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Methane emission from peat-muck soil in the Biebrza River valley in relation to ground water level and fertilisation

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Abstract

The paper presents results of a two-year study on methane emission carried out in lysimetric station situated on Kuwasy peatland in the Biebrza River valley. The aim of this study was to estimate the amount of methane emission from peat-muck soil in relation to ground water level and fertilisation. Methane emission was determined with the chamber method using photo-acoustic probe. Methane emission significantly depended on the ground water level. The largest CH_4 emission was found at full saturation of soil with water. With the decrease of ground water table the emission of methane decreased. Mineral fertilisation increased CH_4 emission. At ground water table depth of 50 cm, CH_4 emission from fertilised variant was by 42.3% bigger than from non-fertilised variant. Peat-muck soils overgrown by meadows in the Biebrza River valley were found to be an important source of methane emission. In the vegetation period at ground water table depths of 0, 25, 50 and 75 cm methane emission was 502, 361, 198, 141 $kg \cdot ha^{-1} \cdot (210\ d)^{-1}$, respectively.

Key words: *CH_4, fertilisation, ground water level, methane, peat-muck soil*

INTRODUCTION

After water vapour and carbon dioxide, methane is the third gas producing the greenhouse effect [DERWENT *et al*. 2009]. One of the natural resources of this gas is peat ecosystems, which cover c. 3% of total terrestrial area [KROON *et al*. 2010]. Methane emission from peat ecosystems depends on their trophic status and amounts from several dozen to almost 360 $kg \cdot ha^{-1} \cdot y^{-1}$ [JUUTINEN *et al*. 2003; SALM *et al*. 2011; VON ARNOLD *et al*. 2005a; 2005b]. Despite relatively low emission of this gas compared with carbon dioxide, heat potential of methane is 21 times higher than that of CO_2. Therefore, methane substantially contributes to the total emission of greenhouse gases expressed in the equivalent of CO_2. In Poland, in the year 2008 the share of methane in the country total emission of greenhouse gases was 9.1% (equivalent to 37 975 Gg CO_2) of the total [KASHUE-KOBiZE 2010]. Methane emission from peat ecosystems shows very high temporal, spatial and seasonal variability [MOORE, DALVA 1997]. For this reason, this emission is not considered in the inventory of methane sources.

Peatlands in Poland occupy 1 211 thousand ha, 15% of which are forested peatlands and 85% – non-forest ones. It has been estimated that 19% of non-forest peatlands are those with active bogging process and 81% – peatlands used in agriculture [CZAPLAK, DEMBEK 2000]. Transformation of bog habitats into agricultural lands is most often associated with a decline of ground water table and, due to aeration of the surface layer of soil profile, with limitation of methanogenesis [LLOYD *et al*. 1998]. In studies on reclaimed peatlands many researchers showed that agriculturally used peat-muck soils absorbed small amounts of CH_4 or emitted it in amounts of less than 1 kg $CH_4 \cdot ha^{-1} \cdot y^{-1}$ [DANEVČIČ *et al.* 2010; LANGEVELD *et al.* 1997; MALJANEN *et al.* 2004; VAN DEN POL-VAN DASSELAAR *et al.* 1999].

The group of agriculturally managed peatlands is dominated by soils in the first stage of mucking which constitute 46% of non-forest peatlands [CZAPLAK, DEMBEK 2000]. A large area of soils with weakly advanced mineralization indicates that relatively high ground water level is maintained in these soils. Therefore, one may expect that not only the bog soils with active peat-forming process but also post-bog soils may be a source of CH_4 emission. Studying the effect of ground water level and fertilisation on the amount of methane emission from peat-muck soil would allow for estimating the amount of emission of this gas in the country scale.

The aim of this paper was to estimate the amount of methane emission from peat-muck soil in the Biebrza River valley in relation to ground water depth and fertilisation.

STUDY OBJECTS AND METHODS

The study on methane emission from peat-muck soil was carried out in the years 2010–2011 in lysimetric station situated in Kuwasy peatland in the Biebrza River village. Lysimeters were filled with soil taken from peatland with moderately deep peat-muck soil MtIIcb. Basic physical properties of this soil are given in Table 1.

Table 1. Physical and chemical properties of peat-muck soil

Layer cm	Organic matter % dry wt.	Bulk density $Mg \cdot m^{-3}$	Porosity % vol.	Total nitrogen % dry wt.
0–10	80.3	0.252	83.0	4.28
10–20	83.7	0.243	83.6	4.17
20–40	87.5	0.167	88.7	2.97
40–60	86.3	0.178	88.0	n. d.
60–80	80.4	0.195	86.8	n. d.

Lysimeters of an area of 0.16 m^2 and height of 1.3 m were filled with soil of undisturbed structure Piesometers of a diameter of 3.5 cm were installed in this soil to maintain constant ground water level. Five study variants of different ground water level and the intensity of use were set up. In four variants, ground water table was kept at a depth of 0, 25, 50 and 75 cm. Fertilisation with NPK and mowing was applied in these variants. In variant 5, ground water table was maintained at 50 cm, soil was not fertilised but the yield was mown. In total, the experiment was performed in 15 lysimeters (5 variants × 3 repetitions). Soil in lysimeters was overgrown by grass. Mineral fertilisation with nitrogen (70 $kg \cdot ha^{-1}$) and potassium (110 $kg \cdot ha^{-1}$) was applied in two equal doses: in spring and after the first cut while phosphorus (46 $kg \cdot ha^{-1}$) – in spring before the onset of vegetation.

The emission of CH_4 was determined with the chamber method using photo-acoustic gauge of a sensitivity of 1 ppb. Measurements were performed once a month from April till October at different insolation. Plexiglass chamber 45 × 45 × 35 cm equipped with a fan was used for measurements. The chamber was placed in a square frame whose bottom part had a 10 cm long steel cylinder pressed into soil. To seal the dome, frames were filled with water. Measurement of CH_4 emission in one lysimeter lasted c. 12 minutes. Due to parallel measurements of CO_2 streams, the measurements of methane emission were carried out for 4–5 minutes at sun light and for the next 7–8 minutes in the dark. Darkness was obtained by shielding the chamber with a cover impervious to light. Methane concentration in the chamber was recorded every minute. The increment of CH_4 concentrations in the chamber often occurred abruptly due to emission of this gas in a form of bubbles [BECKMANN *et al.* 2004; BLODAU *et al.* 2004]. To calculate the increment of CH_4 concentration, the values in the last minute of measurement were regressed on the values in the first minute (Fig. 1). Changes in CO_2 concentration in ppm were recalculated for $mg \cdot m^{-2} \cdot h^{-1}$ according to the equation [MOSIER, MACK 1980]:

$$E = \rho\, V/A\ \Delta C/\Delta t\ 273/(T + 273) \qquad (1)$$

where:
E – emission, $mg \cdot m^{-2} \cdot h^{-1}$;
ρ – gas density, $mg \cdot m^{-3}$;
V – volume of the chamber, m^3;
A – surface area of the chamber, m^2;
$\Delta C/\Delta t$ – mean rate of changes in gas concentration, $ppmv \cdot h^{-1}$;
T – temperature inside the chamber, °C.

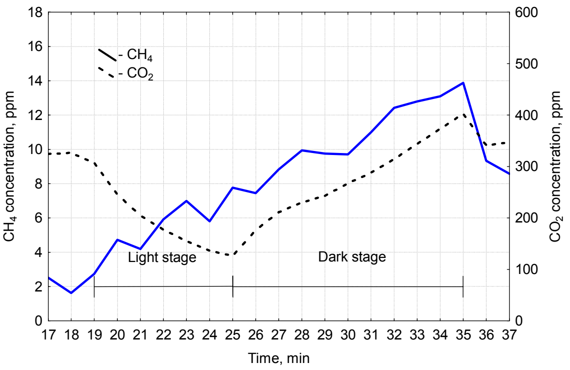

Fig. 1. Changes in CH_4 concentration in the chamber at the ground water level of 0 cm

Air temperature under the dome, soil temperature and moisture were recorded during measurements with the TDR meter.

RESULTS

Methane emission from peat-muck soil depended on the depth of ground water level. The largest emission of CH_4 (9.7 mg·m^{-2}·h^{-1} on average) was found at full saturation of soil profile with water. At declined ground water table in soil profile, CH_4 emission was markedly smaller. At ground water table depths of 25, 50 and 75 cm mean CH_4 emission was 7.0, 3.7 and 2.6 mg·m^{-2}·h^{-1}, respectively, being by 27.7, 61.9 and 72.3% smaller than that at ground water depth of 0 cm (Tab. 2). The regression of CH_4 emission on ground water table depth was statistically significant (Fig. 2).

Table 2. Methane emission from peat-muck soil in relation to ground water level and fertilisation, mg·m^{-2}·h^{-1}

Year	Ground water level, cm					Mean
	0, NPK	25, NPK	50, NPK	75, NPK	50, without NPK	
2010	8.6±2.8	5.5±0.7	3.8±3.8	3.2±3.6	2.7±1.0	4.8±2.4
2011	10.7±2.2	8.5±6.8	3.6±0.4	2.1±2.8	2.6±0.7	5.5±4.2
Mean	9.7±2.0	7.0±3.1	3.7±0.2	2.6±0.5	2.6±0.2	5.1±3.2

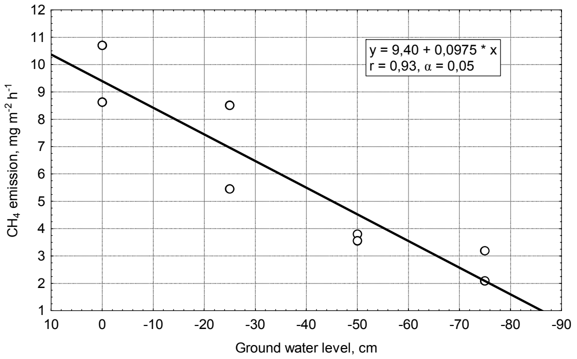

Fig. 2. The relationship between methane emission and ground water level

There was a clear effect of mineral fertilisation on CH_4 emission. At ground water depth of 50 cm, the mean emission in the years 2010–2011 was 3.7 mg·m^{-2}·h^{-1} in the fertilised variant being higher by 42.3% than that in non-fertilised variant (2.6 mg·m^{-2}·h^{-1}, Tab. 2). Application of fertilisers results in the bigger production of biomass and hence, an increased input to soil of organic matter which is the source for methane production [VAN DEN POL-VAN DASSELAAR, OENEMA 1999]. The deficit of nutrients, particularly of nitrogen, apart from lower biomass production, is also followed by the limited growth of methanogenic bacteria and, therefore, by smaller amounts of produced methane [MAGREL 2004].

Methane emission in particular months of the growing season 2010, irrespective of moisture and ferilisation variant, was markedly differentiated. The highest CH_4 emissions were found in July (11.62 mg·m^{-2}·h^{-1}) and the smallest – in October and April (0.9 and 2.0 mg·m^{-2}·h^{-1}, respectively, Fig. 3). Since April till June 2010, mean CH_4 emission did not exceed 4.0 mg·m^{-2}·h^{-1} while in July it was 6 times larger than in April and c. 3 times larger than in May and June. From August till October the emission of CH_4 systematically decrease which was a result of decreased rate of organic matter input to soil and of decreasing temperature. In the year 2011, CH_4 emission in subsequent years of the vegetation season was more uniform than in 2010 and ranged from 1.3 mg·m^{-2}·h^{-1} in October to 8.2 mg·m^{-2}·h^{-1} in June. The emission increased from April to June, remained similar in July and August and markedly decreased in September and October (Fig. 3).

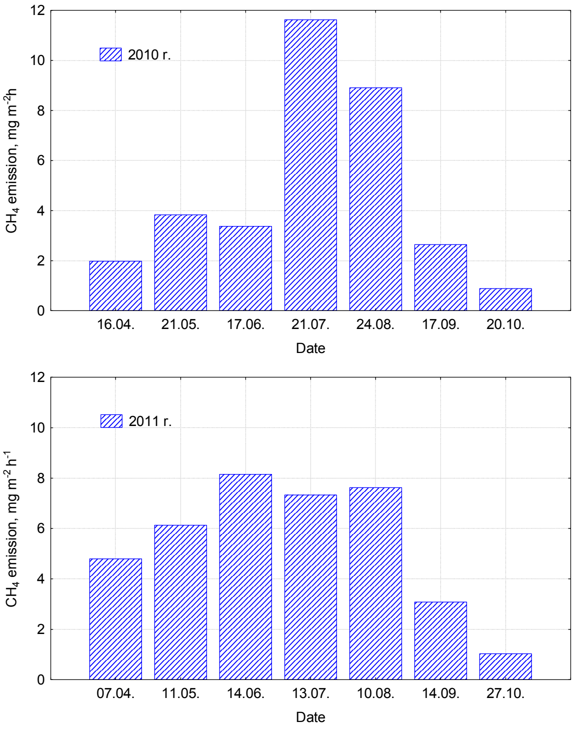

Fig. 3. Methane emission in particular months; mean values from all treatments

Differentiation in the CH_4 emission between years in relation to water conditions was well seen in the graphs of cumulated emission (Fig. 4). In the year 2010, methane emission was similar from April till June regardless of soil moisture. From June till August, particularly at ground water depth kept at 0 cm, it rapidly increased and then stabilised in the next two months. This indicates that methane production was limited directly after changes in the air and water conditions. Such an effect was probably associated with the presence of large amounts of oxidised mineral components (Fe_2O_3, NO_3^-, SO_4^{-2}) in soil which hampered the process of methanogenesis [LANGEVELD *et al.* 1997]. Their reduction and subsequent deficit of electron acceptors probably ended up with

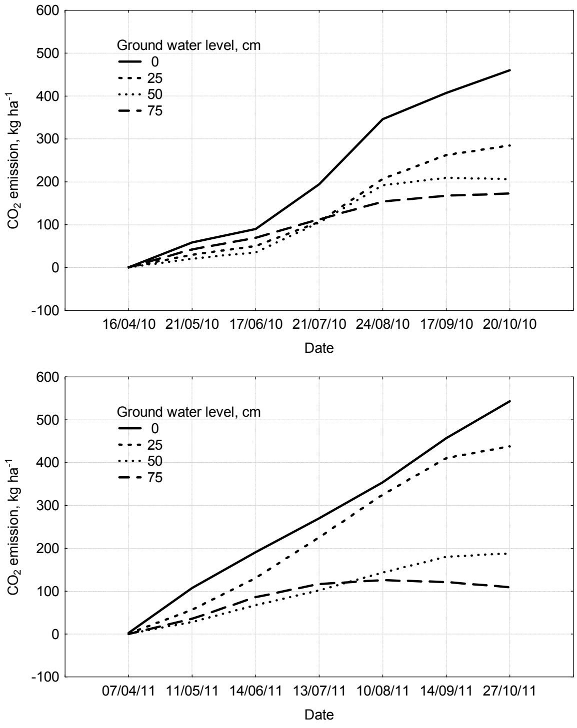

Fig. 4. Cumulated CH_4 emission at the station in Biebrza

plant and microorganism decay and a rapid increase in the emission of methane produced from dead biomass. Very similar course of cumulated CH_4 emission after the change in water conditions was demonstrated by SEGERS and KENGEN [1998] and by TURBIAK and MIATKOWSKI [2012].

In the year 2011, methane emission at a high ground water table of 0 and 25 cm was uniform throughout the growing season (Fig. 4). In variants with ground water table depth of 50 and 75 cm, very small increments or negative rates of CH_4 emission were noted at the end of the growing season which confirms the limitation of methanogenesis in aerated soils.

Mean methane emission was slightly higher in the second year. Its mean rate in 2011 was 5.5 $mg \cdot m^{-2} \cdot h^{-1}$ being by 14.6% higher than that in 2010 (Tab. 2). The difference resulted mainly from increased emission in variants with ground water depths of 0 and 25 cm. In these variants CH_4 emission in 2011 was by 24.0 and 56.1% higher, respectively than that in 2010. Apart from already discussed improvement of conditions for methanogenesis, such increase of CH_4 emission may be explained by a larger amount of organic matter input to soil. Hay yields in the year 2011 from fertilised variants and ground water depths kept at 0 and 25 cm were by 82 and 58% larger, respectively, than the yields in 2010 (Tab. 3). Increased hay yields in these experimental variants were associated with changes in the species composition of the sward. Total saturation of soil profile with water resulted in the disappearance of noble grasses in the year 2010 and their replacement by hydrophilous plants, mainly by rushes.

Table 3. Hay yields in relation to ground water depth, $g \cdot m^{-2}$

Year	Ground water depth, cm					Mean
	0	25	50	75	50, without NPK	
2010	636	751	1026	964	609	797
2011	1159	1188	1163	1261	484	1051

Increased yields were also noted in variants with ground water table depth at 50 and 75 cm. In the former the yield from the year 2011 was by 13.4% larger but this did not increase methane emission. In the variant with a ground water depth of 75 cm, however, despite markedly increased yield in 2011 (by 30.8%), the emission of methane was by 34.4% smaller. It means that at a low ground water depth and associated good soil aeration, the input of plant remains to soil did not affect the amount of emitted methane.

An additional effect on the increase of methane emission in variant with a high ground water table could have the presence of hydrophilous vegetation due to the permeation of this gas from its place of origin to atmosphere through aerynchyma [THOMAS *et al.* 1996]. LLOYD *et al.* [1998] are of the opinion that the diffusion of gas through plant tissues is more important than the diffusion in soil. Laboratory studies of BYRNES *et al.* [1995] showed that methane emission through the tissues of crop rice in the summer time was from 79 to 87% of the total methane emission while in winter from 61 to 68% of this gas originated directly from soil. The rate of CH_4 diffusion through the tissues of plants non-tolerant of flooding e.g. dicotyledons is much smaller [LLOYD *et al.* 1998].

The presence of hydrophilous plants might also explain much higher emission recorded in this experiment than in an analogous experiment carried out in the Noteć River valley [TURBIAK, MIATKOWSKI, submitted]. Methane emission in Biebrza, at ground water depths of 0 and 25 cm, was higher by 40.0 and 33.7%, respectively. It is hard to explain, however, higher emission (by 25.6 and 92.0%) obtained in variants with ground water table depth kept at 50 and 75 cm, respectively. Probably the differences were associated with agro-meteorological conditions e.g. with greater soil moisture in Biebrza due to higher sum of rainfall in the vegetation period.

With the assumption that the rates of methane emission obtained in the lysimetric experiment correspond to the mean values for field conditions, it was calculated that the mean emission of methane in the vegetation season would range from 502 $kg \cdot ha^{-2} \cdot (210\ d)^{-1}$ in variants with ground water depth of 0 cm to 141 $kg \cdot ha^{-2} \cdot (210\ d)^{-1}$ in variants with ground water depth kept at 75 cm and non-fertilised variant with ground water depth 50 cm below ground. With ground water depth of 25 and 50 cm the mean methane emission would be 361 and 198 kg·ha^{-1}·(210 d)$^{-1}$ (Tab. 4). Obtained results confirm that meadows on peat-muck soils may be an important source of methane emission.

Table 4. Mean methane emission during the growing season, kg·ha^{-1}·(210 d)$^{-1}$

Year	Ground water level, cm					Mean
	0	25	50	75	50 without NPK	
2010	460	285	207	173	145	254
2011	544	438	189	110	137	282
Mean	502	361	198	141	141	268

CONCLUSIONS

1. Methane emission from peat-muck soil significantly depended on the depth of ground water. The highest emission was found at full saturation of soil with water. Methane emission decreased with increasing ground water depth. Mean methane emission at ground water depths of 0, 25, 50 and 75 cm was 10.1, 7.6, 4.0 and 2.9 mg·m^{-2}·h^{-1}, respectively.

2. Mineral fertilisation increased methane emission. At ground water depth of 50 cm the emission in fertilised variant was by 42.3% higher than in non-fertilised variant.

3. Peat-muck soils under meadows in the Biebrza River valley may be an important source of methane emission. Assuming that experimental results reflect mean values of methane emission under field conditions, it was calculated that in the growing season at ground water depths of 0, 25, 50 and 75 cm the emission would be 502, 361, 198 and 141 kg·ha^{-1}·(210 d)$^{-1}$, respectively.

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Janusz TURBIAK

Emisja metanu z gleby torfowo-murszowej w dolinie Biebrzy w zależności od poziomu wody gruntowej i nawożenia

STRESZCZENIE

Słowa kluczowe: *CH_4, gleba torfowo-murszowa, metan, nawożenie, poziom wody gruntowej*

W pracy przedstawiono wyniki dwuletnich badań emisji CH_4, prowadzonych na stacji lizymetrycznej zlokalizowanej na torfowisku Kuwasy w dolinie Biebrzy. Celem badań było określenie wielkości emisji metanu z gleby torfowo-murszowej w zależności od poziomu wody gruntowej i nawożenia. Emisję metanu oznaczano metodą komorową za pomocą miernika fotoakustycznnego. Emisja metanu była istotnie zależna od poziomu wody gruntowej. Największą emisję CH_4 stwierdzono w warunkach pełnego wysycenia profilu glebowego wodą. Wraz z obniżeniem poziomu wody gruntowej wielkość emisji CH_4 malała. Nawożenie mineralne powodowało zwiększenie emisji CH_4. W warunkach poziomu wody gruntowej utrzymywanego na głębokości 50 cm emisja CH_4 w wariancie nawożonym była o 42,3% większa niż w wariancie bez nawożenia mineralnego. Stwierdzono także, że użytkowane łąkowo gleby torfowo-murszowe w dolinie Biebrzy były znaczącym źródłem emisji metanu. W okresie wegetacyjnym w warunkach poziomu wody gruntowej 0, 25, 50 i 75 cm emisja metanu wynosiła odpowiednio 502, 361, 198, 141 $kg \cdot ha^{-1} \cdot (210\ dni)^{-1}$.