Biogeosciences Discuss., 6, C2593–C2601, 2009
www.biogeosciences-discuss.net/6/C2593/2009/

Biogeosciences Discussions

Interactive comment on "Effect of peat quality on microbial greenhouse gas formation in an acidic fen" *by* M. Reiche et al.

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Received and published: 20 October 2009

Comment to M. Reiche, G. Gleixner, K. Küsel: Effects of peat quality on microbial greenhouse gas formation in an acidic fen. Biogeosciences discuss., 6, 8775-8803, 2009

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Reiche et al. (2009) present a laboratory study of anaerobic CO2 and CH4 formation

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rates by incubations from four locations along a peat degradation (drainage) gradient from an acidic fen. The observed average anaerobic CO2 and CH4 formation rates over the incubation period were interpreted by a peat quality index derived from the thermo-degradability of the peat substrate and by chemical properties of the peat samples. The authors confirm current knowledge that labile organic matter is a prerequisite for anaerobic CO2 and CH4 formation (e.g. Glatzel et al. 2004). The authors claim that the new peat quality index could help estimate peatland response to changing management and environmental condition.

Anaerobic CO2 and CH4 formation is driven by the activity of anaerobic microorganisms, which itself depends on temperature (kept constant by Reiche et al. 2009), substrate quantity and substrate quality. Under anaerobic conditions the availability of fresh organic substrate, e.g. in the form of root exsudates, roots and residues, is particularly important. Methanogenesis is strongly related to the availability of substrates such as acetate, organic acids, CO2 and H2, depending on methanogenic pathway, and as such, activity of microbial decomposition of (fresh) organic matter. CH4 originates more from fresh organic material than CO2 (Chanton et al. 1995). Microbial methanogenic communities rapidly change and adapt to substrate availability (Chauhan et al. 2004). While anaerobic CO2 formation indicates the instantenous availability of organic substrates from peat and fresh organic matter over a wide range of substances and energetic quality, anaerobic CH4 formation indicates the instantenous availability of fresh and energy-rich substrates. Living vegetation was excluded in the experiment by Reiche et al. (2009) but roots and litter were apparently not separated.

We hypothesize that the variation in anaerobic CO2 and CH4 formation in the experiment by Reiche et al. (2009) can be explained directly by (1) rooting intensity and availability of fresh decomposing plant material (cf. Glatzel et al. 2004) without information on peat quality and (2) delayed anaerobic CH4 formation in the topsoil samples due to aerobic conditions in the weeks prior to sampling. Second we argue that the new peat quality index could be simplified to the fraction of thermally labile organic mat-

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ter, or even more simply, amount of fresh plant litter. We also argue that the data set on which the study is based is not robust, diverse and large enough for the statistical analyses performed and not suitable to substantiate the new peat quality index. Finally we warn that laboratory incubations are not suitable for assessing the actual relevance of peatlands as source or sink of CO2 and CH4.

Data shortage challenges the robustness of analyses

It is well known that CO2 and CH4 formation rates are not constant in the incubations so that the results strongly depend on incubation time and the onset and dynamics of CO2 and CH4 formation rates. Typically, CO2 and CH4 formation rates start low, increase and peak and then decline when substrate becomes limiting (e.g. Chauhan et al. 2004, Glatzel et al. 2004). Therefore the dynamics of CO2 and CH4 formation rates in incubations need to be carefully considered in the interpretation of results. Details on the kinetics of the gas formation are also needed for the modelling. We encourage Reiche et al. to show and discuss not only the average gas formation rates but also the dynamics of the formation rates and how and to what extent the duration of the incubation affects the quantitative and qualitative results. Were the average daily CH4 formation rates given in Table 3 of Reiche et al. (2009) calculated as average of the entire incubation period of 31 days or only for the period after onset of methanogenesis? Moreover, it should be critically assessed, whether and to what extent the incubation conditions (accumulation of CO2 and CH4) could have influenced the gas formation.

The cluster analysis (Fig. 2) is not sensitive to CH4 since the clustering is dominated by CO2 formation rates. It can therefore not be used to interprete differences in CH4 formation.

The subset of samples selected for Py-GC/MS analyses (Fig. 4) does not represent the full range of CH4 formation and misses the intermediate range of CO2 formation (Tab. 3). The correlation between CO2 and lignin is driven by two samples with high

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lignin and high CO2 formation: D2 I and M I (Tab. 3, Fig. 4). However, it has to be noted that the data for correlation of carbohydrates and lignin with gas formation rates cover the full span of CO2 formation, but only the low range of CH4 formation so that the statistical relationship does not cover a representative sample for CH4 (span of 0 – 0.38 instead of 0 – 2.11). A critical reanalysis of significance, functional relations and representativeness of the subset of samples used for correlation analysis is needed. We encourage Reiche et al. to enlarge the spectrum and number of samples for Py-GC/MS to ensure robustness and representativeness of the statistical results.

Alternative peat quality index: fraction of thermally labile organic matter or, more simply, fresh plant litter?

The peat quality index proposed by Reiche et al. (2009) identifies a threshold to distinguish between inactive and active peat. It uses the ratio between two organic matter fractions calculated from three temperature ranges during thermogravimetry analyses. The peat quality index leaves 30 to 50% of "other" organic matter (pyOMother in Fig. 2, Reiche et al. 2009) unaccounted. The peat quality index shows a strong linear correlation with thermally labile pyrolysable organic matter (pyOM; Reiche et al. 2009, Fig. 3c)

Plotting anaerobic CO2 and CH4 formation against labile pyOM (data from Reiche et al. 2009, Tab. 3 and Fig. 2) indicates that there is a threshold of 35-39% labile pyrolysable organic matter (Reiche et al. 2009, p. 8790, line 19) above which high CO2 and CH4 formation can occur: (CO2 formation > 1.5 μmol/ g DM and CH4 formation > 0.1 μmol / g DM). Obviously there is a threshold by energy or substrate limitation rather than a clear functional relationship between anaerobic CO2 and CH4 formation and labile pyOM. In our view, labile pyOM is an ecologically valuable indicator of potential anaerobic microbial activity in peat profiles. We propose to directly use labile pyOM as peat quality indicator rather than a compound index with comparable indicative properties but sensitivity to the fraction of unaccounted organic matter.

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Given the variability in carbon content of the peat samples it could be more useful to relate the formation rates to the amount of carbon rather than dry matter. Previous studies have related anaerobic CO2 and CH4 formation to the Von Post index of peat decomposition (Glatzel et al. 2004). It would be interesting to see whether and why the proposed peat quality index is a progress beyond state-of-the-art.

Labile organic matter in the form of roots and litter needs to be quantified Reiche et al. (2009) argue that the topsoil samples at locations D2, sD1 and M1 could have contained fresh plant litter (p. 8786, lines 11-17). This is an important statement for the functional understanding of controls of anaerobic CO2 and CH4 formation. Unfortunately, the authors did not quantify the content of roots and fresh plant litter as potential substrate in the peat samples. However, this is an important information for interpreting the results of the study correctly.

In agreement with the authors we hypothesize that it is in particular the presence or absence of fresh organic matter such as fresh roots or root derived substances (rhizodeposition) that determines the anaerobic CO2 and CH4 formation. The studied locations and the peat layers might vary with regard to fresh plant litter and rooting intensities as hypothesized in Tab. 1. If our hypothesis is true then presence and amount of fresh plant material could serve as good indicator for the anaerobic CO2 and CH4 formation potential of peat samples.

Seasonal water regime may determine the onset and dynamics of methanogenesis during anaerobic incubation The onset of methanogenesis after a period of aerobiosis depends on methanogenic pathway and alternative redox reactions in soil. Intermittent drainage during the growing season of rice has been proposed as mitigation measure for CH4 emissions from rice paddies since a period of e.g. one to two weeks of aeration is enough to effectively reduce CH4 emissions for several weeks (Yagi et al. 1997). Anaerobic CH4 formation in the incubations by Reiche et al. (2009) in the samples from 0-10 cm depth (I) was low compared to the CO2 formation rate and to CH4 formation in deeper samples (II, III), and onset of methanogenesis in topsoil samples was de-

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layed. This could be explained by incomplete anaerobiosis at the sample date (Tab. 1) and could thus be an artefact of unequal starting conditions for the incubations. The resulting gas formation over a – necessarily somewhat arbitrary – incubation time is therefore very sensitive to the starting conditions of the incubation and the lag time for methanogenesis. We hypothesize that the scatter in CH4 formation in samples with high peat quality results from aerobic conditions in the topsoil prior to sampling so that the potential anaerobic CH4 formation rate could not be reached during the incubation period. Precise data on the behaviour of the groundwater-level in the selected locations in the weeks to months prior to sampling is needed to test our hypothesis. If our hypotheses regarding plant derived carbon substrates and conditions of anaerobiosis prior to sampling are true we could explain the incubation results without any chemical analyses of peat quality.

Vegetation – site interaction matters for greenhouse gas formation and emissions

Laboratory incubations show the instantenous gas formation potential under controlled conditions but do not allow to extrapolate to the response of peat ecosystems to changing environmental conditions. For example, substrate limitation indicated by the peat quality index can easily be overcome by interaction with the vegetation or mineralization during water table fluctuations. Hence vegetation dynamics and the fluctuations between aerobiosis and anaerobiosis in the soil profile will determine the greenhouse gas formation potential in peatlands under field conditions. Therefore, instantaneous anaerobic gas formation potential related to peat quality is not suited for estimating greenhouse gas formation under field conditions (cf. Glatzel et al. 2004). Laboratory scale gas formation potential cannot be taken as proxy or explanatory variable for the greenhouse gas exchange between ecosystems and the atmosphere under field conditions. Quite generally the current gas formation of peat ecosystems will ultimately depend on changes in vegetation productivity, amount and quantity of litter and rhizodeposition, oxygen transfer into the soil and their distribution through the soil profile (Lai 2009), as well as changes in the water regime. As a result, most of the CO2 formation

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activity happens in the active, aerobic peat layer and even a shallow aerobic layer of few cm is enough to oxidize most of the CH4 formed in deeper layers. The actual gas flux rates are directly influenced by the plants in form of photosynthesis, respiration, and internal methane transfer (Lai 2009). In other words: One must clearly distinguish between the CO2 and CH4 exchange between peat ecosystems and the atmosphere, which is relevant in the context of climate change and peatland management, and the CO2 and CH4 formation potential under specific anaerobic laboratory conditions. The peat quality index proposed by Reiche et al. (2009) cannot help estimate peatland response to changing management and environmental condition because (1) their experiment focused on gas formation under laboratory conditions and not on ecosystem level gas exchange, (2) their experiment did not test the key controls under field conditions (vegetation and water dynamics), and (3) the experiment did not study the effects of changing environmental conditions but kept incubation conditions constant.

Acknowledgement

The authors thank M. Reiche and K. Küsel for providing additional data about water table, iron and sulfate contents of the studied peat site.

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Interactive comment on Biogeosciences Discuss., 6, 8775, 2009.

Site	Depth [cm]	Plant litter and rooting intensity	Water saturation prior to sampling
C2 I	0 - 10	high	unsaturated
C2 II	10 - 20	very low	> 4 weeks
C2 III	20 - 30	very low	> 4 weeks
C2 IV	30 - 40	very low	> 4 weeks
D2 I	0 - 10	very high	unsaturated
D2 II	10 - 20	very low	> 4 weeks
D2 III	20 - 30	very low	> 4 weeks
D2 IV	30 - 40	very low	> 4 weeks
sD1 I	0 - 10	very high	< 4 weeks
sD1 II	10 - 20	low	> 4 weeks
sD1 III	20 - 30	very low	> 4 weeks
sD1 IV	30 - 40	very low	> 4 weeks
M I	0 - 10	very high	unsaturated
M II	10 - 20	high	> 4 weeks
M III	20 - 30	low	> 4 weeks
M IV	30 - 40	low	> 4 weeks

Fig. 1. Tab. 1: Hypothesized content of fresh plant litter, rooting intensity and seasonal water regime of the peat samples in studied in Reiche et al. (2009)

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