

## General comments

This study uses a decision analysis approach to explore factors influencing the feasibility and cost-effectiveness of cover cropping in Midwestern maize-soybean systems. The authors also identify knowledge gaps that should be addressed to improve decision support. I commend the authors for their application of an underutilized approach to this crucial topic. Their analysis has produced valid preliminary conclusions and would represent a useful starting place for further work. Overall, the article is interesting, makes a novel and worthwhile contribution to the literature, and is relevant to the goals of *Frontiers in Sustainable Food Systems*. However, I believe that revisions would improve the following aspects of the paper.

Thank you. We have incorporated the suggestions. Major improvements include consolidation of figures and tables, an update to the spring uncertainties/decisions to better reflect producer experiences as pointed out by the reviewer. We have attached two forms of the manuscript - one where changes are indicated in red text, and another where all text is black.

**1. The Introduction does a good job describing the rationale underlying this work. However, it would benefit from a more detailed review of previous studies analyzing risks associated with cover cropping.**

We rephrased that portion to make it clear we are not presenting an exhaustive list, and added the citation provided by the reviewer.

**2. Some aspects of the Methods were difficult for me to understand, including the GDD threshold for cover crop establishment and when cover crop termination and cash crop planting were allowed to occur in the spring (see specific comments below). It would be helpful to revise so that the general approach can be understood from the main text, without needing to consult supplementary material.**

We rewrote a large portion of the methods to address this comment, as well as other comments provided below. We changed the GDD threshold and provided support for the value we chose. We also reworked areas related to the workable field days and the chances of maize yield declines when planted <14 days after cover crop termination.

**3. A major limitation of this work is the fact that many effects of cover crops were not quantified. The analyses focused on direct costs of cover crop and cash crop production, the potential for yield losses especially in maize, and the contribution of the cover crop to weed control in soybean. Other consequences of cover cropping, such as changes to soil health or insect communities, were not included in the analysis. If possible, it would be useful to consider ways to include them. At minimum, this limitation of the work should be noted at least twice: once in the Methods or at the beginning of the Results and Discussion, and again in the Conclusions.**

We added these caveats in the two locations suggested.

**4. The Results and Discussion should focus more on explaining the results and putting them into the context of existing literature. For example, the Abstract, Results/Discussion, and Conclusions all note that maize yield is reduced when maize is planted shortly after cover crop termination, but reasons for this phenomenon are not discussed.**

We added two sentences exploring the mechanisms that could be contributing the reduced maize yields, but also reiterated that research in this area is lacking, and there is no clear consensus on the causes or how the causes may differ due to environmental or managerial conditions.

**5. Although the writing is generally clear, some sentences are unnecessarily complex or contain minor errors.**

We went through the entire text and tried to simplify complex sentences.

## Specific comments

[46-47] Why reduced crop insurance losses? Please give examples of the “numerous other context-specific benefits.”

The sentence was expanded to include more detail, and a more recent citation for soil erosion reductions from cover crop use was added.

*Utilizing over-wintering cover crops in these systems has been shown to reduce soil erosion and nitrate leaching (Kaspar et al., 2007; Kaspar et al. 2012; La Chen et al., 2022), is associated with a reduction in crop insurance losses due to drought, excess heat, and excess moisture (Aglasan and Rejesus, 2021), and possibly offer numerous other context-specific benefits such as increased soil infiltration rates, higher soil water-holding capacity, and increased soil organic matter content (Basche et al. 2017; Nichols et al., 2022; Krupek et al. 2022).*

*Chen, L., Rejesus, R. M., Aglasan, S., Hagen, S. C., & Salas, W. (2022). The of cover on soil erosion in the US Midwest. Journal of Environmental Management, 324.*

[63-64] Please state the conflict(s) explicitly. Delayed cash crop planting due to the need for cover crop termination?

The sentence was clarified:

*Therefore, both the planting and termination of an over-wintering cover crop such as rye (Secale cereale L.) can conflict with cash crop management.*

[65-68] This sentence seems to overstate the novelty of the paper. Numerous studies, including the two cited, provide useful analyses of the risks, costs, and benefits of cover cropping. I think the Introduction needs to spend more time going over this previous work and explaining why more work is needed (assessments like “well-quantified” and even “explicitly included” are sometimes a matter of perspective, and don’t provide much information to the reader). This paper makes a valuable contribution as one of a small number of papers to apply decision analysis to questions about cover cropping, but this isn’t the only valid approach to thinking about cover crops and risk.

The sentence was reworded to acknowledge previous efforts and the fact that it is a challenging topic:

*While perceived risks associated with cover cropping are often cited as barriers to adoption (Arbuckle and Roesch-McNally, 2015), quantifying those risks in economic terms is challenging (e.g., Bergtold et al., 2019; Plastina et al., 2020).*

[77-86] A more complete literature review may be needed here. In particular, please cite this previous study, which applied decision analysis to cover crop selection.

A rigorous review of the literature regarding decision analysis in agriculture is a great suggestion for future work. We appreciate the citation suggestion - we added it to the list of citations, and adjusted the sentence to indicate there are limited applications of decision analysis to cover cropping:

However, to our knowledge decision analysis frameworks have had limited application regarding management decisions related to cover crops in the maize/soybean systems of the Midwestern US.

[93-95] How much cover crop adoption? Differences between central Iowa and the rest of the state could reflect differences in cropping systems, landscape factors, etc.—if these differences are important, is it

possible to explain what's underlying them? If they're not important, it may be better just to emphasize that central Iowa is a good study location due to large areas of maize-soybean production that are broadly representative of the Midwest.

We changed the sentence as suggested:

*We chose to use Central Iowa as a case study because it has large areas in maize/soybean systems that are broadly representative of the US Midwest (USDA NASS CDL, 2021), and currently demonstrates a moderate amount of cover crop adoption (Rundquist and Carlson, 2017).*

[103-110] Should cover cropping after soybean be viewed as an alternative to cover cropping after maize? In any given year, the grower only has three of these six options available, so it seems more like there are two scenarios and three decision alternatives within each scenario.

We agree this was presented in a confusing manner. We changed it as suggested to be broken down into two scenarios, each with three decision alternatives, and put the information in a table rather than a figure based on later reviewer comments.

*Assuming a producer has both the maize and soybean phase of a maize-soybean rotation growing at a given time, there are two scenarios for cover crop integration, each including three decision alternatives with unique benefits and challenges (Table 1)*

[159] How was this estimate reached?

Thank you for pointing out this oversight - we added a sentence with the citation. Additionally, based on a later comment, we changed the threshold to 100 GDDs. We updated all results, text, and figures to reflect this new, more reasonable threshold.

*A study in Minnesota suggested rye required at least 100 GDDs in the fall to produce biomass in the spring (Kantar and Porter 2014). We therefore estimated rye requires 100 GDDs to successfully establish before winter, but tested the sensitivity of this assumption (see Section 2.3.2).*

[194-196] Could you say a bit more about why this approach was chosen? It seems inconsistent to assume that termination would require extra days but would not require extra fuel/input costs.

This is a good point. We re-wrote the text to clarify why we made this assumption:

*While this depends on whether producers typically have a pre-plant or pre-emergent herbicide pass, the operation is much less crucial when the goal is simply to eliminate weeds around cash crop planting compared to killing a live cover crop to comply with federal crop insurance requirements. To account for the increased importance of timely cover crop termination, in this exercise we assumed cover crop termination requires an additional set of field working-days compared to systems without a cover crop. However, because many producers do a pre-plant or pre-emergent herbicide pass in systems without cover crops, we did not assume extra herbicide or fuel costs associated with terminating the cover crop.*

[216-220] I'm not understanding here. Does the method assume that cover crop termination requires two sequential WFDs, and then cash crop planting requires two more WFDs, for a total of four? Do they have to be literally sequential, or just close together in time? [From lines 387-390, I think the answers to these questions are "yes" and "just close together in time", respectively]

The reviewer is correct - we deleted the indicated paragraph as we agree it was overly complicated and confusing. We added simpler and more condensed language:

*We assumed cover crop termination would require two WFDs within a spring category, and cash crop planting would likewise require two WFDs. Therefore, cover crop termination and cash crop planting within a window would require four WFDs. The probability of two and four WFDs being reported in a given spring category was calculated using 30 years of historical data (1988-2019).*

[250-259] Perhaps add the information that a more modest rate of yield loss was assumed when soybean was planted late (according to Table 2) and provide references for the assumption that soybean yield is insensitive to the gap between cover crop termination and cash crop planting.

The following sentences were added in different sections:

*Soybean yields are less sensitive to planting dates compared to maize (Kessler et al. 2020) and therefore was assumed to have a less severe graduated penalty as planting was delayed (5-10%; **Table 2**).*

*Additionally, soybeans are not impacted by the time between rye termination and soybean planting (Acharya et al. 2020), so no yield penalty was assigned in those circumstances.*

[258] "...10% decrease in maize yield if..." or "...10% reduction in maize yield if...."

Good catch, this was corrected.

[258-259] Is cash crop planting assumed to happen on the first suitable occasion after cover crop termination, regardless of when the cover crop is terminated and whether there's a yield penalty associated with planting maize right after cover crop termination? Since 10% yield loss is a significant amount, an intentional delay before cash crop planting might increase the cost-effectiveness of cover cropping according to this analysis.

This is a very good point and we did not make our reasoning or assumptions clear on this issue. The termination-planting window penalty is perceived by producers to be inconsistent, while the penalty from delayed planting is perceived as more consistent, so based on our conversations it seemed producers tended to plant when there was time, regardless of the termination-planting penalty. We added text to explain our assumption of acting in a seemingly irrational manner, and added an element of uncertainty to the penalty (50% chance of a 10% penalty, 50% chance of no penalty). We added a new section (Subsequent maize yield uncertainty) to address this.

*On average, winter cover crops such as rye have been shown to have a neutral effect on subsequent maize and soybean yields (Marcillo and Miguez, 2017). However, numerous studies have shown that under certain conditions, planting maize less than 10-14 days following cover crop termination can result in lower maize yields (Johnson et al. 1998, Acharya et al. 2017, Hirsh et al. 2021, Quinn et al. 2022). We assumed a producer would plant their maize crop as early as possible, regardless of the penalty that would be incurred due to the <14 day window. We made this assumption because conversations with producers confirmed that while they were aware there may be a yield penalty from a small termination-planting window, it was inconsistent and may not occur at all, and they were therefore more concerned with timely maize planting. We therefore assumed if there four WFDs in a given spring category, the producer would plant maize but there would be a 50% chance of a 10% decrease in maize yield. We acknowledge that in our scenarios, the 10% yield penalty from the small termination-planting window is*

*larger than the penalty incurred for delaying planting until late May, but we believe our decision structure captures the uncertainty currently associated with whether that yield penalty will be incurred. Soybeans are not impacted by the time between rye termination and soybean planting (Acharya et al. 2020), so no yield penalty was assigned in those circumstances.*

More generally, I'm having trouble understanding whether the availability of WFDs and likelihood of a 10-day gap between cover crop termination and cash crop planting were incorporated into the main analysis on overall cost effectiveness (e.g., Figures 3-5). If so, how? If not, should WFD availability be understood as more of a secondary response variable (as in, "in addition to the cost/risk issue associated with cover crops, which is the focus of Figures 3-5, there's also a scheduling issue, we'll look at this in table 3...")?

Yes, this confusing. We added the following text, and reworded some other sections to make it clearer:

*We assumed cover crop termination would require two WFDs within a spring category, and cash crop planting would likewise require two WFDs. Therefore, cover crop termination and cash crop planting within a given window would require four WFDs.*

[259] 10 days rather than 14 days elsewhere, e.g., lines 24, 298, 342, Table 2.

Yes this is inconsistent - we changed all references to the gap to be 14 days

[299-301] A bit more detail would be useful here, e.g., the range of values tested in these sensitivity analyses.

Good suggestion, we added the ranges of values tested for each sensitivity analysis in the text.

[304] Why a \$12 incentive? It might be easiest to put the range of current incentive levels (\$12-74 ha-1) earlier in the main text.

Yes, this does seem arbitrary. Since we do a sensitivity analysis on the cost-share, we changed this initial reporting of results to include the scenario where no cost-share is available (text and figures were changed).

[304-313] It might be helpful to reiterate that most benefits of cover crops, with the exception of weed control in soybean, are not represented in this analysis. This is ok—it's very difficult to quantify benefits of cover crops, especially benefits occurring at larger spatial/temporal scales—but it's best not to give the impression that this analysis accounts for all effects of cover crops. As I understand it, the analysis mostly deals with costs of cover crops (direct costs plus risks to crop yield) and how they compare to potential incentives for cover crop planting. In some general sense, these incentives might represent/reflect the value of ecosystem services, but they aren't reliable indicators of how much the services are actually worth.

Yes we agree, this hasn't been explicitly mentioned. We added text to the opening sentence to make those aspects clear, and added a similar sentence to the conclusion.

*Assuming there is no cost-share available for planting a cover crop and long-term or societal economic benefits are not accounted for, the overall expected monetary value of not planting a cover crop is greater than the expected monetary value of planting a cover crop, regardless of the sequencing scenario (Figure 3).*

[314-315] Please note why the difference in termination time has a bigger effect on maize

We reworded the phrase for more clarity:

*However, in areas that lack incentives for delaying cover crop termination to allow the cover crop to grow, our analyses show the optimal decision is to terminate the cover crop as soon as possible, even when there might be cost savings from reduced herbicide use (Figure 2).*

[323-331] I might not frame this result in terms of the potential for fraud (same comment on lines 414-416). Instead, perhaps just note that, according to the analysis, failed cover crop establishment will lead to a better financial result than successful establishment. This finding underscores the importance of considering potential yield losses in the subsequent crop when deciding whether to establish cover crops.

We incorporated the suggested wording:

If a producer chooses to plant a cover crop preceding a maize crop and receives a cost-share or incentive for doing so, **failed cover crop establishment will lead to a better financial result than successful establishment** (Rye-Maize scenario in **Figure 2**). It is important to provide support for producers as they learn to manage cover crops, and often cover crop establishment is out of a producer's control, **but our analyses demonstrate the complexity in determining the best payment structures, and the need to include the risks the cover crop may pose to the subsequent crop yields.**

[345-347] Although it's great to acknowledge uncertainties, please briefly outline some possible mechanisms (e.g., allelopathy or interference from a rye stand that's not fully killed?).

This brings up a good point, we add some possible mechanisms as well as a suggestion that a meta-analysis be conducted (we are not aware of such a summary).

*The exact causes of the reduced yield in maize are not yet clear and it is currently not possible to predict when they will manifest (e.g., Patel et al. 2019; Quinn et al. 2021). The value of perfect information is worth \$20-25 depending on the planned cover crop timing, which is roughly equal to the increased value from eliminating the yield penalty. This indicates that research that allows producers to accurately predict when the yield penalty will occur is equally as valuable as eliminating the yield penalty. Potential mechanisms include altered nutrient dynamics, disease pressure, allelopathy, rye stands that are not fully terminated, changes in soil temperature and/or moisture in a rye cover crop system. A meta-analysis of studies may aid in identifying factors that drive the variation in the effect. Our analyses demonstrate that this phenomenon poses a significant risk to producers, and a better understanding of the drivers and identification of ways to predict when yield declines are likely would greatly reduce the financial risk associated with planting a rye cover crop in these systems.*

[357-361] This finding raises questions about the 200 GDD threshold for me (a corollary would be that less than 23% of rye stands planted after maize harvest actually establish—this doesn't seem right). In the Methods, please provide information about how this threshold was identified.

We agree. We originally chose 200 GDDs based on a study done in Minnesota that showed very minimal spring biomass resulting from less than 200 fall GDDs, but we realize the Minnesota study is likely not a great guide for Central Iowa. We reduced the threshold to 100 GDDs. Wheat often reports needing at least 50 GDDs to germinate, so we think 100 is a more reasonable estimate for Central Iowa. We reran all of the analyses with this new threshold and updated text, figures, etc. Of particular note, we re-wrote this discussion section:

*While the probability of accumulating sufficient GDDs (100) was 100% when the rye was planted following soybeans (15-Oct planting date), it dropped to 71% chance of success when planted following maize (1-Nov planting date; Table S3). The probability of establishment was very sensitive to the sequencing (rye following soybeans or rye following maize). For the 1-Nov planting date, the results are very sensitive to the assumed GDDs required for establishment.*

[394-395] I'm having trouble understanding this statement. I think the study only considered a single form of risk (potential yield losses in the subsequent spring-sown cash crop), which can only occur in the spring. Or am I misunderstanding what "risk" means here?

We reworded this to be clearer:

*Our analyses indicate in Central Iowa, there is generally a high probability the fall conditions will foster cover crop establishment, and that the majority of risk occurs due to the potential for the additional management required in the spring to delay cash crop planting.*

[407-409] Was this additional financial risk ever quantified (in \$)? If so, I did not understand this aspect of the paper—I just understood from Table 3 that a grower is more likely to have enough WFDs to complete their spring fieldwork if they only need two (cash crop planting only) rather than four (cover crop termination plus cash crop planting).

We added text to the results section to better state this explicitly:

*This analysis shows that in addition to the cost of seed and fuel to plant the cover crop (\$50 ha<sup>-1</sup>), there is an additional \$40-70 ha<sup>-1</sup> cost associated with the risk that the spring management of the cover crop will result in reduced maize yields (either through delayed maize planting due to insufficient WFDs or <14 day gap penalties).*

Table 2. Please include reference(s) for these data. Also, are the "<10 day gap" and ">10 day gap" columns reversed? From the text, I understood that maize yield was reduced when the cover crop was planted less than 10 days before crop planting.

Yes again good catch! We changed the column titles to be correct and more visually distinct (14+ day gap and <14 day gap). We also added the citations for each assumption as footnotes in the table.

Figure 1. This figure is confusing for me, largely because I'm having trouble understanding what the advantages and disadvantages represent. Some seem to be (dis)advantages relative to no cover cropping, while others seem to be (dis)advantages relative to cover cropping at a different stage in the rotation cycle or with different termination timing. It might be helpful to revise so that items are more parallel/comparable to each other, or else to remove the figure and rely on the explanatory text in Methods 2.1.

We eliminated the figure and put the information in a table in a more organized format.

Figure 3. Is the effect of cover cropping on spring field operation scheduling (i.e., whether enough WFDs are available and whether cash crop planting will be too soon after cover crop termination) considered here? If

not, does the maize part assume that the maize is always planted within 10 days of cover crop termination, therefore maize is always reduced by 10% when cover crops establish?

This comment was addressed earlier - we adjusted our decision tree to reflect a 50% chance of a <14 day gap yield penalty. Several areas of the manuscript were adjusted due to this change.