Dear referee#1, thank you very much for your comments. We are happy that you find our study interesting. Please find below the suggestions of referee#1 (bold), and our responses to the individual points (normal font):

Ref#1: Abstract:

You should give a bit more information about the simulation set-up. For what period/condition did you run the spin-up?

With the model, first, we conducted a 7000 year spin-up simulation with potential natural vegetation. This is followed by 390 years land use spin-up period with static cropland distribution pattern, all other crop and soil management as for the year 2010 (except for default tillage and bare soil management, Sect. 2.2; S 1.3, 1.4). With this spin-up we aimed to bring C and N pools in a dynamic equilibrium prior to the simulations with contrasting cover crop and tillage practices for the 50 year period.

Did you do a transient run without cover crops before the 50 year period with cover crops?

Yes. During the first potential natural vegetation spin-up simulation period no cropland use dynamics are modeled at all. At the beginning of the subsequent land use (LU) spin-up period we simulated the one time LU conversion of natural ecosystem area to cropland distribution of the year 2010. We assumed that bare soil fallowing practices on cropland during main crop off-season periods as well as tillage on an annual basis on the entire cropland (for seedbed preparation). Cropland distribution as well as all further crop and soil management practices (fertilizer, manure) were held constant at the 2010 level during the entire LU spin-up period.

What does that 50 year simulation period represent, actually 50 years of the historical period to present day, 50 years of projection into the future, or do you simply loop over some years of climate forcing?

The 50-year simulation period represents historical climate for 1962-2011 and all stylized management scenarios (with cover crops and/or no-tillage) are introduced from the year 1962 onwards. Therefore, the first decade after the introduction of the practice is not directly comparable to the last decade (in terms of weather) but we assume this error to
be small, given that we average over larger areas when representing the results. We will add this point to the discussion.

**Do your simulations account for changes in atmospheric CO2 which would affect the soil C uptake as well?**

Yes, our simulations include annual dynamic input data on CO$_2$ concentration levels. We agree that rising CO$_2$ levels affect soil C uptake, which, in the same way as the transient climate, impedes the direct comparison between the first and the last decade. However, some of the field experiments to which we compare our results have been conducted over comparable time periods (up to 54 years) and are therefore affected by increasing CO$_2$ levels, as well. We will add this point to the discussion.

**These are all important details that you should shortly mention in the abstract.**

We will add a very brief summary of the simulation set up details to the abstract. However, since the description requires a lot of information, this can be only in very aggregated form. Beyond that, we will consider moving parts of Sect. S1.2 and S1.3 to the main text in Sect. 2.2., so that the reader can grasp applied methods and data in a quicker and more comprehensive way.

**Ref#1: Introduction: The introduction is overall quite well written. I miss however a bit the connection between the last paragraph of the introduction, which lists the specific objectives of the study, and the rest of the introduction section.**

We will improve the connection between the discussion of the state-of-the-art in modeling carbon and nitrogen dynamics in croplands and our objectives, to better clarify our motivation.

**It would be good if you could work out some existing research gaps that you could fill with your study, and maybe formulate at least one major, overarching research question. (I guess that research question will ask for a global scale, quantitative assessment of the potential of cover crops to increase C storage and reduce N leaching, for a certain number of globally important crops, accounting for differences in climate and soil.)**

We will improve the last paragraph of Sect. 1 on objectives and add there: "The analysis is guided by the following research questions: 1. Which potential have cover crop practices to increase soil C storage and reduce nitrogen loss through leaching from global cropland to improve agroecosystem services and functions? 2. What effects on the productivity yields of following main crop can be expected from cover crop practices?"

**In that context, it would also be good to summarize a bit the potential of land surface models to answer such a research question. In that context, you should also give the state of the art of the use of land surface models for this kind of research (in a broader sense: impact of agricultural land management on C and N cycles), and highlight what is new in your study compared to older studies applying land surface models, and in particular to studies (maybe also of your group) using older versions of LPJmL.**

We will extend the introduction by an overview of the state-of-the-art of applying global vegetation and land surface models to assess impacts of agricultural management practices on C, N, and water dynamics, e.g. citing Pongratz et al. (2018) and McDermid et al. (2017). For the comparison to studies using older versions of LPJmL we will refer to Lutz et al. (2019) and Herzfeld et al. (2021). We will also review the state-of-the-art of
modelling the role of cover crops referring e.g. to Olin et al. (2015) and Kollas et al. (2015).

In the last paragraph with the specific objectives, you should also mention that you only do simulations for herbaceous cover crops.

We will add in the last paragraph of the introduction that in our analysis we focus on effects of non-leguminous cover crops, which are simulated as grasses

**Ref#1: Methods and data:**

**L93:** “model skills” – you mean “model performance”?

We will change the wording as suggested to 'model performance'.

**L96-98: Why do you mention that? Did they do an evaluation of model performance that would support your study?**

We will modify the Herzfeld et al, 2021 sentence, saying that: they found good agreement with literature estimates on global simulated cropland soil carbon content in response to climate when accounting for historical dynamic land use change, cropland use and management practices. They use a similar model code (apart from the here presented modified implementation of cover crops), and crop and management input data) so that we can refer to their model evaluation to describe the model performance of the model setup used here as well.

**L106-109: I am not sure why you are mentioning that. Is that to show a limitation in existing models that you might want to overcome? This is not clear to me. It also seems that this could be put into the introduction section, where you should outline the state of the art for this kind of model approaches (see my comment on the Introduction).**

Yes, indeed we want to say that many crop models, including the older versions of LPJmL used in Kollas et al. (2015) show limitations for this management aspects and we aim to overcome it. We will modify the text to highlight that this motivated our model development work in LPJmL for this study.

**L110-113: So you only use grass like cover crops? That should be mentioned already in the introduction. Do you use the three different grass types (tropical C4, temperate C3, and polar C3 grass) depending on the climate zone?**

Yes, we represent non-leguminous cover crops with LPJmL’s three herbaceous PFTs (grasses). In the model, the establishment of the different grass types is determined by their bio-climatic limits, which characterize them as tropical C4, polar C3 or temperate C3 grass plants. We will revise the text to make this clearer (see also related comment above)

**Section 2.2: Could you say something about your scenarios from fertilizer and manure application? Do you represent irrigation? Or is it all rain-fed agriculture?**

Following the request to better describe the simulation experiments, we will move and extend the sections on the modeling protocol and input data description from the supplementary to the main text. Irrigated and rainfed crop production systems are modeled per crop type and both can occur in the same grid cell. Their grid scale distribution is represented in the model simulations based on LUH2v2 (year 2010) by Hurtt et al. (2020). Also, mineral N fertilizer and manure are separate, gridded model
input data.

L126-129: Did you do that spin-up for present day conditions, or for pre-industrial conditions (in particular with regard to atmospheric CO2)? That is not clear. Does atmospheric CO2 levels impact vegetation-soil carbon dynamics in your model? Which climate forcings did you use? What years do they represent? These are important details and should be mentioned here.

As per the earlier request for more detail (above), we will also describe the spin-up simulations, as well as extend and improve the information on the climate input data (based on CRU for years 1901-2014, (Harris et al., 2014)) and atmospheric CO$_2$ concentrations (based on the times series from Mauna Loa station measurement data for years 1841-2011).

L130-136: With that spin-up, did you bring the C and N stocks on cropland in steady state for conventional management practises? If so, I do not understand the sense of the first spin-up?

Yes, we attempted with the two-step spin-up: to first bring the potential natural vegetation and soil C, N pools into equilibrium to mimic pre-anthropogenic conditions of the environment as a starting point. Then, we continued with a second spin-up in which land use is introduced with the 2010 pattern, so that the simulation years analyzed (after introducing different cover crop and tillage scenarios) start from cropland that has reached a new dynamic equilibrium, which we assume to be representative for field trials, which we compare to.

Ref#1: Results: Table 1: You only start to discuss that table in the discussion section. I would suggest to move this table there, as it mainly serves comparison between simulation results and literature values. Why don’t you also show the results for CCNT is this table? In the last subsection of the results section, you present the statistics applying as mask the map of areas where conservation agriculture was actually applied during 1974-2010. I guess it would make much sense to use that mask also for this table here and the comparison between model results and literature values, in particular for the impact of cover crops on yields.

We will follow the recommendation to move Table 1 to the discussion section. Table 1 merely summarizes CC results shown also in the graphs of the result section to compare them to literature values. Unfortunately, for a similar table for the evaluation of CCNT results we lack appropriate literature values. Although we briefly compare CCNT effects on crop yields to Pittelkow et al. (2015) in section 4.3, the effects of no-tillage in combination with crop rotation do not provide a good reference point for our effects of CCNT. Regarding the use of a conservation agriculture mask to calculate statistics in Table 1 see detailed comment below.

L256-259: I guess this is because in drier regions, you simulate irrigation, as you mention below. But in fact, in drier regions where water is limited, you might want to abstain from planting cover crops if they lead to additional evapotranspiration losses. You should come back to that thought in the discussion section.

We will add a sentence in the discussion about the possible trade-off between yield gains and increased irrigation water demand due to cover crops in irrigated systems and dry regions.

L274-278: Is that because under rain-fed conditions, cover crops increase the
water limitation for the cash crops? What is the irrigation scenario: do you always fully irrigate or is there deficit-irrigation possible? Do you take into account the limited availability of irrigation water? Under irrigated conditions, are cover crops irrigated as well?

In our simulation setup, irrigation is implemented to fully irrigate crops on irrigated cropland (no deficit irrigation). Cover crops are not irrigated at all. In the simulation for this study we did not account for limited water availability to assure unambiguous irrigation effects (removal of water stress). Therefore, the reason for this pattern must be related to a change in N availability from cover crops. We will come back to this in the discussion and improve the method section on irrigation.

Ref#1: Discussion: L300-301: See my comment for table 1. It would make much more sense if you masked your results by the map of conservation agriculture. If you use the statistics including areas where conservation agriculture incl. cover crops is not yet applied (maybe because of water shortage that would be increased by cover crops), your simulation results are not comparable to empirical findings. Further, it would make more sense to also compare model results vs. observations per regions, and further distinguishing more clearly rainfed and irrigated agriculture in that comparison. That seems very important as you have highlighted the huge spatial variations and a general difference between irrigated and rainfed agriculture before.

The literature values to which we compare our CC results in Table 1 are reviews and meta-analyses, which quantify the effects of cover crops in tillage systems (conventional agriculture) and mainly for rainfed systems. Therefore, it would be inappropriate to calculate statistics for CA areas to compare to these literature values. We will improve the description of literature values in the manuscript to make this clear. Regarding the differentiation of regional cover crop impacts as well as in irrigated vs. rainfed systems, we will search for additional studies to include in the comparison.

L307-310: For that upscaling exercise, why would you use the median rate and not the mean rate? The latter would seem more appropriate. At least you should try to justify using the median.

We have chosen the median rate to better relate to the other results in the paper where the median showed larger robustness towards outlier values when aggregating gridded values to the global scale. However, we will add the means in the revised manuscript.

Subsection 4.2: I wonder if you could disentangle the effects of increased N-uptake by vegetation vs. changes in runoff and drainage. You described before how cover crops increase the evapotranspiration, which should lead to a decrease in drainage and thus advective export of reactive N species. You mention that cover crops don’t have a big effect on N leaching in dry regions. Might this be due to the fact that drainage is low in dry areas, and irrigation water is only applied to satisfy evapotranspiration requirements, with no excess water feeding additional drainage?

Due to the complex mutual interactions between water fluxes, N fluxes, and plant growth in LPJmL, it is challenging to disentangle the contribution of N uptake by cover crops and drainage reduction to the reduction in N leaching. We will investigate this aspect and extend the discussion accordingly. At the very least we will improve the description of the different processes that lead to an increase in N leaching. Regarding the question on drainage from irrigation water: Depending on the irrigation system, more water than required by the plant is actually applied to the field, which results in enhanced drainage. The effect is pronounced for surface irrigation and weak for drip irrigation. We will mention
this aspect in the discussion.

L384-386: Soybeans are also often irrigated, and would thus have no penalty from additional water consumption through cover crops. Could you investigate if that is the reason in your findings?

We will investigate if this effect can be attributed to irrigation and extend the discussion accordingly.

References

Harris, I., Jones, P. D., Osborn, T. J., and Lister, D. H.: Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset, International Journal of Climatology, 34, 623-642, doi: https://doi.org/10.1002/joc.3711, 2014.

Herzfeld, T., Heinke, J., Rolinski, S., and Müller, C.: Soil organic carbon dynamics from agricultural management practices under climate change, Earth System Dynamics, 12, 1037-1055, doi: 10.5194/esd-12-1037-2021, 2021.

Hurtt, G. C., Chini, L., Sahajpal, R., Frolking, S., Bodirsky, B. L., Calvin, K., Doelman, J. C., Fisk, J., Fujimori, S., Klein Goldewijk, K., Hasegawa, T., Havlík, P., Heinimann, A., Humpenöder, F., Jungclaus, J., Kaplan, J. O., Kennedy, J., Krisztin, T., Lawrence, D., Lawrence, P., Ma, L., Mertz, O., Pongratz, J., Popp, A., Poulter, B., Riahi, K., Shiyakova, E., Stehfest, E., Thornton, P., Tubiolo, F. N., van Vuuren, D. P., and Zhang, X.: Harmonization of global land use change and management for the period 850–2100 (LUH2) for CMIP6, Geoscientific Model Development, 13, 5425-5464, doi: https://doi.org/10.5194/gmd-13-5425-2020, 2020.

Kollas, C., Kersebaum, K. C., Nendel, C., Manevski, K., Müller, C., Palosuo, T., Armas-Herrera, C. M., Beaudoin, N., Bindi, M., Charfeddine, M., Conradt, T., Constantin, J., Eitzinger, J., Ewert, F., Ferrise, R., Gaiser, T., Cortazar-Atauri, I. G. d., Giglio, L., Hlavinka, P., Hoffmann, H., Hoffmann, M. P., Launay, M., Manderscheid, R., Mary, B., Mirschel, W., Moriondo, M., Olesen, J. E., Öztürk, I., Pacholski, A., Ripoche-Wachter, D., Roggero, P. P., Roncossek, S., Rötter, R. P., Ruget, F., Sharif, B., Trnka, M., Ventrella, D., Waha, K., Wegehenkel, M., Weigel, H.-J., and Wu, L.: Crop rotation modelling—A European model intercomparison, Eur. J. Agron., 70, 98-111, doi: http://dx.doi.org/10.1016/j.eja.2015.06.007, 2015.

Lutz, F., Herzfeld, T., Heinke, J., Rolinski, S., Schaphoff, S., Von Bloh, W., Stoorvogel, J., and Müller, C.: Simulating the effect of tillage practices with the global ecosystem model LPJmL (version 5.0-tillage), Geoscientific Model Development, 12, 2419-2440, doi: https://doi.org/10.5194/gmd-12-2419-2019, 2019.

McDermid, S. S., Mearns, L. O., and Ruane, A. C.: Representing agriculture in Earth System Models: Approaches and priorities for development, Journal of Advances in Modeling Earth Systems, 9, 2230-2265, doi: 10.1002/2016MS000749, 2017.

Olin, S., Lindeskog, M., Pugh, T. A. M., Schurgers, G., Wårlind, D., Mishurov, M., Zaehle, S., Stocker, B. D., Smith, B., and Arneth, A.: Soil carbon management in large-scale Earth system modelling: implications for crop yields and nitrogen leaching, Earth System Dynamics, 6, 745-768, doi: https://doi.org/10.5194/esd-6-745-2015, 2015.

Pittelkow, C. M., Liang, X., Linquist, B. A., van Groenigen, K. J., Lee, J., Lundy, M. E., van Gestel, N., Six, J., Venterea, R. T., and van Kessel, C.: Productivity limits and potentials of the principles of conservation agriculture, Nature, 517, 365-368, doi:
https://doi.org/10.1038/nature13809, 2015.

Pongratz, J., Dolman, H., Don, A., Erb, K.-H., Fuchs, R., Herold, M., Jones, C., Kuemmerle, T., Luyssaert, S., Meyfroidt, P., and Naudts, K.: Models meet data: Challenges and opportunities in implementing land management in Earth system models, Global Change Biology, 24, 1470-1487, doi: 10.1111/gcb.13988, 2018.