Biogeosciences Discussions

Biogeosciences Discuss., author comment AC1
https://doi.org/10.5194/bg-2021-228-AC1, 2022

Reply on RC2

Jenie Gil et al.

Author comment on "Sources of nitrous oxide and the fate of mineral nitrogen in subarctic permafrost peat soils" by Jenie Gil et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-228-AC1, 2022

We thank the reviewers for their interest in our work and for their insightful comments that have greatly contributed to improve our manuscript. We have addressed the general and specific comments provided by the reviewers and have made necessary changes accordingly to their indications as follows:

Comment on bg-2021-228

Anonymous Referee #2

Referee comment on "Sources of nitrous oxide and fate of mineral nitrogen in sub-Arctic

permafrost peat soils" by Jenie A. Gil et al., Biogeosciences Discuss.,

https://doi.org/10.5194/bg-2021-228-RC1, 2021

The manuscript 'Sources of nitrous oxide and fate of mineral nitrogen in sub-Arctic permafrost peat soils' by Gil and co-authors is an interesting study on nitrogen cycling in vegetated and bare soils of the Russian sub-arctic. The authors used an isotope pulse labelling approach to identify the microbial pathways responsible for N2O emissions at their study sites and concluded that emitted N2O mainly originated from microbial denitrification. However, also nitrification was an essential process for N2O production since it produced the nitrate required for denitrification.

The formation and release of N2O from arctic and subarctic soils has not yet gained the attention it deserves. It is crucial to understand how N2O fluxes will respond to future environmental and climatic changes in particular in the high northern latitudes, since there the changes will be most severe. The presented study adds important information on the formation and release of the important greenhouse gas N2O in a remote area of this world. The study is well designed and the conclusions are supported by the presented data. I have only few comments, which hopefully are helpful to improve the manuscript.

1.The title of the study indicates that these soils are affected by permafrost, but in the description of the study site and the soil characteristics I did not find any information on permafrost, except that the sites are situated in the zone of discontinuous permafrost. Are the sites still affected by permafrost? If yes, please give more information e.g. on active layer depths, if not, the title should

probably be adapted.

A: Yes, the site is affected by permafrost. We were studying permafrost peatlands (peat plateaus), which are bogs raised after permafrost aggredation. The active layer depth in 2010 was 60 ± 12 cm on average in vegetated peatlands (VP) and 70 ± 5 cm on average in bare peat (BP) (this is mentioned in table 1 in the MS). We have now added a sentence specifically stating that the sites are underlain by permafrost which reads **(section 2.1, P3 L29 – 35)**:

"The experiment was carried out at the Seida study site which is located in sub-Arctic northwestern Russia (67º03'N, 62º57'E) in the discontinuous permafrost zone. Some common geographical features occurring in discontinuous and sporadic permafrost zone are the so-called palsas and peat plateaus (Seppälä, 2011, Sannel and Kuhry, 2011, Borge et al., 2017). They are formed by permafrost aggradation, which lifts the peat surface, leading to drier conditions than the surrounding unfrozen peatland surface (Seppälä, 2003). As a result of wind abrasion, parts of the palsas and peat plateaus lack vegetation (Seppälä, 2003). These unvegetated bare peat surfaces (BP) are located on the peat plateau, are round in shape with an average diameter of 20 m and have only sporadic bryophytes and lichens."

Specific comments:

P2, L1-4: Which processes do you mean? Could you be here more specific and start with the explanation of the processes you mean?

A: We believe that the reviewer refers to the processes contributing to increased CO2 and CH4 emissions under a changing climate, and have specified them now (decomposition processes). The sentence reads now: (P2 L1-4):

"The Arctic and sub-Arctic regions store more than 50% of the Earth's soil carbon (C) pool (1330 –1580 Pg) (Schuur et al., 2015). The possible increase in release of the greenhouse gases carbon dioxide (CO2) and methane (CH4) from these carbon stocks as a result of increased decomposition processes (aerobic and anaerobic) to the atmosphere under a changing climate has been intensively studied"

P2, L9-10: This sentence is hard to understand.

A: To make the sentence better understandable, we have now changed it so that it reads:

"Soils world-wide are important N_2O sources responsible for 60% of the global emissions (IPCC, 2013). Traditionally it has been suggested that N_2O emissions from Arctic soils are negligible because of the low concentrations of mineral N in soils underlain by permafrost (Mae et al., 2007; Takakai et al., 2008; Siciliano et al., 2009; Goldber et al., 2010)."

P5 L35-P6 L2: What are the results of the comparison between the two methods? In Fig. 1 I only see the results of the current approach. I would expect that inserting the collar only 1h before measurement would disturb the system and affect the outcome of the measurement. Furthermore, a one point measurement introduces uncertainty in comparison to multi-point measurements and it would be good to comment on this uncertainty.

A: The comparison between small chamber, non-permanent, one-point sampling (labeled plots) and the large chambers on permanent plots with multiple samplings points (non-labeled plots) is shown graphically in figure 1 in the MS. We are sorry that it was not clear and have changed the caption and description of figure 1. N2O fluxes from labeled plots (small, non-permanent chambers) were higher compared to N2O fluxes from non-labelled plots (large, permanent chambers) but never higher that the highest N2O fluxes measured on previous years.

In addition, for clarification here, we have calculated N2O fluxes from three random large chambers on permanent plots by taking only the last sampling point (60 min) and compared those to N2O fluxes calculated by linear integration over all sampling points (5, 20, 45 and 60 min) (Table A). We observed that the difference between the two approaches was between 1 to 5 %. Even with ± 5% overestimation, N2O fluxes from labeled plots (small, non-permanent chambers) are in the range of N2O fluxes from non-labeled plots from previous years.

Table A. N2O fluxes from larger chambers on non-labeled plots calculated by linear integration over all sampling points and only the last sampling point.

		linear interpolation	end-time point	% difference
Chamber 1	N2O Flux (µg N2O -N m-2 h-1)	19.0	19.9	5
Chamber 2	N2O Flux (µg N2O -N m-2 h-1)	10.6	10.7	0
Chamber 3	N2O Flux (µg N2O -N m-2 h-1)	58.9	58.6	1

Usually pushing the chamber into the soil disturbs mainly the root system, but there were no plants and roots in BP surfaces roots where N2O fluxes were evident. There are several papers presenting N2O fluxes from non-permanent chambers, by pushing the chamber into the soil (e.g Weitz et la., 1999; Maljanen et al., 2007; Hyvönen et al., 2009). We thus believe that the disturbance was minimal and flux data are reliable.

P6 L16: Do you mean Herrman et al., 2005?

A: Yes, we have corrected in the text. Thank you for noticing it!

P7 L16: If I get this right the 15N in the soil was only considered until a depth of 6 cm, since this is the sampling depth of the soil cores. It was not described how deep the 15N tracer solution was injected into the soil, but I can imagine that the label diffuses relatively quickly below this depth. Would N2O production from the 15N label below the sampled soil depth introduce a bias into their mass balance calculations?

A: yes, the reviewer was right, the label was injected up to 6 cm but soils were sample 0 -10 cm. Some losses due to lateral and vertical movement of N forms, particularly $^{15}NO_3^-$, including downward leaching, were expected. Since immediately after labelling (~1h) and by end of the experiment (24 days), most of 15N label was still retained in the bulk peat soil (71-92% across VP and BP) we can assumed that the losses by leaching were minimum. We discuss and acknowledge the possibility for downward leaching, and production of 15N2O from labelled nutrients below the sampling layers, in the current MS, see **discussion section 4.3, P16 L 19 – 29:**

"The total recovery of applied 15N within 24 hours for both studied surface types was close to 100%. However, this % decreased during the course of the post-application sampling in both VP and BP surfaces, which might be a consequence of lateral and vertical movement of N forms, particularly 15NO3-, in the soils, including downward leaching (Clough et al., 2001), and possibly also of increasing importance of NO fluxes and N2 production which we did not measure here. Downward leaching is a possible explanation for the observed decrease in total recovery of the label, since the total recovery of 15N was higher in VP than in BP surfaces during the 24 days of experiment (~79% vs. ~62%, respectively) because of plant N uptake and microbial immobilization. It is also possible that the 15N might have increasingly accumulated as 15N-N2O and 15N-N2 in soil solution or in gas filled pores in BP. Soil gas concentrations of N2O can reach high concentrations (up to 4500 ppb) particularly in BP where N2O is mainly produced in these permafrost peatlands (Gil et al., 2017). However, since still more than 60% and 80% of 15N was recovered in VP and BP on average, respectively, we accounted for all the major sinks of NO3- and NH4+ in both soils throughout the 24 days of incubation."

P9 L13: Please explain how WFPS was calculated.

A: We have now included this explanation in the MS as follow **(Section 2.3.4, P9 L 5 – 10):**

"Soil water filled pore space was calculated using equation (11). For this, the soil moisture sensor data (in mV) was converted to volumetric water content (θv), after sensor calibration following the instruction of the manufacture. Bulk density (BD) measured in the field and the particle density (PD) estimated after soil organic matter content (SOM) determination by the loss on ignition method were used to determine the total porosity (TP) using equation (10).

$$TP = 1 - (BD / PD) \quad (10)$$

$$WFPS = \theta v / TP \quad (11)$$"

P9 L24: Figure 3

A: Figure 1 is correct, but we have added Figure 3c to this sentence.

P10 l3: 'no'

A: thanks, we have changed accordingly in the text.

P14 L8-10: This was yet said in the introduction.

A: We agree with the reviewer, but still think that it is important to reinforce this fact (that N2O emission from permafrost peatlands are a novel discovery) and that it is important to put the fluxes into the context of N2O emission from other soils. We would thus like to keep that sentence.

P14 L 13: I would admit in this paragraph that addition of label likely increased N2O fluxes. At least that is what the data show. I am sure the heterogeneity is high but the authors do not present these data.

A: The reviewer is right, but we already mention and discuss this in the manuscript (related to Fig. 1). We are sorry that it was not clear and have changed the caption and description of figure 1. N2O fluxes from labeled plots were higher compared to N2O fluxes from non-labelled plots but never higher that the highest N2O fluxes measured on previous years. Addition of label could have stimulated the fluxes to some extent, but as we argue this likely does not impact on the process contribution to the fluxes and on the N processes between BP and VP which were clearly different and the main focus of the MS remain.

P15 L14: Sx?

A: Sorry, this was a typo and we meant table S1. Table with N transformation rates expressed in unites of µg N per g dry weight has been added to supplementary material

(Table S1 and Table S2)

P16 L2: What do you mean by 'evolutionary advantage'?

A: Maybe this term is confusing, we have deleted it.

P17 L28: When was the 'exceptionally dry year'? 2010 is the year of the current study.

A: The 'exceptionally dry year' was 2011. We have corrected the text accordingly.

Figure 2: The y-axis label is misleading. It seems that not the total recovery is presented but the relative proportion of the different pools in the recovered 15N. It might be more informative to present the absolute 15N recovery in the different pools, which would than not always sum up to 100%. Please add error bars.

A: The absolute recovery is shown in figure S1 (total). We think it would be redundant to show then also absolute recovery of different pools (which is a combination of Fig. S1 and Fig. 2). The main point here was to compare the fate of 15N in plants vs. N2O in vegetated and bare peat. For that purpose, we believe that the relative recovery is more informative.

Error bars have been added to figure 2.

Figure 3: Could the authors comment on the large differences in 15NH4-N and 15NO3-N concentrations in the different plots. In particular the 15NH4-N concentrations steeply decrease during the first days, but the increase of 15NO3-N concentrations or 15-N2O-N fluxes seems much lower. Where is the label gone?

A: It is easier to follow the changes in the movement of the 15N label from the figure S4 (in supplement file with answer to the referee). The 15N at% excess values of NO3- and NH4+ behaved in general as expected from the pool dilution experiment. We recovered some of the label in the mineral N pools, N2O emissions and plants (for vegetated surfaces) but most of the 15N label was recovered in the bulk soil (up to 79%) during the entire experiment period (Figure 2 and Figure S1). This could be consequence of different processes including physical and chemisorption of the 15N added to the soil organic matter, (Mortland and Wolcott, 1965; Nõmmik and Vahtras,1982; Nieder et al., 2011) and microbial immobilization, particularly in the vegetated peat surfaces (VP), something previously observed from soils with low N availability in arctic and sub-arctic ecosystems (Nordin, Schmidt & Shaver, 2004; Sørensen et al., 2008, Marushchak et al., 2021). This biotic and/or abiotic process could contribute to remove the 15N added from the extractable N pool. It is reflected in the consumption rates we calculated. Some discussion on this issue was already in the previous version of the manuscript, but we have added a sentence to address it further (section 3.5 in discussion, page 16, L19 -36.

In addition, we observed generally higher enrichment of 15N2O than any of the source pools (e.g NO3-, NH4+). One possible explanation for this could be that the production of N2O occurred from NO2- rather that NO3- and the isotopic enrichment of N2O would be much more similar to that of NO2- than of NO3- (Mulvaney et al., 1997). However, the presence or accumulation of NO2- was never detected in the soils before or during the 15N tracer experiment (data not shown). This is expected because in soils, NO2- typically is rapidly consumed and therefore, we could not detect it in the soil extracts. Another explanation for the mismatch in 15N between sources and mixture is that there was a gap between N2O production in soil (reflecting the source pools at that time point) and the N2O measured in the headspace due to for example time diffusion and or N2O production at deeper soil layers.

Figure 4: Could you add error bars to the average values presented

A: Error bars have been added to figure 4.

References

Hyvönen, N.P., Huttunen, J.T., Shurpali, N.J., Tavi, N.M., Repo, M.E., Martikainen, P.J. : Fluxes of nitrous oxide and methane on an abandoned peat extraction site: Effect of reed canary grass cultivation, Bioresource Technology, Volume 100, Issue 20, Pages 4723-4730, ISSN 0960-8524, https://doi.org/10.1016/j.biortech.2009.04.043, 2009.

Maljanen, M., Martikkala, M., Koponen, H.T., Virkajärvi, P. and Martikainen, P.J: Fluxes of nitrous oxide and nitric oxide from experimental excreta patches in boreal agricultural soil, Soil Biology and Biochemistry, Volume 39, Issue 4, Pages 914-920, ISSN 0038-0717, https://doi.org/10.1016/j.soilbio.2006.11.001, 2007.

Weitz, A. M., Keller, M., Linder, E., and Crill, P. M., Spatial and temporal variability of nitrogen oxide and methane fluxes from a fertilized tree plantation in Costa Rica, J. Geophys. Res., 104 (D23), 30097– 30107, doi:10.1029/1999JD900952, 1999.

Please also note the supplement to this comment:
https://bg.copernicus.org/preprints/bg-2021-228/bg-2021-228-AC1-supplement.pdf