

## ***Interactive comment on “Greenhouse gas emissions from fen soils used for forage production in northern Germany” by A. Poyda et al.***

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RC: How long the oven drying of soil was done to estimate the gravimetric water content? It usually takes 24 hours at 105 °C, but it is better to mention the duration.

AC: The soil samples were dried at 105 °C for roughly 24 hours. At the beginning of our study we tested if the sample weight would be further reduced during a second day of drying but we found that this was not the case.

RC: How did you calculate organic C content from the elemental analyzer? The combustion method used in the elemental analyzer usually gives an estimate of total C. You can do acid digestion prior to the combustion step in order to eliminate the inorganic C

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or offline calculation can be done for organic C. If the assumption is that the peatland is mostly organic soil, then the estimates of loss on ignition are warranted. Please clarify this issue. Also, mention the time taken for oven drying of the samples at 40 °C.

AC: As the peat soil in our study was free of inorganic C, the total C determined by the combustion method equals the organic C content of the soil sample. Oven drying at 40 °C was done for 2 – 4 days, depending on the moisture content of the samples.

RC: Is it normal to collect flux measurements between 9am to noon in these areas? When do you expect to see the peak in the diel pattern of CO<sub>2</sub>? Peak in the CO<sub>2</sub> flux often lags by few hours with respect to the peak in the soil temperature in temperate and boreal forests (see Gaumont-Guay et al., 2006 and Savage et al., 2009) due to a delayed response to the aboveground processes. The time lag in the agricultural system may be much less, if any. Also, to capture the daily mean value, you should take representative readings before and after the flux value peaked. An explanation on this may be of worth to support the sampling time used in this study for a representative mean daily flux.

AC: During the mentioned period of the day we expected the mean daily fluxes of N<sub>2</sub>O and CH<sub>4</sub> as it was described in other studies. For example, van der Weerden et al. (2013) conducted near-continuous measurements of N<sub>2</sub>O fluxes with automatic chambers and stated that mean daily fluxes occurred between 10:00 and 12:00 h and 18:00 and 21:00 h. We expected the peak GPP at the same time when PAR is at its maximum, which is generally between 12:00 and 13:00 h. Maximum daily RECO is usually measured few hours later due to the time lack of temperature maxima. As RECO is the sum of autotrophic and heterotrophic respiration, it depends on both, air and soil temperature. We did not expect a time lag between the maxima of these temperatures and the respiration. However, our CO<sub>2</sub> measurement campaigns were conducted from sunrise until the afternoon (approximately 4 h after PAR peaked) to cover the daily range of radiation and temperature and thus assimilation and respiration. We usually stopped our daily campaigns when we saw no increase in the RECO flux anymore.

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RC: What were your criteria for the acceptance of the CO<sub>2</sub> flux data? Did you follow the same approach like CH<sub>4</sub> and N<sub>2</sub>O flux data for the coefficient of determination?

AC: Quality criteria for CO<sub>2</sub> measurements were changes of chamber temperature of more than 1.5 °C and a standard deviation of PAR more than 10 % of average PAR for NEE measurements (transparent chamber). If these thresholds were exceeded during a measurement, the CO<sub>2</sub> flux was not used for further analyses. Additionally, each single CO<sub>2</sub> measurement was carefully checked and the flux was only calculated for that part of the measurement with a linear concentration change over time. The R<sup>2</sup> was not used as a quality criteria for the CO<sub>2</sub> fluxes as there were up to 60 data points (CO<sub>2</sub> concentrations) during one measurement and especially for measurements in winter times when fluxes were very low, a R<sup>2</sup> of  $\geq 0.9$  could hardly be fulfilled.

RC: What do you mean by "own examination"? Please explain briefly.

AC: I measured the PAR inside and outside the chamber at different light intensities and found that PAR inside the chamber was on average 8 % lower than outside the chamber.

RC: The equation for NEE is little confusing for the general reader. I see that you have mentioned the sign convention of individual flux components in L 19-21. But, it is better to write  $NEE = GPP - R_{ECO}$  and rephrase in the previous line that NEE was calculated as the difference (not sum) between GPP and R<sub>ECO</sub>. It is better to maintain the conventional sign of flux: positive flux as a source to the atmosphere (which R<sub>ECO</sub> is) and negative flux as a sink to the ecosystem (which GPP is) and the net balance of these two ultimately determine whether the ecosystem serves as a source (positive NEE) or a sink (negative NEE) for CO<sub>2</sub>.

AC: We applied the conventional sign convention just like you mentioned it. As GPP is negative, RECO has to be added to get the NEE. In recent studies observing the NEE of peatland ecosystems, the equation is written as a sum of the two processes and we wanted to be consistent at this point.

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RC: It will be worth exploring if the Kolmogorov-Smirnov Goodness-of-Fit Test for normality of data corroborates with the graphical residual analysis, especially for CH<sub>4</sub> and N<sub>2</sub>O, which are often characterized by hot-spots or hot moments.

AC: As we apply the graphical residual analysis as a standard procedure to all data sets as a decision support tool for the statistical analyses, it was done in the same way with the CH<sub>4</sub> and N<sub>2</sub>O flux data. Additional tests could be conducted as well but have not been designated due to consistency issues.

RC: In general, fluxes of N<sub>2</sub>O (and CO<sub>2</sub>) have been reported in literature after thawing of frozen soil due to the release of stored labile C and nutrients. The buildup of these labile substrates during freezing event usually comprised of dead microorganisms, dead fine roots, and C released from the breakdown of aggregates. Also, the response often depends on the intensity and duration of freezing as well as the soil properties. So, please explain clearly your point on the pulse of N<sub>2</sub>O during the freezing event, in addition to the thawing event afterward? Also, it has been reported that the successive pulse of N<sub>2</sub>O has been reduced with increased frequency of freeze-thaw cycle, which may explain the lower winter fluxes in the second year. See Xu et al. (2016) and the articles cited in the reference list for more details.

AC: Our results show that the mentioned N<sub>2</sub>O pulse is occurring during freezing events but N<sub>2</sub>O fluxes decline rapidly after freezing. This was more pronounced when no snow cover was present. These two points suggest that the predominating process that enhanced winter N<sub>2</sub>O fluxes was the freezing rather than the thawing of the peat soils. As the N<sub>2</sub>O flux did not increase directly after air temperatures became negative but a few days afterwards, underlines this conclusion as the wet peat soils have a high heat capacity, which means that the time lag between changes in air and soil temperatures is greater. This could explain the missing N<sub>2</sub>O pulse in the second winter as the frost could not penetrate the peat sufficiently to generate an enhanced release of C and N. However, due to the very high amounts of C stored in the peat soils and the densely rooted top soils in combination with high nutrient loads on the agricultural sites, the

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investigated peatlands have a high potential for N<sub>2</sub>O emissions in general and also for freezing induced N<sub>2</sub>O pulses.

RC: Please note the prerequisite for the release of N<sub>2</sub>O in the incomplete denitrification process (where, complete denitrification: NO<sub>3</sub><sup>-</sup> → NO<sub>2</sub><sup>-</sup> → NO → N<sub>2</sub>O → N<sub>2</sub>) is the onset of anoxic (or reduced) condition. Do you have evidence that the N<sub>2</sub>O emission was greatest from nitrate-rich soils (or soil microsite) with relatively greater water filled pore space?

AC: N<sub>2</sub>O emissions were not significantly related to water filled pore space. The ground water level (GWL) was the dominating factor for annual N<sub>2</sub>O emissions at our sites with increasing emissions at lower mean annual GWL. However, it has to be noted that with lower mean annual GWL also the fluctuations of the GWL are increasing, which means that there is a thicker active peat layer where N can be mineralized and nitrified. The produced nitrate that is dislocated to saturated pores will then be denitrified with potential losses of N<sub>2</sub>O. As a consequence, daily N<sub>2</sub>O fluxes of peat soils can hardly be related to the GWL or water filled pore space at a certain day, at least in field studies. We only found a significant relation between the daily fluxes and the amount of nitrate in the topsoil as the occurrence of high amounts of nitrate that exceed plant uptake can lead to incomplete denitrification and thus N<sub>2</sub>O release.

RC: R<sup>2</sup> adj for the model is 0.05. Does this mean ground water level and soil temperature at 5 cm depth could explain only 5% of the variation in the flux of CH<sub>4</sub>-C? Please clarify the relevance of the model and what is the interpretation of this figure.

AC: The figure is not an illustration of the model as we used a multiple linear regression model with log-transformed daily CH<sub>4</sub> fluxes where the site was used as a covariate, additionally to the groundwater level and soil temperature at 5 cm depth. The figure was made to illustrate the extremely high variability of CH<sub>4</sub> fluxes between the sites but also within single sites and to show that highest emissions occurred when both groundwater level and soil temperature were high. However, this was highly depending

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on the location as the deep-drained sites showed negligible fluxes irrespective of GWL and soil temperature. This was underlined by the model as all three covariates had a highly significant effect on CH<sub>4</sub> fluxes.

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