale. Future research that combines these data sources and Monte Carlo simulations would allow the use of the approach in empirically grounded analyses. Third, as compared to other outcomes-based risk analyses like the mean-variance or conditional value at risk approach, our approach simply recommends the best strategy but not an optimal combination or diversified portfolio of options (literature started by Markowitz 1959). Fourth, given that the risk evaluation approach relies on crop model outputs, any limitations of the crop model are propagated in our approach. For example, the gridded APSIM crop model we use has no N limitation and no irrigation to isolate the effect of sowing dates in addition to not having many interactions. While we acknowledge these limitations, they are not necessary for the merit of this paper in that the paper is aimed at showcasing a methodology for evaluating risk regardless of the nature of the crop model used.*

Specific comments are shown below.  
1. The authors describe two studies that use gridded crop simulations for IGP to investigate the impact of different rice planting strategies (L70-L73). They also mention that the re-evaluation of results from Urfels et al., 2022 is used to demonstrate the need for incorporating risk (L81-L83). It is unclear that why the authors only select to re-evaluate just the Urfels' work, and not the Montes', or both.  
The citation is also inconsistent: Montes et al., 2023 (L86) vs. Montes et al. 2022 (L70). Please check and correct.

Response: The gridded crop simulations in Urfels and Montes are the same. The difference is that in Montes focuses on Bihar with some additional specific analytics of interest for the area of Bihar. We have now clarified this in the paper and you can check the following sections below.

Thanks for pointing the inconsistency in the years for the citations. We have edited the text accordingly.

*Recent compelling evidence suggests that advancing the planting date of rice to match the monsoon onset is a crucial adaptation option for farmers in the Eastern IGP – and might help to alleviate groundwater depletion in the Western IGP (Ishtiaque et al., 2022; McDonald et al., 2022; Montes et al., 2023; Newport et al., 2020; Urfels et al., 2021; Urfels et al., 2022; Wang et al., 2022). To test this hypothesis, Urfels et al (2022) and subsequently, working with the same datasets, Montes et al (2023) use gridded crop simulations for the Indo-Gangetic Plains to investigate the impact of different rice planting strategies (combining sowing dates, variety duration and irrigation) on system level productivity, resilience, and environmental benefits.*

2. Incorporation of farmer risk-aversion is not a new idea. The authors need to elaborate on what this study addresses. For example, spatial risk assessment has also been demonstrated in Hudley et al., 2018. Please explain why it is necessary to consider "a rice-wheat multi-crop system" instead of the one that focuses on "maize only (L113) as in Hudley's study", and why "pairwise comparisons" (L114) alone is insufficient?

Response: We thank the reviewer for the response. We indeed agree that it is not a new idea but in the context of crop growth modelling, except for Hurley et al (2018) there is little literature that provides decision support from crop growth results that takes into account risk aversion. We have emphasized throughout the paper that we have followed the approach of Hurley et al (2018) and our paper is probably the only second paper which uses this approach in the context of agricultural risk analysis and takes this approach to a spatial one.

The added value of a multi-crop systems analysis is that the decision may be optimal in one crop but not in the other crop. That is why we have presented sets of results for rice, wheat and rice-wheat system to showcase how farmer prioritization of the crop may also alter the strategy they can choose.

On pairwise comparisons, we have only added the aspect of choosing the strategy that gives the maximal gains among the pairwise comparisons. This adds value in pinpointing not just the dominant strategies but also the one that is most profitable.

We now provide more details in the introduction:

*We specifically follow the approach proposed by Hurley et al. (2018) to estimate willingness to pay bounds for a risk averse farmer to likely adopt an alternative rice planting date strategy. The key idea of the willingness to pay bounds is that there is an amount of economic gain that will make one choose a new strategy in the sense of second order stochastically dominating the base strategy. Similarly, there is an amount that would make them indifferent . The algorithm uses a golden section search optimization approach to select the maximum and minimum numbers that satisfy these conditions. We depart from their approach in three substantial ways. First, instead of fertilizers and improved varieties, we consider multiple management changes including sowing dates, irrigation amounts, and varieties differing on duration to maturity. This allows a more realistic comparisons of the benefits of the interrelated crop management decisions rather than a piecemeal and partial analysis of specific decisions. Second, we consider a rice-wheat multi-crop system unlike Hurley et al. (2018) who focus on maize only. This has the added value that the optimal decision in one crop may be suboptimal for the next season there providing the trade-offs that farmers make when making adjustments in one crop. Third, we do not only consider pairwise comparisons but also use the willingness to pay bounds to select the best strategy among multiple competing options. This has the advantage that we can select one optimal strategy among the many to recommend for risk averse farmers. Our application shows how this risk-assessment framework can handle increasingly complex decisions.*

*The rest of the paper is organized as follows. We present next the methods focusing on the computational risk assessments. In section 3 we present results and discussion of the yield and economic benefits of alternative planting date strategies. We finally conclude in section 4.*

3. The key idea of this study needs to be explained clearly. The authors only state that they "follow the approach proposed by Hurely et al., (2018) to estimate willingness to pay bounds" without providing any contexts on what willingness to pay bounds are. Additionally, the methodology is also unclear. Figure 1 does not show the four parameters included in the main text (L164-L174) and note (L177-L180).

Response: We thank the reviewer for this comment. We have added additional text to explain the reasoning behind the approach.

We think showing these parameters in the graph will make it look cluttered. These parameters were hypothetically chosen to demonstrate the methodology.

As above, please see above for some of our clarifications in the manuscript:

*We specifically follow the approach proposed by Hurley et al. (2018) to estimate willingness to pay bounds for a risk averse farmer to likely adopt an alternative rice planting date strategy. The key idea of the willingness to pay bounds is that there is an amount of economic gain that will make one choose a new strategy in the sense of second order stochastically dominating the base strategy. Similarly, there is an amount that would make them indifferent . The algorithm uses a golden section search optimization approach to select the maximum and minimum numbers that satisfy these conditions. We depart from their approach in three substantial ways. First, instead of fertilizers and improved varieties, we consider multiple management changes including sowing dates, irrigation amounts, and varieties differing on duration to maturity. This allows a more realistic comparisons of the benefits of the interrelated crop management decisions rather than a piecemeal and partial analysis of specific decisions. Second, we consider a rice-wheat multi-crop system unlike Hurley et al. (2018) who focus on maize only. This has the added value that the optimal decision in one crop may be suboptimal for the next season there providing the trade-offs that farmers make when making adjustments in one crop. Third, we do not only consider pairwise comparisons but also use the willingness to pay bounds to select the best strategy among multiple competing options. This has the advantage that we can select one optimal strategy among the many to recommend for risk averse farmers. Our application shows how this risk-assessment framework can handle increasingly complex decisions.*

*The rest of the paper is organized as follows. We present next the methods focusing on the computational risk assessments. In section 3 we present results and discussion of the yield and economic benefits of alternative planting date strategies. We finally conclude in section 4.*

4. After the results section, the discussions are moved to "recommended rice planting date strategy per grid cell" directly. More discussions need to be included. For example, please discuss how incorporation of risk improves the evaluation results and what limitations of your proposed approach are.

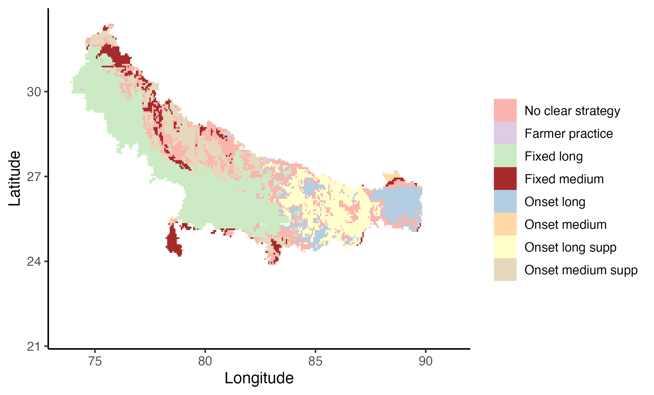
Response: We thank the reviewer for this suggestion. We have now included a separate discussion section and explained the differences between our risk based approach and the average caloric yield approach in the prior works (Urfels et al 2022).

On the questions of limitations, we have now included a limitations and future research section with four limitations including computational burden and that we cannot provide diversified optimal portfolios.

Please see below for our details edits:

*3.2.3. Recommended rice planting date strategy per grid cell*

*Lastly, our risk-based evaluation approach allows us to compare all of the rice planting strategies against each other and identify which strategy performs clearly better and with less risks involved than any other strategy and where several competing strategies might result in similar economic benefits as well as risks. In other words, the above analysis has made binary or pairwise comparisons – while the most important question is: Which strategy should be recommended where? To derive this optimal scenario, we calculate the maximum upper bound WTP among the scenarios and the maximum lower WTP. If one single scenario clearly pays more and clearly induces less risks than the others, we select that scenario for that particular grid cell. As a result, Figure 7 shows the optimal rice planting date strategy.*



*Figure 6: Optimal rice planting date strategy*

*4. Discussion*

*4.1. Spatial variation in recommended rice planting date strategies*

*The results of the adapted have provided climatic risk proof rice planting strategies such that even a risk averse farmer would find it profitable to adopt the proposed strategies. Importantly and in addition to the findings of Urfels et al. (2022) and Montes et al (2023), our framework shows that in parts of the Eastern Gangetic Plains providing only supplemental irrigation rather than full irrigation is economically beneficial from a risk perspective. The same is true for some areas in the northern parts of the Middle and Western IGP – indicating importance of climatic and soil variability. However, in the Northern and Southern parts of the Western and Middle IGP, we get substantially different outcomes – but also indicating that in these areas multiple rice planting strategies perform equally well and farmers have more flexibility to choose amongst various options for similar results.*

*In addition to cited prior works (Urfels et al 2022 and Montes et al 2023) which formed the basis of our analysis and used APSIM crop growth model, our results can be compared to two recent studies (Wang 2022, 2024) which rely on regionally calibrated Environmental Policy Integrated Climate (EPIC) agronomic model.*

*4.2. Value of a risk-based evaluation approach in face of climatic risks*

*The IGP is a hotspot of climate change impacts in that though it supports the most intensive crop production, it also suffers from frequent droughts, volatile monsoon onsets, and heat stress. Farmers delay rice planting in dealing with these environmental and climatic impacts (McDonald et al 2022) thereby suffering substantial yield penalties. Without affordable irrigation infrastructure, timely rice planting becomes very risky for the farmers as evidenced by the recent El Nino event and late monsoon – causing farmers to fallow and reduce rice area. Similar issues of importance of timing and precipitation variability affect other farming systems elsewhere. Recommendations therefore require to consider riskiness evaluation and will need to include also field evaluation of riskiness after the first pass model ex-ante simulations as we do in this paper.*

*Climate variability and change has prompted a rethinking of how the agricultural research and development community can develop climatic risk proof innovations. These are innovations that are expected to be resilient to present and future climatic shocks. In that regard, crop modelling has become the key approach of assessing how different agronomic innovations perform under varying historical realizations of weather. In this paper, we have demonstrated that a nuanced understanding of risk in evaluating such crop model results can generate insights and provide a basis for making climate risk proof recommendations to smallholder farmers. This approach then allows researchers and farmers to understand the plausible strategies they can follow in order to maximize profits even in years when the weather is extreme.*

*Besides the farmers and researchers, our approach provides policy decision makers with a prioritization and targeting framework for extension support services that advances only the strategies that are more likely to be accepted by all the farmers in the location. This then reduces wastage of resources especially when risk neutral and profitable technologies are promoted in locations where most farmers are risk averse. The task of figuring out the risk aversion preferences of the farmers in non-trivial and not possible for each of the individual pixels. The approach we use innovatively circumvents this challenge by placing conditions and extent under which any risk averse farmer will still find the proposed strategy beneficial.*

*4.3. Limitations and future research*

*There are several key limitations to our approach. First, it is computationally heavy especially if the gridded analysis is conducted for larger spatial scales. This challenge can be resolved by reducing the number of pixels in each analysis because the approach uses each pixel separately such that the optimal strategies will not differ based on number of pixels. Second, it requires many years of data to characterize the empirical cumulative distribution function. Our analyses use the period 1982-2015 data which covers enough variation of climatic variability. In the context of long-term trials and surveys, it is difficult to find such longitudinal datasets at scale. Future research that combines these data sources and Monte Carlo simulations would allow the use of the approach in empirically grounded analyses. Third, as compared to other outcomes-based risk analyses like the mean-variance or conditional value at risk approach, our approach simply recommends the best strategy but not an optimal combination or diversified portfolio of options (literature started by Markowitz 1959). Fourth, given that the risk evaluation approach relies on crop model outputs, any limitations of the crop model are propagated in our approach. For example, the gridded APSIM crop model we use has no N limitation and no irrigation to isolate the effect of sowing dates in addition to not having many interactions. While we acknowledge these limitations, they are not necessary for the merit of this paper in that the paper is aimed at showcasing a methodology for evaluating risk regardless of the nature of the crop model used.*

Minor comments  
1. L206-L209: The authors need to better explain what the baseline scenario is.

Response: We have added edits to reflect that fixed long (S1) was considered the baseline scenario.   
2. The authors should keep the expression of units consistent throughout the manuscript. For example, "tons/ha" (L175), "ton/ha" (L246), and "t/ha" (L267) are used for the same unit.

Response: We have revised the text accordingly.

3. Figure 2 and Figure 3: it is suggested to add "S1", "S3", "S4" and so on into the figure as annotations to help readers find the corresponding information more easily in Table 1. Please also keep the image size within each grid consistent (a-f) and place the legend elsewhere beside the entire image. A compass for indicating the direction is also missing in the map. Some texts in the figures are also truncated.

Response: We thank the reviewer for the suggestion. We have reproduced all the figures in the paper following this advice. Our inclusion of the latitude and longitudes that we now magnified in font size helps the reader know the compass.

**Response to reviewer 2 comments**

Reviewer #2:

Abstract:  
1. It would be beneficial to briefly explain the specific nature of the "computational spatial ex-ante approach" to give readers a "face-value" understanding of the approach.

Response: We thank the reviewer for the suggestion. We have included edits to explain the golden section search algorithm used and the implications of the approach to the development of climatic risk proof strategies.

*Abstract*

*CONTEXT: Adjusting crop planting dates and variety durations is emerging as a crucial climate change adaptation strategy for many cereal systems. Such strategies include harmonizing crop planting with the onset of the rainy season or planting at specific recommended calendar dates. Evaluations of these strategies mostly consider yield and yield variability, but focus less on financial risks associated with different planting strategies. However, choosing recommendations amongst competing levels of yield and yield stability is not straightforward and need to cater to farmers that are risk averse – especially financially.*

*OBJECTIVE: Here, we present a novel framework that uses a computational spatial ex-ante approach using golden section search algorithm and second order stochastic dominance for risk-based evaluations of agronomic adaptation options. This framework allows development of climatic risk proof recommendations such that even risk averse farmers would find it profitable to adopt that strategy*

*METHODS: We use a second order stochastic dominance approach that is paired with computational optimization—Golden section search algorithm. To demonstrate our approach, we compare the yield risks and economic risks associated with readily available gridded crop simulation outputs for various rice planting strategies across the Indo-Gangetic Plains – a major region experiencing food insecurity and climate impacts.*

*RESULTS AND CONCLUSIONS: Our findings provide quantitative evidence about the riskiness of previously recommended rice planting date strategies. Our risk-based assessment corroborates the recommendation for planting long-duration varieties at the monsoon onset in the Eastern IGP, and at state-recommended planting dates in most of the Western and Middle IGP. Importantly, our risk-based assessment shows where the results are not as clear cut and which strategy is the least risky. This is especially important in the Middle IGP where farmers appear to have more flexibility to achieve comparable outcomes with several planting strategies.*

Introduction:  
2. While the introduction is rich in content, it might benefit from breaking down technical jargon into clearer explanations to enhance readability and comprehension for a wider audience. For instance, technical aspects of the study, such as the "robust and risk-oriented framework" and the "computational risk assessments," could be explained in simpler terms to ensure clarity for readers who might not be familiar with these methods.

Response: We thank the reviewer for this comment. We have edited all parts to add more detail or use alternative phrases like “climatic risk proof”.

Please see below for additional details such as from the introduction:

*We specifically follow the approach proposed by Hurley et al. (2018) to estimate willingness to pay bounds for a risk averse farmer to likely adopt an alternative rice planting date strategy. The key idea of the willingness to pay bounds is that there is an amount of economic gain that will make one choose a new strategy in the sense of second order stochastically dominating the base strategy. Similarly, there is an amount that would make them indifferent. The algorithm uses a golden section search optimization approach to select the maximum and minimum numbers that satisfy these conditions. We depart from their approach in three substantial ways. First, instead of fertilizers and improved varieties, we consider multiple management changes including sowing dates, irrigation amounts, and varieties differing on duration to maturity. This allows a more realistic comparisons of the benefits of the interrelated crop management decisions rather than a piecemeal and partial analysis of specific decisions. Second, we consider a rice-wheat multi-crop system unlike Hurley et al. (2018) who focus on maize only. This has the added value that the optimal decision in one crop may be suboptimal for the next season there providing the trade-offs that farmers make when making adjustments in one crop. Third, we do not only consider pairwise comparisons but also use the willingness to pay bounds to select the best strategy among multiple competing options. This has the advantage that we can select one optimal strategy among the many to recommend for risk averse farmers. Our application shows how this risk-assessment framework can handle increasingly complex decisions.*

*The rest of the paper is organized as follows. We present next the methods focusing on the computational risk assessments. In section 3 we present results and discussion of the yield and economic benefits of alternative planting date strategies. We finally conclude in section 4.*

Methods:  
3. In table 2: comparison of SOSD, why is the interpretation of upper and lower bound for column Q(base) vs G, "G F/SOSD Q"?

Response: We have now just included SOSD to mean G second order stochastically dominate Q. The F/ part was to show that G also first order stochastically dominate Q.   
  
4. Could you possibly give the resolution of the APSIM model results and the gridded LCAS data?

Response: APSIM was run using 0.05◦ × 0.05◦ spatial resolution input data. We now clarify this in the manuscript.

Please see below:

*2.3. APSIM spatially gridded crop model scenarios*

*The data used in this paper was based on gridded APSIM crop growth simulation model results for climate variables for the period 1982-2015 reported in Montes et al. (2023); Urfels et al. (2022) . The model was run using 0.05°×0.05° spatial resolution input data. We use seven scenarios from crop simulation results reported in (Urfels et al., 2022). The scenarios correspond to variation in irrigation, varietal duration and the planting of rice at the onset of the monsoon. Table 21 shows the details for the scenarios. We used the fixed long (S1) scenario as the baseline scenario. This scenario involves planting long duration rice variety at a fixed recommended date based on a state recommendation. We considered this as the baseline scenario instead of the farmer practice (S0) because S1 had observations for all pixels in the area of interest unlike the farmer practice which due to limitations of data had a limited number of pixels .*

5. Clarify any specific assumptions or limitations in the APSIM model inputs and how these might affect the study's outcomes.

Response: Reported in the previous papers that we cite (Urfels et al 2022 and Montes et al 2022) but we have now edited so as to clarify the assumptions. The key limitations are: no N limitation. Future studies would need to consider more interactions with eg. Temperature, water, and nitrogen stress – but again our paper is meant to showcase the methodology for evaluating risk regardless of whether APSIM or other crop models are used.   
  
6. Are there specific details regarding data sources, accuracy, and representativeness of the simulated strategies that could be included for reference?

Response: As stated in the methods sections, the crop model details are reported in Urfels et al (2022) and for Bihar in Montes et al (2022) as well as the full crop model can be replicated from: These references already provided extensive data sources, accuracy and representativeness assessments. For example: state recommendations were based on state government recommendations while the onset is strategy we hypothesized to be beneficial and evaluated for yield in Urfels et al (2022) and here to show the riskiness onset was calculated based Stiller reeves methods for monsoon rainfall detection (see Urfels 2022). In addition, the study of Urfels et al. (2022) where the dataset was published in a well-respected peer-reviewed journal also includes extensive Supplementary Information that demonstrates the validation and performance evaluation of the simulation results.

We now provide specific pointers for the readers on where to find these information e.g. see detailed edits below:

*.3. APSIM spatially gridded crop model scenarios*

*The data used in this paper was based on gridded APSIM crop growth simulation model results for climate variables for the period 1982-2015 reported in Urfels et al. (2022) . The model was run using 0.05°×0.05° spatial resolution input data and the original study includes extensive performance evaluation for validating the results and modelling setup with other datasets on reported phenology and yield outcomes. We use seven scenarios from crop simulation results reported in (Urfels et al., 2022). The scenarios correspond to variation in irrigation, varietal duration and the planting of rice at the onset of the monsoon. Table 21 shows the details for the scenarios. We used the fixed long (S1) scenario as the baseline scenario. This scenario involves planting long duration rice variety at a fixed recommended date based on a state recommendation. We considered this as the baseline scenario instead of the farmer practice (S0) because S1 had observations for all pixels in the area of interest unlike the farmer practice which due to limitations of data had a limited number of pixels .*

7. How does the analysis incorporate or consider climate variability and potential changes in weather patterns over time?

Response: We simulated as mentioned in Urfels et al (2022) across climate from 1982-2015 so that it incorporate climate variability and change across a historical time slice to represent in more than 20 years common for climate change analyses.   
  
Results  
8. While the data presented is extensive, linking it back to the broader context of rice agriculture or the socio-economic landscape of the Indo-Gangetic Plains could provide a more holistic perspective.

Response: We thank the reviewer for the suggestion. We have now included a discussion section which goes into these issues.

*. Discussion*

*4.1. Spatial variation in recommended rice planting date strategies*

*The results of the adapted have provided climatic risk proof rice planting strategies such that even a risk averse farmer would find it profitable to adopt the proposed strategies. Importantly and in addition to the findings of Urfels et al. (2022) and Montes et al (2023), our framework shows that in parts of the Eastern Gangetic Plains providing only supplemental irrigation rather than full irrigation is economically beneficial from a risk perspective. The same is true for some areas in the northern parts of the Middle and Western IGP – indicating importance of climatic and soil variability. However, in the Northern and Southern parts of the Western and Middle IGP, we get substantially different outcomes – but also indicating that in these areas multiple rice planting strategies perform equally well and farmers have more flexibility to choose amongst various options for similar results.*

*In addition to cited prior works (Urfels et al 2022 and Montes et al 2023) which formed the basis of our analysis and used APSIM crop growth model, our results can be compared to two recent studies (Wang 2022, 2024) which rely on regionally calibrated Environmental Policy Integrated Climate (EPIC) agronomic model.*

*4.2. Value of a risk-based evaluation approach in face of climatic risks*

*The IGP is a hotspot of climate change impacts in that though it supports the most intensive crop production, it also suffers from frequent droughts, volatile monsoon onsets, and heat stress. Farmers delay rice planting in dealing with these environmental and climatic impacts (McDonald et al 2022) thereby suffering substantial yield penalties. Without affordable irrigation infrastructure, timely rice planting becomes very risky for the farmers as evidenced by the recent El Nino event and late monsoon – causing farmers to fallow and reduce rice area. Similar issues of importance of timing and precipitation variability affect other farming systems elsewhere. Recommendations therefore require to consider riskiness evaluation and will need to include also field evaluation of riskiness after the first pass model ex-ante simulations as we do in this paper.*

*Climate variability and change has prompted a rethinking of how the agricultural research and development community can develop climatic risk proof innovations. These are innovations that are expected to be resilient to present and future climatic shocks. In that regard, crop modelling has become the key approach of assessing how different agronomic innovations perform under varying historical realizations of weather. In this paper, we have demonstrated that a nuanced understanding of risk in evaluating such crop model results can generate insights and provide a basis for making climate risk proof recommendations to smallholder farmers. This approach then allows researchers and farmers to understand the plausible strategies they can follow in order to maximize profits even in years when the weather is extreme.*

*Besides the farmers and researchers, our approach provides policy decision makers with a prioritization and targeting framework for extension support services that advances only the strategies that are more likely to be accepted by all the farmers in the location. This then reduces wastage of resources especially when risk neutral and profitable technologies are promoted in locations where most farmers are risk averse. The task of figuring out the risk aversion preferences of the farmers in non-trivial and not possible for each of the individual pixels. The approach we use innovatively circumvents this challenge by placing conditions and extent under which any risk averse farmer will still find the proposed strategy beneficial.*

*4.3. Limitations and future research*

*There are several key limitations to our approach. First, it is computationally heavy especially if the gridded analysis is conducted for larger spatial scales. This challenge can be resolved by reducing the number of pixels in each analysis because the approach uses each pixel separately such that the optimal strategies will not differ based on number of pixels. Second, it requires many years of data to characterize the empirical cumulative distribution function. Our analyses use the period 1982-2015 data which covers enough variation of climatic variability. In the context of long-term trials and surveys, it is difficult to find such longitudinal datasets at scale. Future research that combines these data sources and Monte Carlo simulations would allow the use of the approach in empirically grounded analyses. Third, as compared to other outcomes-based risk analyses like the mean-variance or conditional value at risk approach, our approach simply recommends the best strategy but not an optimal combination or diversified portfolio of options (literature started by Markowitz 1959). Fourth, given that the risk evaluation approach relies on crop model outputs, any limitations of the crop model are propagated in our approach. For example, the gridded APSIM crop model we use has no N limitation and no irrigation to isolate the effect of sowing dates in addition to not having many interactions. While we acknowledge these limitations, they are not necessary for the merit of this paper in that the paper is aimed at showcasing a methodology for evaluating risk regardless of the nature of the crop model used.*

9. Consider including content on limitations, addressing any potential constraints or weaknesses in the methodology. For instance, absence of nutrient-limited and/or other management practices that play a role in farmers' risk aversion.

Response: Thanks for the suggestion. We have included a limitations section in which we have mentioned some of these limitations. Please see details of the discussion section presented above.  
  
10. Some sentences are lengthy and might benefit from breaking them down into shorter, clearer phrases for easier understanding. For instance paragraph starting line 370-374.  
Response: We thank the reviewer. We have edited the text accordingly. Please kindly refer to the manuscript for extensive overviews.

Conclusion:  
11. It would benefit from providing specific figures or statistical outcomes that reinforce the concluded statements.

Response: We thank the reviewer. We have edited the text accordingly. Please kindly refer to the manuscript for extensive overviews.  
  
12. Rather than only using statements, consider alternative ways (using examples/scenarios) that can emphasise the potential real-world impact of the risk-assessment approach on smallholder farmers, and how this framework could aid them in decision-making

Responses: We thank the reviewer for the comment. We have added some explanations in the discussion section.  
  
13. Consider touching upon potential policy implications of the recommendations arising from the study, highlighting actionable insights for policymakers or stakeholders.

Responses: We thank the reviewer for the suggestion. We have included these discussions in a new discussion section.  
  
General comments:  
14. Review and proof read to correct any grammatical or spelling errors e.g., line 54, 161, 96, 251, among others.  
Response: We thank the reviewer. We have edited the text accordingly. Please kindly refer to the manuscript for extensive overviews.

15. Review the image resolution, aspect ratio and font size of all image/figure axes and axes labels, to enhance visibility.  
Response: We thank the reviewer for the suggestion. We have edited all graphs in the paper to ensure visibility and adequate formatting.

**Response to reviewer 3 questions**

Reviewer #3:

Major comments:  
This paper on 'Risk-based evaluations of competing agronomic climate adaptation strategies: The case of rice planting strategies in the Indo Gangetic Plains' has developed customized planting dates of rice in IGP, in a quite big area ranging from latitude 22-32 °N and longitude 75-90 °E. Actually, this study has made a lot of effort, however as they hugely depended on secondary and simulated data all the time and tried to develop their framework and recommendation on the basis of those datasets without ground validation, the reliability, applicability, and trustfulness of the results presented is very low. Authors mapped rice and wheat area without following proper method of mapping (excluding water bodies, other vegetation, infrastructure, etc). Also, the novelty is not sufficient to publish in Agricultural Systems.

Response: Thank you for these comments. We kindly contend that these suggestions, while very nice studies in themselves, are outside the scope of this paper. Mapping out water bodies, infrastructure, etc. is inconsequential for evaluating our results and illustrating our method.

On the trustfulness, reliability and applicability, it depends on whether the reviewer trusts any crop growth model results. If not, then our paper indeed will not help him/her. However, agricultural systems journal has published many other crop growth model based papers including recently by Wang et al 2024 focusing on the area of interest. And in this article we provide additional advances for evaluating such studies with a risk-based spatial approach for multi-cropping systems.

We use APSIM growth model which has already been well calibrated and validated with already several published papers that we cite having discussed these aspects of the model.

Other major comments:  
1. Too much dependency on simulated results, and computer programming and programmer (Lines 204-205) having/including no or very low real ground data.

Response: We thank the reviewer for the comment and agree with the importance of ground data for informing agricultural studies, For the purpose of this paper, the model inputs are based on ground data and the validated model is already published in peer reviewed articles (Balwinder, Urfels) with extensive documentation for the interested reviewer to explore in detail. In addition, the purpose of this data is about methods innovation on how to evaluate multi-crop production systems from a risk perspective in a spatial manner. Since long-term data of different management strategies does not exist at scale – we rely on simulated results to produce a dataset that is handy to illustrate our method for the IGP. Of course, one may apply the same method for long-term trials or other longitudinal datasets but remain outside the scope of this paper and do not cover spatial variation of climate – at least not in what is normally and may reasonably be funded for ground level long-term data collection. At the same time, setting up new experiments would require 20 years of data collection for establishing the performance of new strategies across climate years – but farmers and decision-makers require insights now and not in 20 years. So, well calibrated crop models fill an important role and can inform and guide investments in cost-effective trial strategies.

2. Model calibration and validation work was dependent on previous work by Balwinder-Singh from CIMMYT. For how many varieties and agro-ecological conditions had he calibrated for rice and wheat crops? As the study area covers a huge area (spreading from latitude 22-32 °N and longitude 75-90 °E), I do not believe the users do not need to re-calibrate and validate the models for different biophysical and management conditions. When the scenarios for planting strategies were made, for how many climatic conditions was the APSIM model run?

Response: This again is a question on the crop model not necessary on what our focus in the paper is. First, the model outputs were evaluated for their performance across the area of interest and the reviewer may refer to the original paper for these evaluations which is published in a peer-reviewed journal. Second, we could of course work further developing the model but this remains outside the scope of this paper. In principle, we could have used any crop model or any hypothetical results to illustrate our case but using peer-reviewed and published results provide more useful context and help to refine the conclusions that were drawn from the initial paper and thus improve the literature by improving the evaluations. The focus of the paper is on making risk based evaluations that consider risk aversion of the farmers. Something that is not well done in the literature.

3. Highly coarse mapping work. Proper mapping needs to disaggregate rice, wheat, and rice-wheat systems area systematically in the 1st step. And then using current farmers' practice data as the baseline, further scenarios and willingness to pay can be implemented. Mapping everything (buildings, other vegetation, water bodies, etc, in rice or wheat areas) is not the correct approach. Even for the disaggregated maps, validation (matching between observed and simulated) is required.

Response: We thank the reviewer for the comment. This again is not needed for this paper. If there is a building, surely no one will plant rice or wheat there. There is no need for us to go into that unnecessary granularity for the sake of illustrating our novel method and results.

As specified in the Methods section, we do not use farmer’s practice as baseline because it did not have data for all pixels as such it would have affected crop model comparisons for all the other scenarios in those pixels. We matched pixels, the choice of the baseline does not matter to our results. We have included edits to reflect more clearly this choice of the baseline.

4. Planting data is one of the components for risk analysis (as one of the factors of production); what about the effect/risks of a series of other factors and their interaction on rice as well as wheat cultivation? Risk analysis based only on planting date might be misleading as there are several other biophysical and socio-economic factors that affect the production process, which are not included in this study.

Response: We have included this as a limitation of using crop models but this is not just a problem with our approach and addressing the whole realm of possible factors affecting farmers choice of planting dates is outside the scope of this paper.

5. Confusing write-up in many places and difficult to follow, mixing methodology in the introduction, see line 111-116, similarly in several places methods are included in results.

Response: These repetitions are meant to remind readers as this paper advances a methodology that is not well known and our key contribution is the approach.

6. Missing clear objective at the end of the introduction section.

Response: We have added an objective statement at the end of the first paragraph.

7. Missing logical discussion section

Response: We have added a discussion section as suggested.

8. Line 130-131: To assess the economic return from rice and wheat, simulated yield (without using properly calibrated model) multiplied by price data (interpolated using random forest from Landscape Crop Assessment Survey, Line 212-213, without validation). As IGP is a huge territory, the values vary across location and socio-economic conditions. Whole computation of economic analysis and costing without ground information, for me is very hard to believe.

Response: We thank the reviewer for the comment. We used ground truth data from the Landscape Crop Assessment Survey and interpolated using the approach that Cedrez and Chamberlain developed. We also assumed irrigation costs for each scenario. While these are approximations, the aim is to showcase how the approach can use existing data. A more comprehensive economic costing and analysis is an area of future research but given that we apply the same interpolations and costs across scenarios, a better approximation of these values will not change the final comparisons because whatever the errors of approximation are, they can nullified when making relative comparisons of the scenarios.

10. Line 231-233- is methodology, not the result.

Response: We have edited accordingly.

11. Line 231 and Table 1: Baseline should be the farmers' practice, not the government recommendation. One cannot imagine farmers using exactly the recommended planting date (and other practices), especially under highly variable rainfall conditions and also the uncertainty of input supplies.

Response: We thank the reviewer for the comment. We have chosen not to use farmer practice as the baseline because unlike the other scenarios it does not have data for all the pixels. We did robustness checks for Bihar (not reported in the paper) that showed that the results are consistent for the matching pixels. We have added edits to explain our choice.

12. No ground verification of all those obtained riskiness results.

Response: See comment above regarding the use of field level data. Our results are based on clear theory and explicit assumptions for definitions of riskiness. Datasets for validating these across the simulated area of interest and time scales do not exist. Experimental trials for long-term evaluation of different management strategies would be a useful next step for further research in the areas we identified. We thus provide useful evidence for stratification future cropping trials.