

Thank you for your review. Below, we respond first to your general comments and then to your detailed comments made in the pdf you attached to your review. Our answers are in blue text.

## Response to your general comment

The paper presents a well-designed experiment that compares digestates, their potential to replace mineral fertilisers and nutrient (nitrogen) efficiency. As such the paper has potential, however there are some issues that need to be addressed before publication. Thereby I am suggesting to revise the paper for potential reconsideration. The main issue with the paper is that as it is written it lacks originality and the novel contribution to science needs to be much clearer. Many other papers have described the potential of digestates to replace mineral fertiliser and have also compared different types of digestate. I think authors need to articulate the novel contribution to the field before it is published.

It is true that we have not emphasized enough the novelty of our study. We see three main points:

- 1) We monitored both the agronomic performance and the N losses of different fertilization systems, so that it was possible to compare the N balance of the different systems and to interpret the agronomic performance in relation to the measured N losses. Most published studies have focused on either agronomic performance or N losses, not both together.
- 2) We studied different fertilization systems combining logically different but related exogenous organic matters (EOMs) (e.g., slurry and manure, liquid and solid digestate) as farmers do. Most published studies have considered liquid and solid digestates separately.
- 3) We studied these systems over a three-year experiment, which allowed us to consider the effect of climate and to study two different crops, whereas most studies have focused on a single year.
- 4) We measured  $\text{NH}_3$  emissions after application of solid digestate and after application of raw digestate application with high DM content. The lack of references for this type of digestate has recently been pointed out by Pedersen & Hafner (2023). Especially lacking is the measurement of  $\text{NH}_3$  in the field with micrometeorological method that do not perturbate the  $\text{NH}_3$  emissions contrary to most methods found in the literature like static chambers and even wind tunnels.

We will emphasize these aspects more in the revised manuscript. However, it is true that some recent studies have also partially addressed these aspects (Häfner et al., 2022; Rittl et al., 2023; Zilio et al., 2023). We will cite these recent studies and discuss their results in the revised manuscript.

Grammatically it is generally ok (although often excessively wordy in places which could be reduced easily), but there is a lot of ambiguity that needs to be cleared up. For example, it is not always clear where "effects" are statistically robust or not. In addition, terminology such as "treatments varied somewhat in their N inputs", "slightly lower", "similar or slightly higher" (there are many other examples) need to be tidied up as they don't mean anything. The last paragraph of the introduction identifying the objectives needs to be tidied up and made much sharper. The results section often seems to be mixed up with discussion comments, authors need to ensure that results sections are for results only and not discussion comments.

We will revise the whole manuscript according to these remarks.

Methods in is mostly ok with some corrections. There seems to be various "data not shown", my question is why it isn't shown. As you suggest in your detailed comments, the information is not

necessary to emphasize the points discussed, and we will remove these “data not shown” statements.

Also, some information/results seem to be in the supplementary information that could be better in the main manuscript.

We did not consider the information we included in the supplementary material to be essential to the understanding of the manuscript. The manuscript is already very long in our opinion, so we prefer to keep this information in the supplementary material.

Are all the data manipulations described in the statistical analysis section? I think some aspects of the stats section are incomplete. Statements such as "therefore no statistical tests were performed to compare treatments" and "could not be determined for replicates" in a statistics section represent a concern as if no statistical analysis was performed you cannot ascertain whether there were treatment effects. If statistical analysis could not be performed then the data cannot be presented as results in a scientific publication.

It is true that in the current version of the manuscript, the statistical analysis is not sufficient for some of the measured variables. We have not done any statistical analysis so far because the design of the experiment is not a randomized block design, with only one strip per treatment. However, we have some replicates within each strip, and we propose to include a statistical analysis in the revised manuscript (for yield, NH<sub>3</sub> and N<sub>2</sub>O emissions), while mentioning the limitations of the experimental design. We also propose to include a statistical analysis of the EOM characteristics (nutrient content, N mineralization in controlled conditions). The proposed analyses demonstrate that most of the effects discussed are significant.

Discussions (and conclusions) seems to back-up existing work but doesn't really being our originality (what is different to the other work, what is the new knowledge).

We will highlight the originality in the revised discussion and conclusion, as already stated before (i.e., 3 years study, fertilization systems combining EOM as farmer do, both agronomic performance and different N losses, results on ammonia emissions of solid digestate).

So, in summary with a major revise and represent the work could be turned into a paper if these issues are addressed.

## Response to your detailed comments

Line 15: The abstract is well written. But the novelty doesn't come across well. There are already other papers that have compared digestates to the undigested versions, and to mineral fertilisers. And we already know that digestates can be used as a crop fertiliser and NH<sub>3</sub> emission is a danger. What is new about this study.

See our response to your previous comment about the same issue.

Line 43: I don't think you need these references to describe what a slurry is. I would remove them.  
Okay

Line 44: during the anaerobic digestion process. Okay

Line 50: "solid" is a little misleading. I usually refer to it as the fibrous fraction. But appreciate others call it a "solid" fraction.

Okay, we will add this in the revised manuscript.

Line 59: is this still the case. 2019 is 5 years ago and I think others have published since? Please check.

It is true that some new studies have been published. We will include them in the revised manuscript as stated before (Häfner et al., 2022, Rittl et al., 2023, Zilio et al., 2023). However, Pedersen & Hafner (2023) pointed out that more studies about ammonia emissions of raw digestates with high DM content are needed, because most published studies used digestates with low DM content that are not representative of all contexts (Denmark in their case). We will add that in the revised manuscript.

Line 64: maybe add a range so that readers can see what "high" means.

We propose to add the ranges indicated in the paper of Nkoa (2014): 0.15-0.68%FM for TAN, 7.3-9.0 for pH

Line 67: isn't that simply because the NH<sub>4</sub> is low in the solid fraction as most of it is in the liquor?

It is true that ammonia emission from solid digestate certainly received less attention because of that, and we could add this statement in the revised manuscript. However, we showed in our study that TAN content of solid digestate is not neglectable, as well as its NH<sub>3</sub> volatilization.

Line 90: that's fine, but this has been done multiple times before. I would think the 2nd objective is the more important as this addresses knowledge gaps?

Okay, we can invert the two objectives.

Line 91: gases and leachables?

Yes, we will add it, even if we were not able to monitor N leaching and that we estimated it from the difference in soil mineral nitrogen stock before/after winter.

Line 90: what about the aim. Usually the aim is stated before objectives.

& Line 92: what do you mean by "factors". Soil factors, environmental, digestate?

& Line 93: surely we know this already as there has already been research on this.

& Line 92: I think these questions can be summarised more effectively as one aim. Or actually they would be better written as hypothesis. What did you expect would happen.

We propose to reformulate this paragraph, with an emphasis on our hypotheses. We will also emphasize the questions regarding N losses that were less studied than the fertilizing value of digestate. It is a known fact that digestates make good fertilizers. However, there is a debate about the impact of anaerobic digestion on NH<sub>3</sub> emissions (with or without phase separation), compared to raw animal manure. And some questions regarding how NH<sub>3</sub> volatilization can decrease the fertilizing value of digestates. More globally, we aimed to investigate integrated fertilization systems where both liquid and solid digestates were used together, rather than studying them separately as it is commonly reported in the literature.

Line 103: abbreviation in full the first time please.

INRAE = Institut national de recherche pour l'agriculture, l'alimentation et l'environnement. It will be added in the revised manuscript.

Line 114: storage in the open is of course common but is an important consideration for NH<sub>3</sub> loss. Is this reflected in the discussion?

We propose to add a statement about that in the discussion (section 4.2), even if we focus on losses in the field in this study. For example, Baldé et al. (2018) reported 42% of TAN emitted as N losses. This may indicate that N losses during storage could be higher than NH<sub>3</sub> emissions in the field. Moreover, it also results in a decreased quantity of N applied in the field, N supplied to crops and of N subject to NH<sub>3</sub> volatilization in the field.

Line 114: I'm guessing the "open storage platform" is a heap on the side of the field? Depth of the heap is an important consideration, does some of it go anaerobic during storage?

The depth is around 2-3 m, and it can compost or anaerobically decompose if the storage is long. The storage platform is covered for solid manure, not for solid digestate. We can add this information in the revised manuscript.

Line 117: wow, large plots.

Yes, indeed! This design facilitated the study of the application of EOM using full scale machinery and the NH<sub>3</sub> measurement.

Line 120: not sure what this means? Do you mean you were not able to analyse?

There were some issues with the water collection system and the flow meter, such as flooding in the pits, which prevented a correct estimation of the quantity of drained water. This will be rephrased in the revised manuscript.

Line 117: were the plots randomly allocated? What was the design.

The design is showed in supplementary material 2. Only one plot per treatment.

Line 127: was it needed?

No, based on soil analysis, it was not needed during this 3-year period.

Line 129: ah I see. I don't think I got that point until now. The liquid and the solid fractions were added to the same plots just at different times. Please check that is clear earlier (in the aims and objectives).

We agree, it is an important point in our study. We investigated different fertilization systems that combine various EOM: slurry and solid manure, liquid and solid digestate, as farmers typically do in this region. We will provide this information earlier in the revised manuscript.

Line 130: add a note about on farm application. Does this reflect how the digestates are/would be used on farm.

The application rates reflect what is done usually on the farm. However, raw and liquid digestate are usually applied only once in the end of winter on wheat and not on rapeseed, which is not a common crop in the farm. We will add this information in the revised manuscript.

Line 137: of course this is important as it reduces N volatilisation. Is this reflected in the discussion of the results.

Yes, it is important. Nevertheless, we still measured some high NH<sub>3</sub> losses. We will add this point in the discussion (section 4.2) of the revised manuscript.

Line 147: its difficult in field-trials, but certainly this needs to be reflected in the discussion.

The effect of different N input is already mentioned in the results section (lines 449-451) and reminded in the discussion section (lines 676-677). We propose to more detail in the discussion the potential effects: different total N input may partly explain the measured differences in terms of crop performance and N losses. That is why we also used emissions rates and NUE (observed effect relative to the applied N), as stated line 674.

Line 151: t ha<sup>-1</sup> will be changed to t ha<sup>-1</sup>

Line 194: seems like a high temperture. Please check, usually its less than this. If this is correct please add a reference.

This analysis of soil organic matter is not used in our study. We only present the soil organic carbon content obtained by a different method (see lines 191-192). Although we will verify the temperature with the lab that performed the SOM analysis, we propose to remove the mention of the SOM analysis of SOM in the revised manuscript as it is not used.

Line 321: I'm not sure I get this, you are measuring aboveground biomass and grain yield in section 2.5.1 so surely variability can be ascertained??

We measured grain yield for the whole plot for each treatment with conventional machinery. Therefore, we could not analyze the results statistically (no replicates). However, we also manually sampled subplots in each treatment. We propose to add in the revised manuscript the yield obtained with manual sampling in addition to the whole plot yield, and to make a statistical analysis on these results.

Line 325: again, I'm not entirely sure I follow this. If you can generate a mean and SD why can't you apply statistical analysis?

& Line 326: do you mean it could not be determined for all replicates? You don't need all replicates to apply statistics, degrees of freedom of course is compromised with less replication but you can still apply statistics if replicates are compromised. Maybe expand on this point?

As explained before, we will include more statistical analyses in the revised manuscript.

Line 348: I wouldn't consider "characteristics" as results and as such I suggest considering putting this information in the M+M section. Characteristics describe the materials that were used in the experiment. Results should describe the effect of the "products" within the experiment, and then why the effects occurred (for example linking characteristics to results) explored in the discussion.

Okay, we agree.

Line 347: its not clear throughout the results whether "effects" are statistically valid or not. Terminology needs to be sharper, for example what does "similar" mean. In addition there seems to be a mix of discussion in with the results in places.

As explained before, we will include more statistical analyses in the revised manuscript. We will also check the terminology and move the sentences that should be in the discussion.

Line 362: Here you are incubating soil with the digestate, so its no longer "characteristics of the products (see heading of this section). As such these are results

Okay

Table 3: do you need both SD and CofV? I guess its ok to use both but I think only one is needed.

Okay, we will remove CofV. Instead, we will add the letters corresponding to the statistical grouping in this table.

Line 364: mineralisation of N?

Yes, it will be changed in the revised manuscript.

Line 366: ensure you are clear regarding significance. Was "slightly lower" or "slightly higher" significant?

We will, see previous comment on the statistical analysis.

Line 371 – Table 3: usually g kg<sup>-1</sup> FW rather than g kg FW<sup>-1</sup>. Same for the others.

Okay, it will be changed in the revised manuscript.

Line 382: if detailed data is required to emphasis a point then it needs to be shown. If not you can remove this statement. Okay, it will be removed in the revised manuscript.

Line 379: could be or was?

& Line 379: rapid and substantial compared to what. How do we know it was rapid and substantial unless compared to soomething else? Similar later, what does "high volatilisation" mean.

As suggested in other comments, we should not mix results and discussion and we will remove this sentence.

Line 380: in many places the results and discussion are getting mixed up together. Results sections should describe results without attributing the "why" which is a point for discussion.

We will check the whole manuscript and move the sentences that should be in the discussion.

Line 384: as above, why mention this if its not needed and if it is needed then it needs to be displayed.

Okay, it will be removed in the revised manuscript.

Line 388: this type of statement should be saved for the discussion. Results sections describe the results, and then the discussion why the results occurred. There seems to be a mix-up of results and discussion in various places in this manuscript. Suggest checking this point.

We will check the whole manuscript and move the sentences that should be in the discussion.

Line 391: this doesn't mean anything. Were they the same or higher. What did the statistics say.

See previous comment on the statistical analysis.

Line 396: this should be a discussion point rather than in the results.

Okay.

Line 435: control or treatment? Its not both.

Treatment. We will change in the whole manuscript.

Line 435: this doesn't make sense. Why exclude the control from the results analysis.

True. We will include it in the revised manuscript.

Line 442: what does "similar" mean? No significant difference? The results needs to be tidied up throughout for these ambiguities.

See previous comments on the statistical analysis.

Line 443: again, this is a point for discussion and not results. There are many examples of this throughout the results section.

We will check the whole manuscript and move the sentences that should be in the discussion.

Line 454: where is this data?

& Line 455: where is this data. Results needs to present the results of your experiment alone.

No data were acquired on root N uptake or N immobilization after crop residue decomposition. This was only a hypothesis. However, it should not be included in the results section.

Line 464: are error bars SD?

No, it represents the uncertainty of the balance for the whole plot grain yield. However, as explained before, we suggest including the mean yield estimated by manual sampling from the subplots within each plot, along with the standard deviation.

Line 466: error could not be calculated

See previous comment.

Line 482: why put results in supplementary material? & Line 486: again, why put results in supplementary material. These are direct results so I suggest better in the results section rather than supplementary material?

We did not consider the information we included in the supplementary material to be essential to the understanding of the manuscript. The manuscript is already very long in our opinion, so we prefer to keep this information in the supplementary material.

Line 519: what does "the drainage period" mean??

We propose to replace it with "the late autumn and early winter period" (when usually drainage occurs).

Line 543: conclusions are in discussion.

Okay, we will remove this sentence.

Line 537: The reader here has no idea as to whether your assertions are based on statistical analysis/evidence or not, especially as the figure doesn't show error.

We will add some statistical analyses where possible, as mentioned before in response to your previous comment. However, in this figure, some fluxes are not measured but estimated, and it was not possible to compute the error (soil N supply, applied N, crop N uptake from roots, N mineralization after EOM decomposition). Therefore, we do not think that it is possible or useful to add some error bars.

Line 554: all abbreviations for the treatments need defining in each figure

Okay, we will define them.

Line 551: phrases such as "fairly consistent" don't mean anything. Does that mean it wasn't consistent.

We will remove this sentence in the revised manuscript.

Line 569: none of this is really news as we already know that the materials are different. Its not really a strong start for a discussion.

Okay, we will remove this paragraph (lines 569-575)

Line 583: this paragraph is poorly worded and requires expansion and clarification.

Okay, we will rephrase it and add details.

Line 604: I'm not convinced this is true, please check.

We have made a search in Google Scholar (March 25, 2024) with the terms: ammonia volatilization "solid digestate". We found 510 articles. We quickly checked the first 200 articles, and none of them seems to measure NH<sub>3</sub> volatilization from solid digestate. Some papers measure NH<sub>3</sub> volatilization during the storage and composting. We will check more in detail for the revised manuscript.

Line 637: this is not really news as many studies have said the same.

Yes, but we think it is important to include because we do want to consider both agronomic performance and N losses in this paper. Moreover, some results are quite new or not so often published, as the NUE of digestate for rapeseed, the interpretation of NUE value with regards to measured NH<sub>3</sub> volatilization and organic N mineralization.

Line 669: most of this paragraph is not really needed as it is repetition from previous.

Okay, we will remove it (lines 669-676).

Line 668: this section is quite wordy and could easily be re-worded to improve focus.

We will reword it in the revised manuscript.

Page 33: this really is known already. Whats new here. & Line 695: conclusions seems quite wordy, but more importantly I can't see the innovations. What does this study tell is that we didn't know before, what are the practical implecations to farmers.

We will reword the conclusion and more focus on the novelty (see previous comments about this issue).

## References

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