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Original Research

Ability of Peat Soil to Oxidize Methane and Affect Temperature and Layer Deposition

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Abstract

Methane-oxidizing bacteria that inhabit peat play a significant role in carbon recycling. They reduce methane emissions to the atmosphere and supply carbon dioxide for photosynthesis. Our investigations aimed at determining the peat profile's (0-80 cm) ability to oxidize methane focused on the low peat Garbatówka Peatland in southwestern Poland. The experiments were carried out for four 20 cm layers. Samples of peat material of natural moisture were incubated in atmosphere enriched in 5% [v/v] CH_4 at 5, 10, and 20°C. It was observed that methane oxidation (up to 145 mg CH_4 kg d.w.$^{-1}$ d^{-1}) was most efficient at 20°C. The highest methanotrophic activity at each tested temperature was observed for a different zone of the peat profile. At 5°C the most active layer was 0-20 cm, at 10°C 40-60 cm, while at 20°C the deepest layer (60-80 cm) showed the highest methanotrophic activity.

Keywords: methane, methane oxidation, peat

Introduction

Methane is one of the main greenhouse gases responsible for global warming. Although its concentration in the atmosphere is low compared to CO_2, (1.745 ppm versus 367 ppm), the high ability of CH_4 to absorb and radiate energy back to the Earth makes it a 21-times more efficient greenhouse gas than CO_2 [1]. The only known biological sink for methane is its oxidation by methanotrophic bacteria that utilize methane as a source of carbon and energy [2].

Wetlands are the main source of natural CH_4 emissions, with an estimated level of 100-200 Tg per year globally [3, 4]. It is believed that methane formation takes place in deeper layers of a soil profile, while in aerobic layers of peat near the surface, 20 to 90% of produced methane is oxidized. Therefore, CH_4 emission is a result of the balance between methane production and methane oxidation [3, 5, 6].

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Peatlands are important ecosystems in the context of biospherical feedback to climate change, due to the large amount of stored organic carbon [7]. They can act either as a source of or a sink for carbon [7-9]. Water table level determines which processes responsible for carbon emission to the atmosphere occur. When moisture is higher, anaerobic processes dominate, whereas aerobic processes will take over when the water table drops. Temperature also is an important factor in the carbon balance in the peatland environment. Higher temperatures and lower water tables increase rates of ecosystem respiration and methane oxidation [10]. Changes in temperature and the water table could cause the release of carbon that has been sequestered in the peatlands for thousands years to the atmosphere.

Peat covers about 3,985,000 km^2 globally, but the estimations remain uncertain owing to different typologies in different countries. In Poland there are 17,060 km^2 of peatlands – 5.5% of the country area. They are located mainly in northern and eastern Poland in Biebrza and Noteć river valleys [11].

Table 1. Climatic factors in sampling site.

Season of the year	Temperature ºC
spring	12
summer	18.1
autumn	5.8
annual	8

The aim of the presented paper was to examine the effect of temperature and layer of peat deposit on the ability of peat to oxidize methane. We have focused on a peatland in the Łęczyńsko-Włodawske Lake District, one of Poland's largest complexes of peatlands and lakes.

Experimental Procedures

Peat soil sampled from different depths (0-20, 20-40, 40-60, and 60-80 cm) of the Garbatówka Peatland were used for laboratory experiments. Vegetation of peatland composed of *Molinia caerulea*, *Phragmites australis*, *Carex lasiocarpa*, some species of mosses, and a few trees, mainly *Betula pendula*. Garbatówka peatland is constantly flooded with 5 cm of water from rainfall or snowfall. Peat material was collected in the first part of September 2006 and stored up to 2 weeks at 4°C. Soil pH, moisture content, bulk density, decomposition index, and specific surface area were determined prior to the study.

Peat pH was determined in the soil suspension obtained by shaking the peat sample in deionized water (1:1) for 30 min. After 1 hour (EPA SW-846 Method 9045), pH was measured by means of a pIONeer 65 (Radiometer Analytical S.A., France) multifunctional meter (pH/Eh/DO/cond) and a Cartrode glass electrode pHC 5977 [12].

Soil moisture content was estimated by drying the sample at 105°C for 48 h. The content of water was calculated from the difference in peat weight before and after drying [11, 13]. Bulk density and actual moisture were determined using undisturbed peat samples, collected into 100 cm^3 metal cylinders [11]. In order to define the macroscopic decomposition level of peat material, the von Post scale was used [11, 14, 15]. The specific surface area of soil samples was evaluated from adsorption-desorption isotherms of water vapour, which were measured at 20°C (PN Z 19010-1) by gravimetric method using a vacuum chamber [16-18]. Soil subsamples (10 g) of natural moisture collected from each depth were placed in dark, tightly closed bottles, and incubated at 5, 10, and 20°C in air atmosphere enriched in 5% of CH_4 [v/v]. The combinations of temperatures were chosen based on mean temperature values of the seasons in this region (Table 1).

During incubation (in 3-day intervals) the composition of gases, mainly the content of CH_4, in headspace, were analyzed by means of gas chromatograph (Varian CP-3800, equipped with FID, TCD, and ECD detectors, USA). The measurements were carried out until added CH_4 was completely depleted. Methanotrophic activity of peat material was estimated by the rate of methane oxidation and expressed as an amount of CH_4 (in milligrams, oxidized per kilogram of peat, dry weight, per day).

In order to confirm the biological character of the methane oxidation process, autoclaved peat samples (120°C per 1 h) were used as a control [19]. All experiments and analysis were performed in triplicate. Statistical processing of data (ANOVA test, regression analysis) was performed using Statgraphic Plus 3.0 software. The mean values of methanotrophic activity and their standard deviations were calculated. Dependence of methanotrophic activity on temperature was examined.

Results and Discussion

Collected soil materials differed from each other with respect to pH, moisture, bulk density, specific surface area, and degree of decomposition (Table 2). The pH of tested profiles increases with depth, the highest drop between neighbouring layers was observed for the surface (0-20 cm) and subsurface (20-40 cm) layers. Statistically significant differences in pH did not occur only between layers 20-40 and 40-60 cm (P>0.05).

The highest moisture, bulk density, and specific surface area were observed for samples collected at a depth of 60-80 cm. Soil moisture content was different in each layer (P<0.05). In the case of bulk density and specific surface area, no significant differences (P>0.05) were observed between the levels of 40-60 and 60-80 cm. Peat material is characterized by a low degree of decomposition as defined by the von Post index [9]. Among tested levels it was possible to distinguish two groups (Table 2): 0-40 cm decomposed maximally in 20%, and 40-80 cm in 30%.

Table 2. Characteristics of peat soil material; mean values followed by the same letter are not significantly different at the 5% level.

Depth [cm]	pH [H_2O]	Humidity [% w/w]	Bulk density (actual) [g cm^{-3}]	Specific surface S_{BET} (H_2O) [m^2 g^{-1}]	Decomposition of soil material [%]
0-20	6.93±0.02c	592.96±0.07c	0.708±0.022a	243.9±7.32b	10-20
20-40	6.8±0.02b	530.07±0.01a	0.743±0.026b	221.6±6.65a	10-20
40-60	6.83±0.02b	582.36±0.2b	0.859±0.045c	278.4±8.35c	20-30
60-80	6.75±0.02a	667.8±0.25d	0.879±0.004c	287.9±8.64c	20-30

Figs. 1 and 2 present the effects of temperature and peat sampling depth on peat methanotrophic activity. Depth and temperature had a significant influence on methanotrophic activity. In each case the value of *P* was lower than 0.05, which indicates significant differences in the methane oxidation capability between particular deposit layers and temperatures at 95% confidence level. No methane oxidation was observed in autoclaved peat soil, which confirms that the peat ability for methane oxidation is connected with the presence and the activity of soil microorganisms.

In the examined temperature range the highest difference in methane oxidation rate was observed for samples originating from a depth of 40-60 cm. A more than tenfold increase in methane oxidation activity was found when incubation temperature increased from 5 to 20°C. Relatively high differences in methanotrophic activity also were observed in samples collected from 20-40 cm. In the case of surface layer material (0-20 cm) the differences were much lower, with three times higher activity at 20°C than at 5°C. Similarly, Whalen et al. [3] noted that an increase of temperature from 15 to 25°C doubled the methane oxidation rates.

Statistical analysis of obtained results showed that at each tested temperature, statistically significant differences ($P<0.05$) in methanotrophic activity between tested peat layers occurred (Fig. 1). A temperature of 5°C did not prevent methanotrophic activity but significantly decreased it, on average by 80% in comparison to 20°C.

The most favorable temperature, among all tested, for methane oxidation was 20°C. At all selected layers methanotrophic activity increases with temperature, which is described by equations and correlation coefficients in Table 3.

When temperature decreased, the length of time necessary to oxidize all added methane was observed. This is in accordance with the previous data that metabolic processes of methanotrophs are closely connected with temperature and that higher temperatures enhance their metabolism [20].

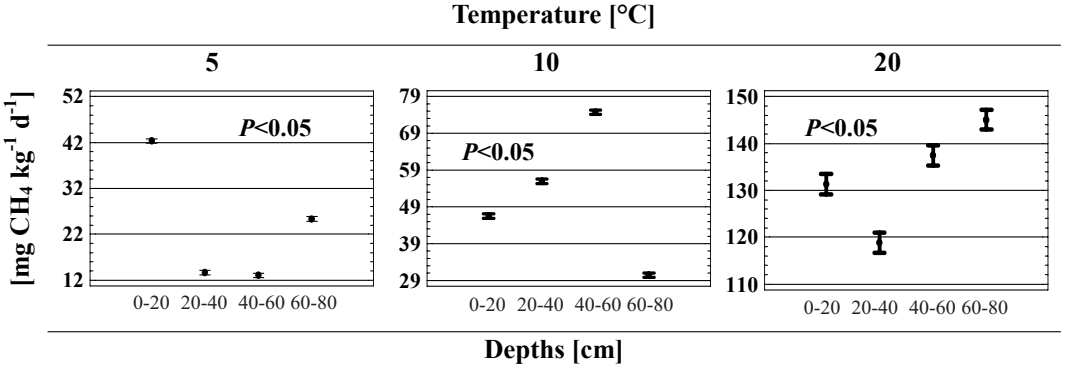

Fig. 1. Methanotrophic activity (mean values) and standard deviations in peat deposit profile at 5°C, 10°C, and 20°C (n=12).

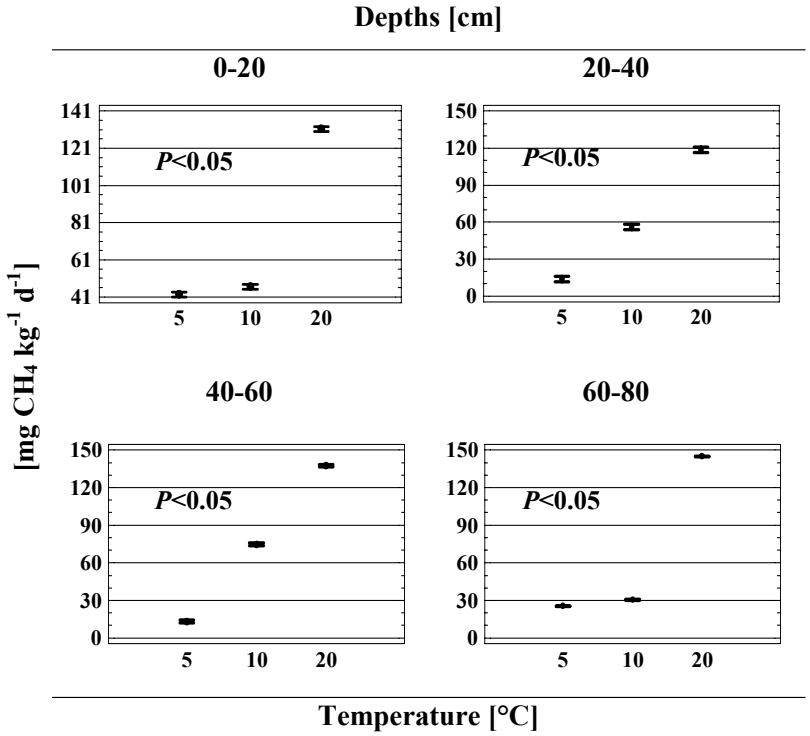

Fig. 2. Effect of temperature on methanotrophic activity in particular depths of peat deposit profile (n=9, error bars are standard deviations).

Table 3. R coefficients and equations describing the correlations between temperature and methanotrophic activity for each peat layer (n=9).

Depth [cm]	R coefficient	Equation
0-20	0.967***	y = exp(3.23 + 0.08x)
20-40	0.996***	y = -17.84 + 6.91x
40-60	0.999***	y = -131.60 + 89.75ln(x)
60-80	0.972***	y = exp(2.45 + 0.12x)
Total	0.961***	y = -17.06 + 7.43x

*P<0.05; **P<0.01; ***P<0.001.

Most methanotrophic bacteria show optimum methane oxidation between 20 and 37°C. Many researchers have found that optimum temperatures for methane oxidation in soils are around 25 to 35°C [12, 21].

There are some earlier observations that soil methane oxidation rates are positively correlated with temperature, which indicates greater oxidation during summer than in autumn, spring, and winter [6, 22].

As reported by Christophersen et al., the lowest temperature most often chosen for soil exposure on high concentrations of CH_4 is 5°C [21]. The investigations of Whalen et al. [23] showed that the oxidation of methane in natural wetlands is on average 0.02 mg CH_4 kg d.w.$^{-1}$ d^{-1} at 5°C, while Czepiel et al. [24] found the value of 0.38. In this study the ability of peat material for methane oxidation was higher and ranged between 12 and 42 mg CH_4 kg d.w.$^{-1}$ d^{-1} at 5°C.

Methanotrophic activity in Korean pine forest soil increased with temperature in the 4-35°C range [25]. Scheutz and Kjeldsen [26] investigated the ability for methane oxidation in soils collected from Skellingsted Landfill in south of Holbæk (Denmark). They determined that the oxidation process intensifies with an increase in the whole examined temperature range from 0-30°C, with the most intensive increase between 20 and 30°C.

Methane oxidation in 12 peatlands from South America, tested by Yavitt et al. [27], rose 1.1-4.5 times with an increase of temperature from 12 to 22°C. An experiment with peat material from Siberia showed that methane consumption increases with temperature up to 22-28°C. Above these values there was a significant drop of methanotrophic activity [28]. The optimum temperature for methane oxidation in forest soil examined by Reay and collaborators was around 25°C [29]. Consumption of CH_4 in landfill cover also increases with temperature in the range 1-19°C, and the highest increase of methane oxidation was observed between 12 and 19°C [30].

Our experiments revealed the differences in methane consumption between tested layers of a peat deposit profile. At each incubation temperature a different layer showed the highest methanotrophic activity. At 5°C the 0-20 cm layer was most active, at 10°C the 40-60 cm layer and the 60-80 cm layer at 20°C; methanotrophic activities were 42.2, 74.7, and 145.1 mg CH_4 kg d.w.$^{-1}$ d^{-1}, respectively.

Many studies reported differences in CH_4 consumption in soil profiles. Some showed maximum uptake rates in top soils [31-33], while others were in a subsurface level of soils [31]. In rice paddy soils during drainage the highest methanotrophic activity was observed in the 0-10 cm surface layer [32]. Acid peatlands in southeastern England showed the highest ability for methane oxidation in a surface layer (0-20 cm), which was above the water table level [33], while in natural peatlands of northern Canada the most efficient methane consumption was reported for subsurface depths of 20-30 cm and 30-40 cm [31]. A Welsh wetland examined by Freeman et al. [6] showed the maximum ability of CH_4 oxidation at the depth of 5-12.5 cm. During investigations of a coniferous hardwood forest, Benstead and King [34] found that atmospheric methane consumption occurred most efficiently at a depth of 5 cm, while in Klosterheden Forest soil (Western Jutland, Denmark), the maximum rate of methane oxidation was observed at a deeper layer: 12-15 cm [35]. Laboratory incubation of soil samples taken from a beech forest at Craigieburn showed the depth stratification of CH_4 oxidation rates, with the greatest microbial activity at 5-10 cm [36].

Maximum methane oxidation in mineral soils occurred generally at a depth of 8-13 cm [22]. Soils from Japan tested by Ishizuka et al. [37] also showed the differentiation of CH_4 consumption with the depth. At a depth of 0-10 cm, methane was most efficiently oxidized in a valley head and upper part of the slope. In a cedar forest the oxidation was highest at a depth of 10-20 cm, while in soil planted with a Japanese cedar the depth was 20-30 cm.

To summarize, our peat material showed methanotrophic activity in the range of 13 to 145 mg CH_4 kg d.w.$^{-1}$ d^{-1}; at 20°C it was between 119-145. This was greater than methanotrophic activity in a Finnish boreal peatland (0.24-2.88) [38], peatlands of Canada (13.1) [31] and England (1.7 mg CH_4 kg d.w.$^{-1}$ d^{-1}) [6]. Forest soil investigated by Saari et al. showed low ability for methane oxidation, which fluctuated around 0.05 mg CH_4 kg d.w.$^{-1}$ d^{-1} [23]. Soils taken from the Welsh wetland tested by Freeman et al. demonstrated maximum methane oxidation at 1.69 mg CH_4 kg^{-1} d^{-1} [6]. Forest and prairie soils investigated in an elevated CH_4 level headspace by Chan and Parkin [1] showed methane oxidation at 107.5 and 46.1 mg CH_4 kg d.w.$^{-1}$ d^{-1}, respectively, while in agriculture, no fertilized soils reached up to 282.6 mg CH_4 kg d.w.$^{-1}$ d^{-1}, which is twice that found in Garbatówka.

Waste soil (from stimulated landfill reactors) and clay soil (from landfill cover) were examined by He et al. [39]. These authors found methane oxidation at 5,176-384 mg CH_4 kg d.w.$^{-1}$ d^{-1}, respectively, which is significantly greater than the CH_4 oxidation values estimated for Polish peat material examined in this study.

Conclusions

Our investigation showed that tested peat material originating from different depths (0-80 cm) had a high ability to oxidize methane, and that peat methanotrophic activity is affected by temperature as well as being defined by the

layer of peat deposit. At 20°C the most active material in methane oxidation was that collected from the layer of 60-80 cm, in theory more proper for methane formation. On the other hand, high methanotrophic activity in surface layer (0-20 cm) also was observed at 5°C. That zone, among all in natural conditions, theoretically has easier access to the atmospheric oxygen that is essential for the methane oxidation process.

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