Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2018-455-AC1, 2019


Biogeosciences Discussions
Open Access
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# *Interactive comment on* "Review of key causes and sources for $N_2O$ emissions and $NO_3$-leaching from organic arable crop rotations" *by* Sissel Hansen et al.

**Sissel Hansen et al.**

sissel.hansen@norsok.no

Received and published: 20 February 2019

Reply to referee comments

In the enclosed PDF bg-2018-455-supplement, all comments and responses are presented in a more reader friendly way than in the present plain text.

https://www.biogeosciences-discuss.net/bg-2018-455/#discussion Paper: Review of key causes and sources for N2O emissions and NO3- leaching from organic arable crop rotations General comments from referee 1 The subject matter "N2O and NO3 losses from organic agriculture" is an interesting subject, unfortunately the paper is



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poorly written. A lack of organization (1) results in repetition of certain points and completely missing other points. This lack of organization also creates a lack of focus. By the time I finished reading the paper, I still didn't have a good idea of what the authors were trying to achieve. Also, I had difficulty following the paper in places because the authors just attached databases as supplementary material, rather than actually including summary tables or figures based on the supplementary materials. The authors need to find some way to summarize the data and present the summary in a meaningful way (either tables or figures (2)). Once the data has been summarized, patterns may emerge, which can then be explored. But everything right now just seems haphazard. I also got the impression that the authors only used simple regression to look at drivers of N2O/NO3 losses. Why not some kind of multivariate analysis (3). There are also many more comments in the attached document. Responses to general comments from referee 1 The authors are grateful that the referee has taken the time to work thoroughly with the manuscript and for the many useful comments that will improve the paper. 1) Lack of organization We understand that the referee found the manuscript difficult follow, and we have therefore simplified the structure of the paper. We have also reformulated and simplified the research questions and improved the reasoning for the new research questions in the introduction, thus providing a more focused review. In section 3, we explain the nitrogen cycle in organic arable farming with focus on aspects that influence N2O emissions and N-leaching. This provides the background for understanding and discussing how crop and soil management in organic farming can be adapted to reduce N losses. In comment no 28, the referee suggests that section 3 and 4 should be a part of the introduction. We think there is a risk that this will make the introduction too long and ill focused. Instead we have moved part of section 3 (crop rotation) to the introduction, and we have targeted section 3 towards supply of organic matter and soil N-dynamics in organic arable crop rotations. We have shortened and included the previous section 5 "Dynamics of SMN in organic arable crop production" in the new section 3. We have removed the section on soil acidity, and the section on soil structure has been moved to the section on N2O (New section 5). The text on crop





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yields has been moved to the new discussion section. The previous section 4.3 has been moved to the introduction. As a start of the new sections 4 and 5 we focus on the processes responsible for N2O emission and NO3-leaching, respectively, and we show that the same mechanisms are responsible in organic and non-organic systems.

The new table of contents is as follows: Abstract Abbreviations 1. Introduction 2. Methodology 3. Drivers of SMN and degradable C in organic arable crop rotations 3.1. Supply and quality of soil organic matter 3.2. Soil biological activity 3.3. Soil N-dynamics 4. Drivers of N2O emissions in organic arable crop rotations 4.1. Biogeochemical processes leading to N2O emissions 4.2. Legumes during plant growth 4.3. Plant residues 4.3.1. Freeze - thaw / dry - wet 4.3.2. Plant residue quality 4.3.3. Soil and tillage effects 4.4. Organic fertilizers 4.5. Contribution of total N-input and high emission events to N2O emissions 4.6. Impact of earthworms 5. Drivers of NO3 leaching in organic arable crop rotations 5.1. Biogeochemical processes leading to NO3-leaching 5.2. Legumes 5.2.1. Grain legumes 5.2.2. Forage legumes 5.3. Cover crops 5.4. Tillage effects 5.5. Soil type and climate 6. Discussion 6.1. Key drivers of N2O emissions 6.2. Key drivers of NO3 leaching 6.3. Suggested strategies to mitigate N2O emissions and NO3 leaching 6.4. Research and innovation needs 7. Conclusion

Revised Research questions: We address the following questions for organic arable crop rotations: 1. How does supply and quality of organic matter in above- and below ground residues and organic amendments influence availability and type of SMN and degradable carbon? 2. How does supply of nitrogen through organic inputs drive N2O emissions and how can these be mitigated? 3. Are there a lack of correlation between total N-input and N2O emission in organic arable crop rotations, and are total N2O emissions primarily driven by baseline emission or by single high N2O fluxes? 4. What are the main drivers for NO3 leaching in organic arable systems and how can the leaching be reduced?

We are currently revising the MS, but are not done with that yet. During revision, there may be some adjustments in outline and research questions.

2) Tables or figures of the data in the paper The referees do miss tables and figures within the paper. We are providing a new figure illustrating N-dynamics in organic arable crop rotations, a new table with performance of selected indicators of SMN dynamic in organic and conventional arable systems, and new figures that are extracting the essence N2O data presented in S1 and NO3-leaching data presented in S2.

3) Want multivariate analyses instead of regression Given the actual problems and data we find regression analysis to be the most relevant. As long as the referee do not suggest one or more other specific multivariate methods / models that can be used to solve our problems in a better way using our data, we keep regression analysis as a good method to use in our situation.

General comments from referee 2 While there is merit in the work, I think the paper needs a lot of work before it is ready to publish. Many of the points raised are not comprehensively explored (4) or the explanations are not sufficiently considered. Work in this area could enhance the paper. I think the tables also need further work. I think the tables (5) should be included in the main paper but in a revised format Responses to general comments from referee 2 4) Not comprehensively explored or the explanations are not sufficiently considered As we intended to find a balance between giving a comprehensive and enough explanations and not being too detailed and thus making the paper too long, referee 2 need to be more specific in what he/she thinks need to be more comprehensively explored or more sufficiently considered, before we can respond to this comment. 5) Tables should be included in the main paper See response to comment 3).

Comments given the paper from referee 1 or 2 (the comments are numbered from 6 to 98 in the paper supplemented by the referees, for responses see below (page 8) Abstract 6) You include NO3 leaching here, which is not an "emission". I think the term "losses" would be more appropriate. Page 1,line 25 7) This is a generalisation, you can get poorly managed organic fields too. Maybe use the term "in general"? P1, l 28 8) crop termination? senescence? P1, l 31 9) and the form of N, whether available or

unavailable P1, l 33 10) 'the risk "of" not "for", please replace throughout P1, l 33 11) remove "These" P1, l 34 12) for P1, l 34 Section 1 Introduction 13) combine these two sentances P2, l 7 14) the term "arable" refers to the land (i.e. land fit for agricultural production), so you don't produce "arable". the terms "crop production" or "agricultural production" would be better. P2, l 16 15) define these "challenges" P2, l 16 16) N use efficiency P2, l 16 17) ...efficient conversion of organic material to reactive N and reactive N into plant material.... P2, l 27 18) But it isn't just green manures that rely on BNF, you have intercropping, or the use of N fixing plants in rotation (e.g. Soybean). P2, l 30 19) why do you provide the symbol for nitrate here? you have already used the word "nitrate" a few times. Please indicate symbol at the first use (i.e. line 10). P2, l 35 20) I find that these 5 points follow a nice, logical order. However, the rest of the manuscript does not follow the same order. Why not? I would think that having everything consistent would be better, no? P3, l 2 21) I think the term "driver" is better word than "trigger". P3, l 2

Section2 M 22) I'm not sure what you mean by "characteristics". Soil types? Management? climate zone? please be more precise with your wording. P3, l 8 23) Not in the list of references. P3, l 13 24) The presence of NH4-N does not contribute directly to N2O emissions, NH4-N needs to be nitrified to NO3-N prior to denitrification to N2O P3, l 4 25) why "site"? Why not "mean annual precipitation" or "soil clay content" or something more meaningful? Site seems completely arbitrary. P3, l 4 26) I think this section should go in the section describing the stepwise regression. P3, 21-27 27) Cumulative P3, l 34

Section3 28) Shouldn't this follow the 5 points laid out in the introduction? The first point in the Intro was "what determines the dynamics of SMN concentrations and when do high SMN concentrations occur? I would actually move all of section 3 into the introduction. Probably all of section 4 should go into the introduction as well. P4, l 1 Section3.1 29) are longer and more diversified than non-organic rotations P4, l 5 30) Is this required? This sounds more like it should be in the introduction. While differences

in rotations likely have an effect on emissions and leaching, I'm not sure that we need to know the area associated with the different plant species. And actually, these aren't really rotations, but only specific plant types within a rotation. P4, l 9-11 31) This seems redundant. Essentially you are saying that N fixing crops are more abundant because there are more N-fixing crops (i.e. legumes) as temporary fodder crops. Also, what is a "temporary fodder crop"? Also, I think the main reason why N fixing crops are more abundant in organic rotations is because organic farmers can not use synthetic fertilizers. P4, l 11-12 Section3.2 32) Isn't this still part of the "Crop Rotation"? P4, l 15-18 33) Do you mean just in Europe???? I think this is too much of a generalisation, many organic agriculture systems remove all of the organic material as the whole crop is used eg root stem and leaves - depleting soil fertility eg subsistence agriculture in Ethiopia P4, l 18 34) A single sentence is not a proper paragraph. Please revise. this could probably be part of the following paragraph that discusses the SOM quality. P4, l 20-25 35) Shouldn't this be part of section 3.3? P4, l 24 36) . . .fertility as it is a short-term pool for nutrients (Marriott and Wander, 2006; Martyniuk et al., 2016). However, it can also enhance SMN. . . P4, l 29 Section3.3 37) how much higher? P4, l 37 38) You essentially say the same thing (i.e. earthworm biomass and population were higher in organic soils) over and over again. Please be more concise here. This can probably be trimmed by about 50-60%. P5, l 1-11 Section3.4 39) do you have a reference for this? P5, l 21 40) this is essentially a repeat of the first sentence in the previous paragraph P5, l 23-24. 41) How much? 50%? 80% P5, l 28 42) If you are talking about PMN pools, they are not the same as "concentrations". I would suggest writing "They showed that more diversified crop rotations resulted in larger PMN pools". P5, l 34 -35 43) SOM.... stay consistent. P5, l 39 44) The DOK trial should be identified the first time it is referenced. This is already the second time. P6, l 5 45) This section is on the N supply. Keep the information on denitrification in the section on N2O emissions. P6, l 5 46) You can just use "DOK" here, now that you have already stated what the acronym refers to. P6, l 17 47) is this relevant? P6, l 21-24 48) can you be more specific what you mean by "soil life"? is it plants? macrofauna? fungi? P6, l 26 49) which properties? You





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mention "macropores" in the next sentence. Is this one of the properties? since this is the only one that you mention, why not just state that Marinari observed that organic fertilizers increased macropores and particularly elongated pores? P6, l 29 50) which are? P6, l 32 51) as long as the organic rotations include more perennial leys. P6, l 32-33 52) Is this realistic in the context of increased pressure for urbanisation? This suggests is the existing agricultural landbase is insufficient - that we need to cut down some trees? P6, l 38 53) this is a huge range.... Any idea why it ranges to much? are there differences between crop types? species? do different soils or climates respond differently? P6, l 39 54) There are many studies that look at how mouldboard ploughing effects N2O emissions. why have you not looked at any of these? P7, l 4 55) Do we really need a 2-sentence summary of each section? I think this is just repeating what was already said and is therefore unnecessary. P7, l 10-13 Section4 56) You should also include something on the paper by Balaine et al. 2013 (SSSAJ 77:1496-1505) on how gas diffusivity affects N2O fluxes. P7, l 14 57) you said earlier (lines 17 and 18 above) that nitrification is a biological process. So why is it stated that there are abiotic reactions during nitrification? P7, l 22 58) I understand what you are saying here, but it seems like an odd way of saying it. I also think you need to clarify that it is the native SOM, especially in organic farming when N applied as manure or slurry can be quickly considered part of the SOM. P8, l 1 59) this explanation of priming is inadequate. Please add a bit more information about what is meant by priming. P8, l 3-5 60) there should also be studies that use 15-N applications to determine whether the source is nitrification or denitrification. And this could also differ based on soil textures / structure / precipitation because of their effect on soil aeration and gas diffusivity P8, l 10-11 61) Please don't have paragraphs that consist solely of a single sentence. Also, this doesn't really explain why nitrifier denitrification would be a major N2O source here. And also, I can't figure out if you mean that the soil has low content of easily degradable C, or if the OM that is applied has low content of easily degradable C. P8, l 15-17 62) Why nothing on nitrification inhibitors? if you can reduce the amount of nitrification, then you should also reduce NO3 leaching. There are both synthetic and biological Nitrification

inhibitors. P8, l 18 63) say the same thing in next sentence P8, l 33 64) lower than what? P8, l 36 65) Table S1 presents a lot of data (as do S2 and S3 actually). This makes it very difficult to come to any conclusions about the studies. Some tables and figures that summarize some of this data would be helpful. P9, l 10 Section5 66) You seem to use "organic grass-clover leys" as a synonym for "N-limited grass-clover ley". Why is that? are all organic grass-clover leys N limited? vice versa? This should be clarified. P9, l 12-13 67) why two different numbers? is one for the 1 yr and the other the 3-yr leys? I assume so, but it is not explicitly stated. P9, l 19 68) which conditions? why? P9, l 22 69) I feel like I am missing some important details from the Plaza study, because I can't the the obvious explanation of "priming". Why couldn't it just be from the decomposition/mineralization of the added catch crop? P9, l 27-29 Section6 70) this might be better in section 6.2. P10, l 13-20 71) incorporation of the CC? P11, l 13 72) There are few studies that actually show this directly, however Freeze/thaw has been consistently shown to increase mineral N availability (similar to the Birch effect). The release of N2O during thawing could be related to a few things, one of which is the release of labile C and N due to cell lysis (the term "blasted" is the wrong term, by the way). But there are other theories as well. Disruption of soil aggregates due to F/T may also release labile C and N; frozen soils may have ice lenses that lead to N2O accumulation under the ice, which can be released upon thawing, etc. There are many papers by Wagner-Riddle (in addition to the ones you mention here) that examine N2O pulses during thawing of soils. I would suggest adding some of those citations here to aid in providing a more detailed description of how Freeze/thaw affects N2O fluxes. There is a good one in SBB (Congreves et al. 2018. vol. 117: 5-15) and another in Nature Geoscience: Wagner-Riddle et al. 2017. vol 10: 279-283. P11, l 20-21 73) sorry, but the way this supplementary material is set up makes it really difficult to find the information to which you are supposedly referring. The Tables must be organized in a way that they present summary rather than just raw data (although the raw data is good to have as supplementary materials). P11, l 13 74a) which study are you referring to? P12, l 1 74) This seems to be to be a very large leap in logic.





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P12, l 2-4 75) or it could be that deep incorporation of crop residues in soils with restricited air diffusivity will be mineralized much more slowly, reducing the amount of NO3 available for denitrification. P12, l 15 76) There are many other studies that look at N2O emissions from application of various organic N sources. And there is one paper that describes how the response in N2O fluxes differs by soil type (Pelster et al. 2012. J. Environ. Qual. 41:427-435). You need to expand these points more clearly. P12, l 36-37 77) if you want another example from a cool humid climate, there is also Chantigny et al. 2012. JEQ. 42:30-39 P13, l 2-3 78) provide numbers please. P13, l 23 79) what did these studies actually find? did they also find a relation between N2O flux and SOM content? P14, l 5 80) Using the term "site" is completely meaningless. How was this entered into the model? Site is categorical, how was that worked into a multiple regression model? that makes no sense to me. Why not use site-specific variables (i.e. soil clay content; annual precipitation; soil sand content... or something like that). P14, l 16 81) how? You can make a case for the presence of labile N during reducing conditions, but where do you show the relation with labile C? P14, l 19-20 82) The inequality in length of study is really a problem here, because the numbers for Frick and Aberdeen are so different from the other two. I just am not sure how to normalize this in a way that makes sense. P14, l 23-25 83) how long was the measurement period for this study? P14, l 28 84) can you give the model (with co-efficients for the different variables). Also, are all of these just simple linear regression? did you try multiple regression? why not? P14, l 34 85) isn't this tautological? and therefore does not need to be stated. P14, l 34 86) what aspect? expression of the enzyme? enzyme activity? provide details. P15, l 9 87) if the N2O/(N2O+N2) ratio is higher in organic agriculture that means that a larger proportion of N is emitted as N2O, which seems to me to be the inverse of what you think you are saying here. Maybe I am misunderstanding something. P15, l 11-13 88) in what way? P15, l 13-14 89) earthworms often have producing bacteria in their gut. This should also probably be explored a bit P15, l 20-21 Section7 90) It seems to me that much of what is presented here is just a repetition of what was already provided in the section on N2O. Which makes sense. Both N2O

emissions and NO3 leaching are strongly related to available soil NO3 and high water content (anaerobicity). Here you talk about legumes, grain legumes, etc as possible triggers. But in my opinion, the trigger is the available NO3 combined with high water (low O2 content). All of this crop rotation information should be dealt with once in the section on soil mineral N. Not repeated in multiple sections. I would include section 7.2 as part of this as well as catch crops are ways to control the concentrations of NO3. P15, l 20-21 91) were the weeds 50% taller? or was their coverage 50% greater? P18, l 30 92) how does tillage affect the soils? pore size distribution, continuity, etc? how about rainfall impact and splashing on tilled vs non tilled soils? what effects may that have on soil infiltration and percolation? Again, you are only discussing the soil mineral N aspect again (which has already been done in a slightly different context), but you are completely missing how tillage may affect NO3 leaching in particular. P18, l 38-39 93) any idea why? P18, l 10-11 Section8 94) You don't really provide much information on strategies in this section. At least not in any organized way. this whole section needs to be completely re-written. P20, l 5 95) This belongs in one of the previous sections as it is not a strategy to reduce N2O and NO3 losses P20, l 7-8 Section9 conclusion which is numbered 10 96) why only rotary harrow? what is specific about this form of mixing that enhances the risk? P21, l 21 97) If you showed this somewhere, I completely missed the point. For me, this comes out of nowhere and with no justification. P21, l 22-23 98) could this be related to statistical power? Also, as you mention, site was a significant factor. was there a correlation after controlling (normalizing) for "site"? As I remember only reading about simple regression, I can only guess that this was not done. P21, l 25-26

Responses to comments given the paper from referee 1 or 2 (the comments are numbered from 6 to 98 in the paper supplemented by the referees) During revision of the MS, there will be some adjustments in the sentences suggested below 6) We have replaced emission with loadings 7) Agree, this is included in the new version of the paper 8) Agree, senescence should also be included as a possible course. New text in paper . . . after crop termination, harvest or senescence. 9) We do not understand





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what Referee mean. In the sentence it is already referred to “readily available nitrogen. We have added degradable carbon to make it clearer that we refer to C and N that that are rapidly available for micoorganisms.. 10) Agree, this is done in the new version of the paper 11) Do not agree in that. 12) “For” is changed to “of” throughout the paper 13) Agree, this is done in the new version of the paper 14) Agree. New sentence: It is therefore timely to review the impact of organic farming on N2O emissions and NO3 leaching, in production of arable crops particularly, as the yield gap between organic and non-organic production are larger with arable crops than with grassland. 15) Agree that writing challenges without explaining or defining what we mean are not OK. On the other and this is lengthy to explain and a bit of the scope of this paper, we therefore removed challenges and kept yield gap which is the main issue. 16) Agree, this is included in the new version of the paper 17) Agree. New sentence: Increasing yields in organic farming is an important goal to allow it to remain competitive, and this requires more efficient conversion of efficient conversion of organic material to reactive N and reactive N into plant material and reduction of associated N losses (Röös et al., 2018). 18) Agree, this is included in the new version of the paper. New sentence:” Although mineral N fertilizers are not allowed in organic farming, there are substantial amounts of N used, which derive from manure and other organic fertilizers, organic amendments and crop residues, biological N fixation (BNF) by legume crops, intercropping and green manures.” 19) Agree, this is included in the new version of the paper 20) To make it easier to follow the papers structure, we are adding questions in the introduction that are better introducing the sections 3 and 4. To help the reader we have also introduced a table of contents. New text. “We address the following questions for organic arable crop rotations: 1. Which agronomic managements, soil properties and yield level do characterise organic arable crop production? 2. What are sources and mechanisms underlying N2O emissions and NO3 leaching? 3. What determines the dynamics of SMN concentrations, and when do high SMN concentrations occur? 4. What are the main drivers of N2O emissions? 5. What is the contribution of single high N2O emission events to total N2O emissions? 6.





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When does NO3 leaching mainly occur? 7. What are the most efficient measures for reducing N2O emissions and NO3 leaching?" 21) Agree, this is included in the new version of the paper 22) We have defined this better. New sentence: Based on the authors own field trials, literature databases and searches through Google Scholar, we compiled data on agronomic managements, soil properties and yield level of organic arable crop rotations and measurements of soil mineral N (SMN), N2O emissions and NO3 leaching from field trials relevant for organic crop rotations in climate and soil conditions present in Europe. 23) This is now included: Molodovskaya, M., Singurindy, O., Richards, B.K., Warland, J., Johnson, M.S., Steenhuis, T.S.: Temporal Variability of Nitrous Oxide from Fertilized Croplands: Hot Moment Analysis. Soil Sci. Soc. Am. J. 76, 1728. https://doi.org/10.2136/sssaj2012.0039, 2012. 24) In this postulate the referee is not consistent with the main understanding. See for instance Firestone and Davidson, 1989; Butterbach-Bahl et al., 2013). No change is made. 25) Agree with referee, we have recalculated the regression and included %clay, pH and SOC in the regression. We have also added some more text to make it clearer what we did. 26) We do not understand this comment as this is in the section where we describe the stepwise regression. The expanded text will hopefully make this easier to follow. 27) Neither cumulated or cumulative is needed as N2O emission is defined as the cumulative flux reported. The word is removed 28) Se answer to comment 1 and 20. Section 3 and 4 are too long to be a part of the introduction as suggested by referee, and they are important part of this paper. 29) Agree, this is included in the new version of the paper 30) Agree, the sentences are removed 31) The sentence is modified. New sentence: Barbieri et al., (2017) observed that more legumes are included in temporary fodder crops, and there are more catch crops, under sown cover crops and intercropping that contain nitrogen-fixing species than in non-organic rotations. This is a natural consequence of that synthetic N-fertilizers are not used 32) Agree. The sentence is moved to 3.1. 33) The referee is correct. We have now underlined that this is relevant for European cropping systems. New sentence: ...." are returned to soil than in non-organic systems in cropping systems that are common in Europe" 34)





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Agree, this is done in the new version of the paper 35) Agree, this is done in the new version of the paper 36) Agree, this is included in the new version of the paper 37) Without being too comprehensive for this paper, where N2O and NO3 is the focus, it is difficult to give numbers on this. There are many ways to estimate/determine biological activity in soils. See for instance “Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U., 2002. Soil fertility and biodiversity in organic farming. Science 296, 1694–7. https://doi.org/10.1126/science.1071148” where microbial biomass, dehydrogenase, protease, phosphatase, saccharase and mycorrhiza are used as indicators for microbial activity and earthworms, carabids, Staphylinids and spiders for faunal activity. The exact increase of biological activity in % will also vary with the sites climatic and soil conditions. The main thing is that it is a general trend with increased biological activity, which is shown in many investigations. No change is made. 38) Most of the examples are removed to make it less repeating. Earthworms do only have minor part of this subject so the referee has a good point. 39) Reference included: Pandey et al., 2018 40) Agree, the sentence is removed in the new version of the paper 41) This section will be rewritten 42) Agree. The suggested sentence is included in the new version of the paper 43) Agree, this is done throughout the paper 44) The first time is removed, so this is the first time and adjusted accordingly. 45) We have removed this sentence. 46) To focus the MS more on the aspects where organic farming differ from most conventional farming, we have taken out the aspects of pH, and this text is therefore removed. 47) Same as for 46. 48) The text on soil structure will be modified and moved to new sections 4.3.3 and 5.4 49) Agree, this is done in the new version of the paper 50) In this paper it is to comprehensive to go deep into why perennials improve soil structure, but more which structure improvements that is relevant for N2O-emission /NO3-leaching. 51) Agree, “as long as the organic rotations include more perennial leys” is included 52) This article is not about organic farming or not, but about how different aspects that are typical for organic farming influence N2O emission and NO3 leaching. However, a much larger impact on feeding the world’s population and the area needed for agricultural production, than if the yields are 80 or 100%, is





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the unequal distribution of resources in the world, the land that is taken out of use for roads, building ground or other purposes, all the food that is wasted, corn and wheat used for bio-energy and so on. No change is made. 53) . . . . . yield level will be moved to the new discussion. Comment 53 relate to Meier et al. (2015) observed that 9 to 214% more land is needed to produce one arable crop unit by organic compared with non-organic production. The requested information is not easy to extract from the present article. We will rewrite this whole section when used in the introduction. 54) This section is about yields. The impact of ploughing on N2O emission is discussed in the new section 4.3.3 Soil and tillage effects 55) We have removed the summaries 56) Thank you for this reference. A text is included in new section 4.1. Oxygen availability depends on soil microbial activity and gas diffusivity which is in dependent on soil moisture content, texture and density. Gas diffusivity is a promising predictor for N2O fluxes from soils with varying bulk density as observed by Balaine et al., (2013) who found that the production of N2O increased when the relative gas diffusivity was between 0.006 and 0.020 and the soil became anaerobic. 57) Yes the reviewer is right that Âń nitrification is a biological process" during this process NH4 is oxides to NO2- via hydroxylamine (NH2OH) by ammonia oxidizing bacteria (AOB). During this process N2O is produced as by product due to some partially understood abiotic reactions of hydroxylamine and NO2-. Recent studies (i.e Liu et al 2017) have shown that there are certain abiotic reactions of hydroxylamine that can contribute to N2O production in this process, also another hypothesis is that NO2 (which is an intermediate in this process) can also be converted to N2O through abiotic reactions. That's why we wrote partially understood biotic (for sure) and abiotic (unclear) reactions. We have made this clearer by adding "abiotic reactions of hydroxylamine" 58) We have changed the sentence slightly: "The N2O emission from native SOM is often referred to as the background or baseline emission, and will vary between years because of variations in temperature and precipitation " 59) We have decided to remove the text about priming as it does not have a major impact on N2O emissions 60) This is the main picture. We have included some more on gas diffusivity (comment 56). It is to comprehensive

for this review to cover all aspects of N2O formation in this review. 61) The sentence is modified to make it more clear 62) Inhibitors are not allowed in organic farming. This is now specified in introduction 63) Actually, there is not the same meaning in these two sentences. Sentence 1, is a postulate, sentence 2 is observations which is contradictory to the postulate. This is made clearer. 64) This is now included 65) See respons to comment 2). 66) The sentence is rewritten to emphasise that it is SMN content that matters:" SMN is normally very low under organic grass-clover leys (Table S1, Watson et al., 1993; Nadeem et al., 2012; Brozyna et al., 2013; Frøseth et al., 2014; Krauss et al., 2017b), thus grasses will quickly take up soil NO3 in the root zone (Brophy et al., 1987)." 67) We have added the word "respectively" to make it clearer that this is Soil SMN after 1 and 3 years, respectively. 68) This sentence is removed, and the content is covered in the rest of the revised section 3.3 69) We have decided to remove the text about priming as it does not have a major impact on N2O emissions 70) We were uncertain about what is the best place, because of the relation to growing clover. A part of this is now moved to new section 4.3.1, and a part is deleted. 71) Agree, this is included in the new version of the paper 72) Thanks for these references. Freezing/thawing is a large area and we think that for this article it is correct to emphasis what is relevant for organic systems: high content of SOM, soil biota, CC. We have included relevant information from Congreves et al. 2018. vol. 117: 5-15 and Wagner-Riddle et al. 2017. vol 10: 279-283. P11, l 20-21, which helps to complete the picture. New text: "The mechanisms behind freeze/thaw have been comprehensively reviewed by Congreves et al. (2018) showing that the causes for N2O emissions are different for these two mechanisms and that freeze/thaw has a larger impact on N2O emissions from temperate agroecosystems than drying/rewetting do. Wagner-Riddle et al. (2017) estimated that neglection of freeze/thaw emissions will underestimate global agricultural N2O emissions by 17 to 28%. In the present article we do discuss freezing/thawing and drying/rewetting during conditions that are particularly relevant for organic crop rotations. Freezing/thawing of soil rich in organic matter and soil biota, or soil covered with plant residues may result





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in a N2O boost as easily degradable C and N is released from cells lysis after frost." 73) See respons to comment 2 74) It is understandable that the referee misunderstood this. The last sentence is removed as it is enough covered from earlier sentences. 75) Agree, this is included in the new version of the paper 76) Thank you for this reference. Nice article. When revising the MS we will include these points and also expand the discussion on the impact of N-content and the type of N-compound in the organic fertilizers on N2O fluxes 77) I assume you mean this one: Chantigny, M.H., Angers, D.A., Rochette, P., Bélanger, G., Massé, D., Côté, D., 2007. Gaseous Nitrogen Emissions and Forage Nitrogen Uptake on Soils Fertilized with Raw and Treated Swine Manure. J. Environ. Qual. 36, 1864. https://doi.org/10.2134/jeq2007.0083, but this is also relevant Chantigny, M.H., Pelster, D.E., Perron, M.-H., Rochette, P., Angers, D.A., Parent, L.-É., Massé, D., Ziadi, N., 2013. Nitrous Oxide Emissions from Clayey Soils Amended with Paper Sludges and Biosolids of Separated Pig Slurry. J. Environ. Qual. 42, 30. https://doi.org/10.2134/jeq2012.0196, and will be used in revised version 78) Numbers for N2O-N and C are included. "Krauss et al. (2017b) found that fertilization with slurry and manure compost increased annual N2O emissions during winter wheat after more than ten years of differentiated management compared to sole slurry fertilization (mean values in the period (369 days), were 2.2 and 2.9 kg N2O-N ha-1, respectively). They related this to higher microbial biomass and content of SOC. Mean values for the upper 10 cm in soil were 28 and 30 Mg C ha-1 for fertilization with slurry and manure compost and sole slurry fertilization, respectively." 79) The text is rewritten to make it more clear that this refer to : Lack of correlation between N2O emissions and N fertilization. Neither Pugesgaard et al (2017) nor Peyrard et al. (2016) have related their findings to the content of SOM. 80) See respons to comment 25. We do not longer have a categorical variable. (That is however in principal no problem to include in a stepwise regression). 81) The sentence has been improved so it now should be easier to relate to the first sentence, which was the intention.: "The content of NH4-N in soil did not affect peak N2O fluxes. These findings indicate that denitrification is the main cause for high N2O-flux rates in these studies" 82)

Agree with referee. This is indeed problematic. We have tried to overcome this by estimating the impact of the highest emission on the mean daily N2O emissions, but still this is tricky because longer periods with low emissions are not included in the shorter periods. The best would be to have yearly emissions, but we did the best we could do from the data available. 83) Agree that this is essential information. This is now included. 84) model (with co-efficients for the different variables) is now given in section 2 (Methodology). In the first model where we tested different factors we used multippel, stepwise regression. In the second model where we tested the impact of the highest peak on the total emission linear regression was the best option. 85) We do difference between flux and emission. Emissions relating to the total period. The sentence is rewritten to make this clearer." From this we can conclude that when the conditions for high N2O fluxes are met at one or more days, there is a large chance for high total N2O emissions in the period." 86) In order to focus the MS more on the aspects where organic farming differ from most conventional farming, we have taken out the aspects of pH, and this text is therefore removed. 87) The same as for comment 86 88) The same as for comment 86 89) We have moved the sentence that described this to an earlier position, and have made it clearer that body fluids is a part of earthworm gut. This, to make it easier to perceive for the reader 90) See comment 1. We are restructuring the MS and will go through the new section 5 to avoid repetition from section 3 and 4. 91) We have clarified by including that the weed incidence was higher. 92) We have focused the paper, and do think that general effects of tillage on nitrate leaching is out of the focus. 93) We have added an explanation and the new text is: "A field experiment over 13 years in the UK showed that N leaching in winter from fertilized grass (non-organic) was highly correlated with the preceding summer's soil moisture deficit, with the highest losses following dry summers (Tyson et al., 1997). In this case, poor grass growth due to drought lead to a buildup of NO3 from unused fertilizer present in the autumn. Prolonged mineralization of organic fertilizers or crop residues due to drought may also lead a similar situation in organic farming systems." 94) See comment 1. We are restructuring the MS and will rewrite new

section 6. The suggested new text to comments (95-98) might therefore no longer be relevant 95) An explanation is now included. 96) The sentence is rewritten and rotary harrow is removed 97) This is from section 6.4. It is understandable that this sentence was confusing. High is removed, as this gives wrong impression. 98) This is from the literature review presented in section 6.4 and not from our statistical calculations as we were not able to run statistic on the impact of total N because of lack of data in the relevant experiments. 99) Miss the comment from referee.

Please also note the supplement to this comment:
https://www.biogeosciences-discuss.net/bg-2018-455/bg-2018-455-AC1-supplement.pdf

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Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2018-455, 2018.



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Biogeosciences Discuss., https://doi.org/10.5194/bg-2018-455
Manuscript under review for journal Biogeosciences
Discussion started: 27 November 2018


# Review of key causes and sources for $N_2O$ emissions and $NO_3$-leaching from organic arable crop rotations

Sissel Hansen[1], Randi Berland Frøseth[2], Maria Stenberg[3], Jarosław Stalenga[4], Jørgen E. Olesen[5], Maike Krauss[6], Paweł Radzikowski[4], Jordi Doltra[7], Shahid Nadeem[8], Torfinn Torp[9], Valentini Pappa[10], Christine A. Watson[11,12]

[1]Norwegian Centre for Organic Agriculture, NO-6630 Tingvoll, Norway
[2]Department of Grain and Forage Seed Agronomy, Norwegian Institute of Bioeconomy (NIBIO), NO-1431 Ås, Norway
[3]Department of Soil and Environment, Swedish University of Agricultural Sciences (SLU), Skara, Sweden
[4]Department of Systems and Economics of Crop Production, Institute of Soil Science and Plant Cultivation - State Research Institute, 24-100 Puławy, Poland
[5]Department of Agroecology, Aarhus University, DK-8830 Tjele, Denmark
[6]Department of Soil Sciences, Research Institute of Organic Agriculture (FiBL), 5070 Frick, Switzerland
[7]Cantabrian Agricultural Research and Training Centre, CIFA, 39600 Muriedas, Cantabria, Spain
[8]Department for Feed and livestock, Norwegian Institute of Bioeconomy (NIBIO), NO-1431 Ås, Norway
[9]Department of Research, Norwegian Institute of Bioeconomy (NIBIO), NO-1431 Ås, Norway
[10]Texas A&M, Energy Institute, College Station, TX 77845-3372, USA
[11]Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden
[12]SRUC, Craibstone Estate, Aberdeen, AB21 9YA, UK

*Correspondence to*: Sissel Hansen (sissel.hansen@norsok.nu)

**Abstract.** The emissions of nitrous oxide ($N_2O$) and leaching of nitrate ($NO_3$) have considerable negative impacts on climate and the environment. Although these environmental burdens are on average less per unit area in organic than in non-organic production, they are not smaller per unit of product. If organic farming is to maintain its goal of being an environmentally friendly production system, these emissions should be mitigated. We discuss the impact of possible triggers within organic arable farming practice for the risk of $N_2O$ emissions and $NO_3$ leaching under European climatic conditions, and possible strategies to reduce these. Organic arable crop rotations can be characterised as diverse with frequent use of legumes, intercropping and organic fertilizers. The soil organic matter content and share of active organic matter, microbial and faunal activity are higher, soil structure better and yields lower, than in non-organic, arable crop rotations. Soil mineral nitrogen (SMN), $N_2O$ emissions and $NO_3$ leaching are low under growing crops, but there is high potential for SMN accumulation and losses after crop termination or crop harvest. The risk of high $N_2O$ fluxes is increased when large amounts of herbage or organic fertilizers with readily available nitrogen (N) and carbon are incorporated into the soil or left on the surface. Freezing / thawing, drying / rewetting, compacted and/or wet soil and mixing with rotary harrow further enhance the risk for high $N_2O$ fluxes. These complex soil N dynamics mask the correlation between total N-input and $N_2O$ emissions from organic arable crop rotations. Incorporation of N rich plant residues or mechanical weeding followed by bare fallow increases the risk of nitrate leaching. In contrast, strategic use of deep-rooted crops with long growing seasons in the rotation reduces nitrate leaching risk. Reduced tillage can reduce N leaching if yields are maintained. Targeted treatment and use of herbage from green manures, crop residues and catch crops will increase N efficiency and reduce $N_2O$ emissions and $NO_3$ leaching. Continued regular use of catch crops has the potential to reduce $NO_3$ leaching but may enhance $N_2O$ emissions. A mixture of legumes and non-legumes (for instance grasses or cereals) are as efficient a catch crop as monocultures of non-legume species.

**Abbreviations**: BNF: biological nitrogen fixation, C: Carbon, CC: Catch crops or cover crops, $CH_4$: methane, EF: Emission factor = % of N applied emitted as $N_2O$-N, N: nitrogen, $N_2O$: nitrous oxide, PMN: Potentially mineralizable N, SMN: Soil mineral nitrogen, SOC: Soil organic carbon, SOM: Soil organic matter.



**Fig. 1.**