A lysimeter study on the effect of temperature on CO_2 emission from cultivated peat soils

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Abstract
A lysimeter method was evaluated for its suitability in gas emission studies by studying the effect of temperature on CO_2 emissions (dark respiration) from cultivated peat soils. The study was carried out with organic soils from two locations in Sweden, a typical cultivated fen peat with low pH and high organic matter content (Örke) and a more uncommon fen peat with high pH and low organic matter content (Majnegården). A drilling method with minimal soil disturbance was used to collect 12 undisturbed soil lysimeters per site. CO_2 emission was measured weekly from the vegetated lysimeters and the results were compared with data from incubation experiments. The CO_2 emissions measured in the lysimeter experiment were in the same range as those in other studies and showed a similar increase with temperature as in the incubation experiment. With climatic and drainage conditions being similar in the lysimeter experiment, differences in daytime CO_2 emission rates between soils (483 mg ± 6.9 CO_2 m^{-2} h^{-1} from the Örke soil and 360 ± 7.5 mg CO_2 m^{-2} h^{-1} from the Majnegården soil) were presumably due to soil quality differences. Q_{10} values of 2.1 and 3.0 were determined in the lysimeter experiment and of 1.9 to 4.5 in the incubation experiment for Örke and Majnegården respectively. CO_2 emission data fitted well to a semi-empirical equation relating CO_2 emissions to air temperature. The lysimeter method proved to be well suited for CO_2 emission studies.

Keywords
Carbon dioxide; undisturbed soil; emission; agricultural organic soil; peat; lysimeter.

Introduction
Peat soils cover around 500 million ha world-wide (Franzén, 2006) and have been estimated to contain up to 26% of the world's soil organic carbon (Smith et al., 2004). More than a quarter of the European (not including Russia, Belarus and Ukraine) peatland resource is located in Sweden (Montanarella et al., 2006). Peat soils are important contributors to the carbon cycle. In the virgin state, peatlands are accumulators of organic plant material and therefore sinks for CO_2. Drainage and cultivation of peat soils increase soil aeration and reverse the carbon flux into net CO_2 emissions. Drained peatlands subside due to oxidation of the organic material but also due to consolidation, shrinkage and compaction (Eggelsman, 1972; Heathwaite et al., 1993; Berglund, 1996). Losses of peat can also occur due to fire, wind and water erosion. Peatlands dominate the emission of CO_2 from agricultural land in Sweden (Eriksson, 1991; Kasimir-Klemedtsson et al., 1997).
The effect of temperature on the release of CO_2 from soils has been widely investigated and quantified for many types of soils (Kirschbaum, 1995). Silvola et al. (1996) found that temperature was the most important factor controlling CO_2 emissions from drained peat soils in Finland, while Lafleur et al. (2005) reported that temperature was the only factor regulating respiration in an ombrotrophic bog in Canada. When the temperature increased from 10 to 23°C, Moore and Dalva (1993) recorded a 2.3-fold increase in CO_2 emissions from peat soil in a laboratory experiment. Q_{10} values (the Q_{10} temperature coefficient is a measure of the rate of change of a biological or chemical system as a consequence of increasing the temperature by 10 °C) between 2 and 3 have been reported by Blodau (2002), but both smaller (Scanlon and Moore, 2000; Waddington et al., 2001) and larger (Chapman and Thurlow, 1996,1998; Nieveen et al., 1998) values have been reported. Many emission studies have been conducted on disturbed peat samples, without vegetation or under uncontrolled conditions in the field, as pointed out by Blodau et al. (2004), but none on undisturbed soil with vegetation cover and under controlled conditions.
The aim of the present study was to evaluate the suitability of a lysimeter method (Persson and Bergström, 1991) for emission studies by studying the effect of temperature on CO_2 emissions from two different types of cultivated fen peat soils in Sweden. The original lysimeter method (Persson and Bergström, 1991) was refined for use with peat soils and emission studies. The study was carried out using undisturbed soil monoliths in vegetated lysimeter experiments, a set-up that resembles natural conditions quite well but where different soils can be kept under controlled conditions. Incubation experiments were carried out in the laboratory on undisturbed small soil cores and the results obtained were compared with those from the lysimeter studies.

Materials and methods

Soil description
Soil monoliths were extracted from two sites, Örke in central Sweden (60°N, 17°E) and Majnegården in southern Sweden (58°N, 14°E). Both sites are dominated by pasture and hay production, but Majnegården is more intensively cultivated whereas Örke is very extensively used. Even though both sites are classified as fen peat soils, there is a great difference in soil properties between the sites (Table 1). The Örke site has a very well decomposed peat dominated by Carex-Amblystegium, while the soil at Majnegården is dominated by Phragmites-Carex and is less decomposed, especially in the subsoil and has quite a lot of mineral material and shells mixed into the upper layers. The soils were classified as according to US Soil Taxonomy (Soil Survey Staff, 2003) as a Euic Terric Haplofibrist (Majnegården) and a Euic Typic Haplosaprist (Örke).

Soil physical and chemical analysis
Four replicates of undisturbed soil cores (7.2 cm diameter, 10 cm high) were taken from 5 soil layers (0-10, 10-20, 20-30, 30-40 and 40-50 cm) at both sites. These undisturbed soil cores were used for determination of bulk density and water content at a tension of 0.05, 0.3, 0.5, 0.7, 1.0 and 6.0 metres water column (0.5, 3, 5, 7, 10 and 60 kPa) (Andersson, 1955). All soil cores were vacuum-dried at 50-60 °C before dry bulk density measurement. This low temperature was used to avoid

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any loss of organic matter during the drying process (Landva et al., 1983). Physical wilting point (water content at a tension

Table 1. Soil physical and chemical properties of the Majnegården and Örke soils (Standard deviations in brackets)

Site and depth (cm)	von Post (H1-10)	Loss on ignition (%)	Dry bulk density (g cm^{-3})	Density of solids (g cm^{-3})	Tot-C (%)	Tot-N (%)	$CaCO_3$ (%)	pH (H_2O)
Majneg.								
0-10	7-8	32	0.64 (0.03)	2.07	21.4 (0.14)	1.5 (0.04)	32	7.4 (0.08)
10-20	7-8	29	0.62 (0.01)	2.12	21.4 (0.14)	1.5 (0.04)	32	7.5 (0.02)
20-30	3-4	30	0.53 (0.03)	2.16	25.3 (0.64)	1.5 (0.01)	12	7.6 (0.03)
30-40	1-2	53	0.21 (0.01)	1.80	27.5 (4.88)	1.3 (0.36)	0.1	7.8 (0.13)
40-50	1-2	48	0.21 (0.02)	1.87	n.d.	n.d.	n.d.	7.7 (0.07)
Örke								
0-10	9-10	86	0.31 (0.02)	1.62	37.7 (0.14)	2.6 (0.01)	n.d.	5.9 (0.05)
10-20	9-10	86	0.28 (0.02)	1.57	37.7 (0.14)	2.6 (0.01)	n.d.	5.9 (0.05)
20-30	9-10	86	0.22 (0.01)	1.59	39.3 (0.00)	2.6 (0.02)	n.d.	5.7 (0.01)
30-40	8-9	83	0.22 (0.02)	1.60	38.0 (1.48)	2.3 (0.04)	n.d.	5.6 (0.00)
40-50	8-9	87	0.18 (0.00)	1.59	n.d.	n.d.	n.d.	5.7 (0.04)

of 150 meters water column) and particle density (ethanol method described by Andersson (1955)) were determined on disturbed soil samples. Porosity was calculated from particle and dry bulk densities. Shrinkage was not considered when calculating water content at different tensions.

Chemical analyses were conducted on duplicates of finely ground air-dried samples from the topsoil (0-20 cm), a transition layer (20-30 cm) and the subsoil (30-40 cm) at each site. Soil pH was measured in de-ionised water at a soil:water ratio of 1:2.5 and organic matter content (loss on ignition) was determined by dry combustion at 550°C for 8 h (Schnitzer and Hoffman, 1966). Total carbon and nitrogen were analysed by dry-combustion on a LECO CHN-932 analyser (St. Joseph, MI). $CaCO_3$ was determined using a Passon apparatus (Talme and Almén, 1975).

Lysimeter collection

Soil sampling at Majnegården was carried out in autumn 2002 and at Örke in late spring 2003. A drilling method with minimal soil disturbance (Persson and Bergström, 1991) was used at each site to collect 12 undisturbed soil monoliths within lysimeter casings. The casings consisted of PVC pipes (29.7 cm inner diameter and 59.8 cm in length), which were lidded above and below and transported to the lysimeter site (Figure 1) at the Swedish University of Agricultural Sciences, Uppsala (59°N, 17°E).

Lysimeter set-up and measurements

The lysimeter set-up is illustrated in Figure 2. In lysimeter studies, shrinkage of peat soils on drying can create problems (Schwärzel et al., 2002) such as gas and water flux from the sides of the soil column. Cameron et al. (1990; 1992) resolved this problem by injecting liquefied petroleum into the gap between the lysimeter wall and the soil. In the present study, we constructed a system that was flexible, giving the peat core the opportunity to both shrink and swell. The peat core was horizontally pushed into a new lysimeter with the same outer diameter and length as the PVC pipes used for collection of the peat core, but with a 7 mm thinner wall. The new lysimeters were constructed with a 0.5 mm neoprene rubber sheet (Kuntze, Hägersten, Sweden) with the same inner diameter as the lysimeter, placed between the lysimeter wall and the soil monolith (no. 4 in Figure 2). In the event of shrinkage, the space between the rubber sheet and the lysimeter wall was filled with water (no. 9 in Figure 2) to seal the walls of the soil monolith, while in the event of swelling the water between the wall and soil was pressed out into its container, making room for the soil to expand.

To allow the watertable level beneath the base of the lysimeter to be regulated, three layers of a borosilicate glass filter (Munktell MG 160) that could withstand a tension of 2 metres water column (pore size < 0.15 µm) were used. The watertable level was controlled by an overflow device (no. 12 in Figure 2) and an air trap with frost protection to maintain a hanging water column.

With the neoprene rubber sheet located between the lysimeter wall and the soil monolith, all measuring probes had to be inserted from the top instead of being installed from the side as in the original lysimeter method for mineral soils. A special probe was constructed for measurement of soil temperature comprising a 2.4 mm NTC resistor with accuracy ± 0.2°C (RTI Electronics Inc, Ca, USA) connected to a data logger (model CR10X, Campbell Scientific Inc, Utah, USA) and sampling of soil water (through a porous polyethylene (PE) filter with pore size 50-150 µm connected to PE hoses reaching the top of the probe) (Figure 3).

The lysimeter site set-up with all measuring devices can be seen in Figure 1.

Measurements started in spring of 2004 and continued until April 2005. The lysimeters were saturated from below with water, fertilised (0.25 g P as $Ca(H_2PO_4)_2$, 4 g K as K_2SO_4 and micronutrients including S and Mg) and sown with ryegrass (*Lolium perenne*). During the growing season, water was supplied from below via a 1 litre flask connected to the air trap (Figure 2). This flask was continuously filled to allow the watertable level to be kept constant. The watertable was set at 40 cm depth for 8 lysimeters and 80 cm depth for 4 lysimeters for both soils (the unbalanced set-up was due to a planned third treatment that proved impractical). Meteorological monitoring was carried out at the lysimeter site during the whole experimental period. Soil temperature was continuously monitored at three depths (5, 20 and 35 cm) in 12 lysimeters (6 from each site) and stored in a data logger.

During the growing season, weekly gas flux measurements were made using the closed dark chamber method (Moiser, 1990). This method provides an estimate of total respiration, which includes root and plant respiration, respiration from newly formed organic matter and oxidation of the peat itself (Kasimir-Klemedtsson et al., 1997). The chambers had the same diameter as the lysimeters and were 20 cm high, insulated and covered with a reflective layer (Figure 1). They were placed in collars over the lysimeters and sealed with an impermeable plastic material.

The headspace of the chambers was sampled 10, 20, 30 and 40 minutes after closure by circulating air (300-500 mL min^{-1}) from the chambers through a 22 mL headspace flask (sealed with butyl rubber septa) for 30 seconds. The sampled gas was analysed by gas chromatography (Klemedtsson et al., 1997). The emission rate was calculated from linear regression of the increase in gas concentration over time.

Incubation experiment setup

Incubation experiments were conducted with undisturbed soil cores in steel cylinders, 7.2 cm diameter and 10 cm high (407 cm^3), with holes in the cylinder wall to increase aeration of the sample. The soil was saturated with water and thereafter

Figure 1. The lysimeter site used in the experiment. Service pits in the middle. The overflow device to control the watertable level is in a temporary elevated position in the second row. The dark chamber and the pumping device for gas sampling can be seen to the right.

drained with a tension of 40 cm water column. The steel cylinders were incubated at 2 °C (5 replicates), 13 °C (4 replicates) or 25 °C (5 replicates) and during the emission measurements the steel cylinders containing the soil were placed in a gas-tight container (Robertson et al., 1993). The container was closed and the air was circulated through a Vaisala CO_2 Probe (GMP343, Vaisala Ltd., Vantaa, Finland) where CO_2 was measured during 3 minutes with a sample interval of 5 seconds, using the same method to circulate the air as in the lysimeter experiment.

Statistics

Gas emission rates were calculated by linear regression of CO_2 concentration and time in Microsoft Excel 2003 sp3, discarding samples with R^2 less than 0.85. Differences between treatments and soils were tested with ANOVA using SAS 9.1 software for repeated measurements (Littel, 1996) and a mixed model was used for LSD calculations. A polynomial regression model (Lloyd and Taylor, 1994) was used to analyse the relationship between air temperature and CO_2 emissions using the software Grapher 6.3 from Golden Software Inc. Co, USA.

Results and discussion

Soil physical and chemical properties

The two soils exhibit great natural differences in dry bulk density, chemical properties and water-holding properties. Majnegården is a carbonate-rich fen peat with a well decomposed topsoil (von Post H7-8) but a low degree of decomposition in the subsoil (von Post H1-2) (Table 1). The upper layers of the Majnegården profile have some mineral soil with high lime content mixed in with the peat, which is reflected in a very high bulk density for an organic soil (0.63 g cm^{-3} in the top 20 cm) and low porosity, but with more

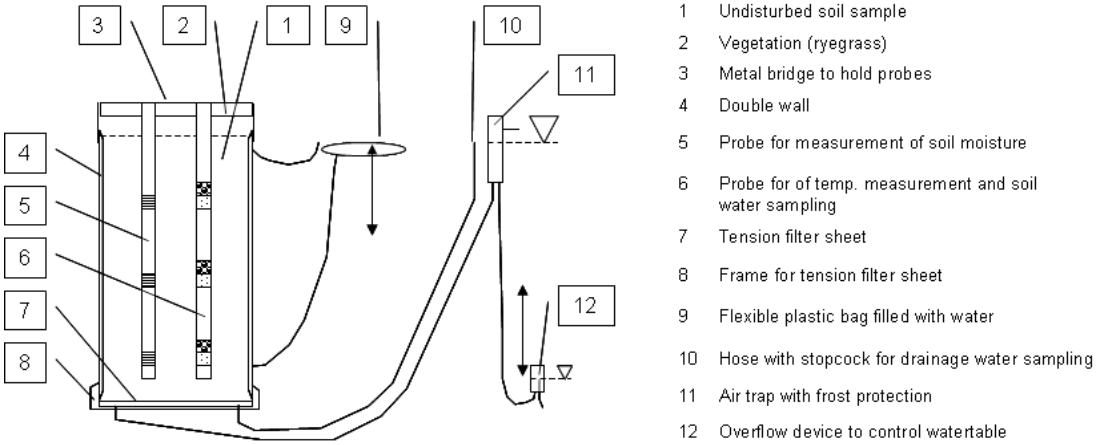

Figure 2. Construction of double-walled lysimeter. Height 59.8 cm, inner diameter 29.7 cm and inner diameter of PVC hoses 4 mm.

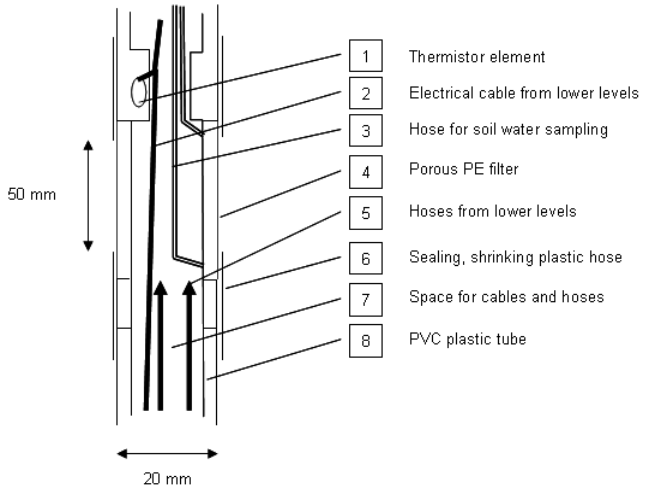

Figure 3. Schematic diagram of the probe used for temperature measurement and soil water sampling. From every filter section, two thin hoses (1.5 mm) lead to the top of the probe. The lower one is for sampling and the upper one for emptying and rinsing.

characteristic peat values in the layers below 30 cm (0.21 g cm^{-3}). Volume relationships with depth are illustrated in Figure 4a. The Majnegården profile has a marked difference in properties between the mineral mixed upper layers and the more typical peat layers deeper in the profile. The topsoil is very compacted and only a limited amount of air can enter the soil at small matric tensions. The soil in the 30-40 cm layer, with its very compacted and layered structure, has very few macropores that can be drained at normal drainage depths.
Örke is a very well decomposed fen peat (von Post H9-10) (Table 1) with a bulk density of 0.30 g cm^{-3} in the topsoil and 0.20 g cm^{-3} in lower layers. The porosity is about 80% in the topsoil and even higher in the less humified subsoil. The Örke profile has a great amount of air entering the upper layers at normal drainage (Figure 4b).

The soil chemical properties of the two soils differ greatly, mainly due to the lime and mineral-rich material mixed into the upper layers at Majnegården. It is important to bear in mind the great difference in bulk density between the sites when evaluating the nutrient status of the soils. The bulk density in the top layers at Majnegården is double that at Örke. As Table 1 shows, the nitrogen content at Majnegården is 1.3-1.5% and at Örke 2.3-2.6%, which are common values for peat soils. As humification increases, the C/N ratio decreases. The C/N ratio is around 14 in the topsoil of both soils, which is within normal range for a well decomposed peat soil, and increases with depth in the less humified layers. The nutrient storage capacity of organic soils is in general very high and this is reflected in a high CEC value. CEC is high for both soils but is extremely high at Örke, with Ca as the dominant cation (values not included in Table 1). Örke is a very typical cultivated fen peat but Majnegården, with its high pH, low organic matter content and high bulk density in the topsoil, is a more uncommon type.

CO_2 emissions

The CO_2 emission data of both soils and all treatments in the lysimeter experiment are presented in Figure 5. Temperature is a very important factor influencing the CO_2 emission rate from peat soils. To allow results to be compared with those from other studies, data of this study were fitted to a semi-empirical

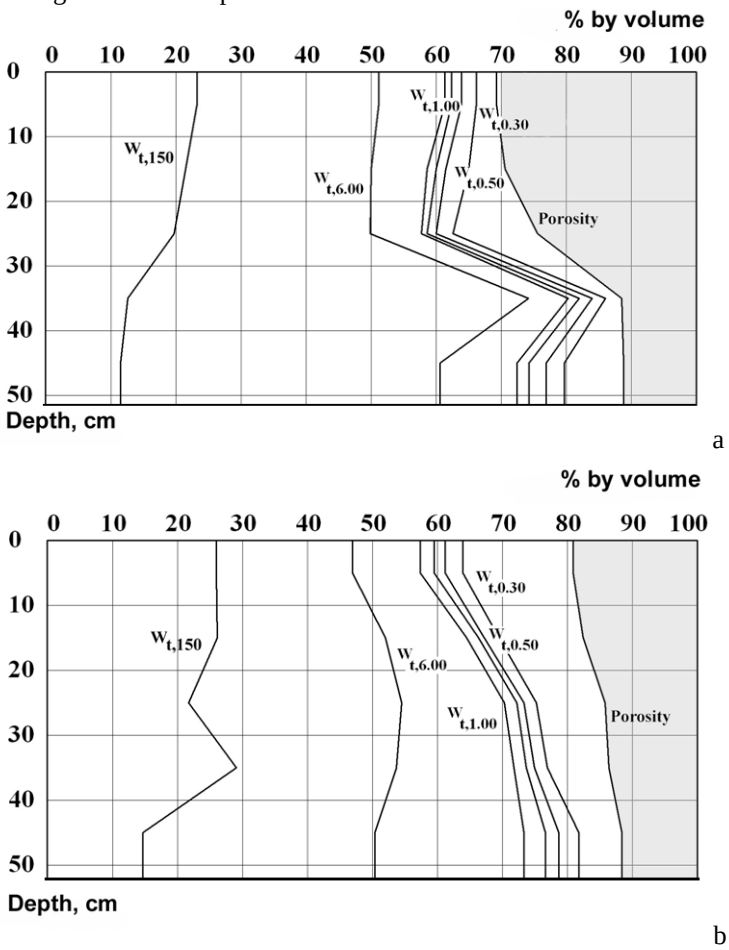

Figure 4. Volume relationships with depth at matric tensions (Wt) of 0.3, 0.5, 0.7, 1.0, 6.0 and 150 m water column at (a) Majnegården and (b) Örke.

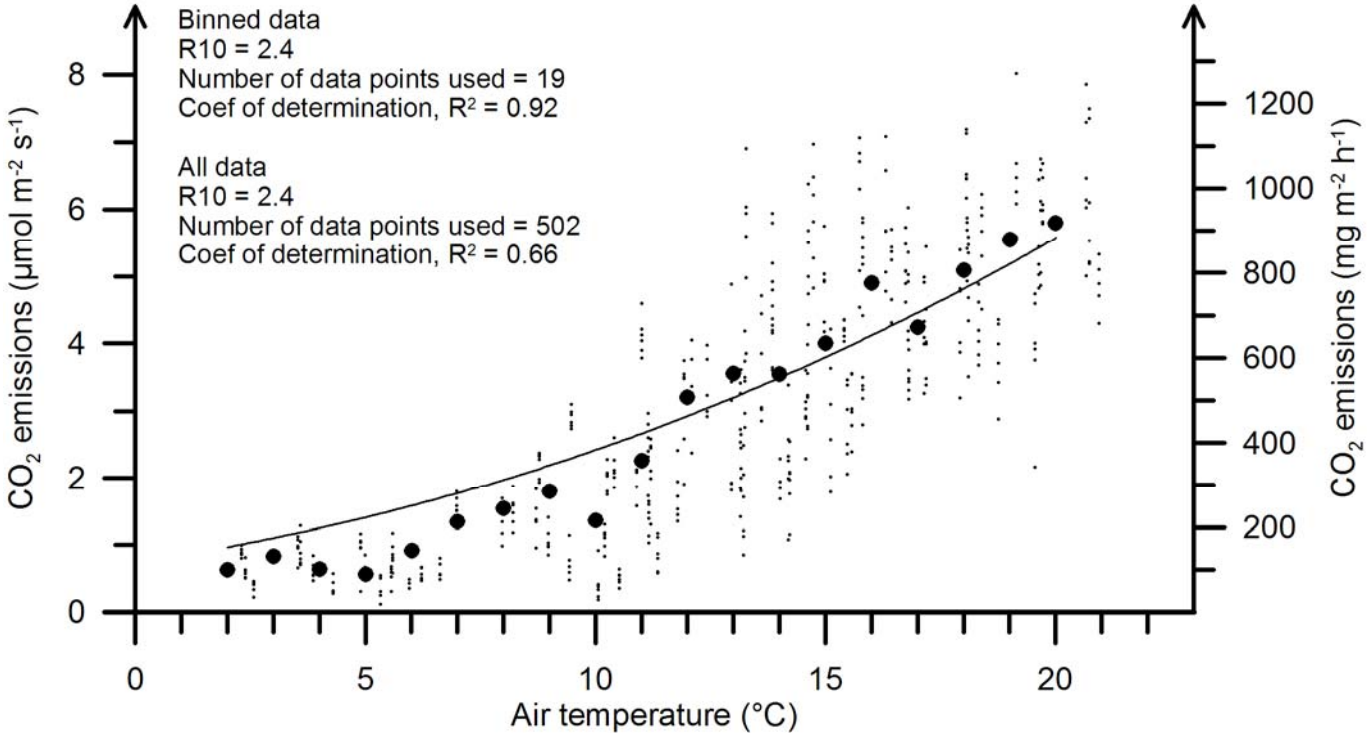

Figure 5. Results of CO_2 emission data from all lysimeters 1 April – 8 Dec 2004 and modelled effect of air temperature on emissions using an equation from Lloyd and Taylor (1994). Small dots represent individual measurements. Large dots represent binned data of all measurements at certain temperatures.

model describing emission as a function of temperature (Eqn. 1.) (Lloyd and Taylor, 1994).

$$R_e = R_{10} e^{308.56\left(\frac{1}{56.02} - \frac{1}{T_s - 227.13}\right)} \qquad \text{Eqn. 1}$$

where R_e is total respiration of CO_2 (µmol m^{-2} s^{-1}), R_{10} is the sum of plant and soil respiration at 10°C and T_s is temperature (°K). R_e and T_s are measured data and R_{10} is the result of the fitting procedure. An R_{10} of 2.35 µmol m^{-2} s^{-1} was determined (R^2=0.66, n=502) using our lysimeter experiment data. There was a considerable amount of scatter in the emission data. To overcome this, the data were averaged in 1°C bins and plotted (large dots in Figure 5). This gave a better correlation (R^2=0.92, n=19) between air temperature and CO_2 emission from the lysimeters, with a R_{10} value of 2.42 µmol m^{-2} s^{-1}. The equation had a better fit at high temperatures than at low temperatures. R_{10} value is in agreement with results reported by Nieveen et al. (2005) for a drained rush and sedge peat in New Zealand with R_{10} = 2.44 µmol m^{-2} s^{-1}, and in the same range as reported by Lohila et al. (2003) for a peat soil under pasture with R_{10} = 3.1 µmol m^{-2} s^{-1}. Conditions in the New Zealand experiment were very similar to those in the present experiment in that watertable depth ranged between 0.2 and 0.8 m (in our experiment between 0.4 and 0.8 m) and the vegetation at their site was a mixture of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). Other studies with water-logged conditions (Nieveen et al., 1998) report a lower R_{10} of 1.3 µmol m^{-2} s^{-1}, indicating anaerobic conditions.

The temperature dependence was more pronounced in the incubation experiment than in the lysimeter experiment due to less restricting conditions. (Figure 6).

The incubation experiment was conducted with undisturbed soil cores to avoid the elevated emission rates found with common incubation techniques using disturbed soil samples in flasks (Blodau et al., 2004). The incubation experiment showed a great difference between the two soils in CO_2 emissions from the topsoil (Figure 6), which were higher for the Majnegården soil than for the Örke soil. This is probably due to differences in physical and chemical soil properties (Table 1). The soil properties in the lower part of the profile (30-40 cm depth) are more similar between soils, which can explain why the differences in CO_2 emissions in the subsoil were small. The lower emission rate in the subsoil compared with the topsoil could be due to differences in soil quality, with the subsoil being more resistant to oxidation by microorganisms than the topsoil. The emission rates were higher from the Örke soil than for the Majnegården soil in the lysimeter experiment, while the converse was observed in the incubation experiment. This could be explained by better aeration conditions in the incubation experiment due to the holes in the cylinder wall, which allow evaporation of water from the side of the soil columns and facilitate gas emissions.

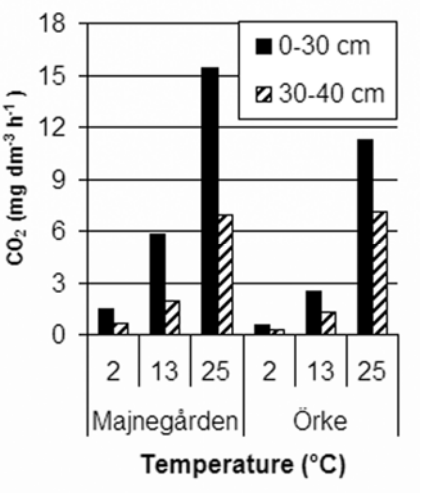

Figure 6. Results of CO_2 emission data from the incubation experiment on undisturbed small soil cores from two depths (0-20 cm and 30-40 cm) and three temperatures (2, 13, and 25°C).

Table 2. Q_{10} values (CO_2 emissions) from incubation experiments with undisturbed soil cores from Majnegården and Örke. 4 or 5 replicates

	Soil and soil temperature range (°C)			
Soil depth	Majnegården		Örke	
(cm)	2-13	13-25	2-13	13-25
5-15	3.8	2.6	3.9	4.2
20-30	3.3	1.9	4.5	2.9
30-40	3.2	2.9	3.7	4.1

The potential respiration rate for Majnegården soil was high (incubation results) but in a field situation or in the lysimeter experiment, respiration is hampered in this soil because the air-filled pore space is limited at normal drainage (Figure 4a). Q_{10} for the whole lysimeter dataset was 3.0 for the lower temperature range (between 2 and 13°C) and 2.1 for the upper temperature range (13-25°C). This is in agreement with other similar studies (Silvola et al., 1996; Lohila et al., 2004). Q_{10} values determined in the incubation experiment with undisturbed small soil cores were higher than in the lysimeter experiment (Table 2), which might be an effect of better oxygen availability. On average for both soils, Q_{10} was 3.8 for the lower temperature range and 3.1 for the higher range. Decreasing Q_{10} values for CO_2 with increasing temperature have also been reported in other studies (Lloyd and Taylor, 1994; Pietikåinen et al., 2005). There is some evidence that CO_2 emission might be better correlated to soil temperature than air temperature. A regression on a small dataset from 2005 with bare soil using Eqn. 1 gave R^2 values of 0.67 for air temperature and 0.71, 0.69 and 0.66 for soil temperature at 5, 20 and 35 cm depth respectively. Although the correlation is slightly better for soil temperature, air temperature values are easily available and may provide a useful tool in CO_2 emission modelling. The statistical analysis showed that CO_2 emissions from the Örke soil were significantly higher than those from the Majnegården soil during the whole year for both watertable levels, with an average daytime emission rate of 483 ± 6.9 mg CO_2 m^{-2} h^{-1} from Örke soil and 360 ± 7.5 mg CO_2 m^{-2} h^{-1} from Majnegården soil. These CO_2 emission results were in the same range as those reported by Maljanen et al. (2001) but somewhat higher compared with other investigations. Joosten and Clarke (2002) and Wessolek et al. (2002) found that drained grassland emitted about 170-200 mg CO_2 m^{-2} h^{-1}, while Kasimir-Klemedtsson et al. (1997) reported that CO_2 flux from Majnegården measured in the field, including root respiration of 38%, was 276 mg CO_2 m^{-2} h^{-1}. Differences in emission rates between the soils could be due to the lower organic matter content in the Majnegården topsoil and to differences in organic matter quality, which is supported by results reported by Stewart and Wheatley (1990), or due to aeration differences due to pore size distribution. The variation in gas emission rates due to daily temperature changes can be considerable. If the main focus is to compare treatments, this problem is of less importance, but if the results are used for modelling or scaling-up, this must be taken into consideration. Silvola et al. (1996) found that with only daytime measurements, CO_2 emissions were overestimated by 7-36%. To investigate the temporal variation in our experiment, measurements of CO_2 emissions were made at 3-hour intervals during 24 hours. During the summer the

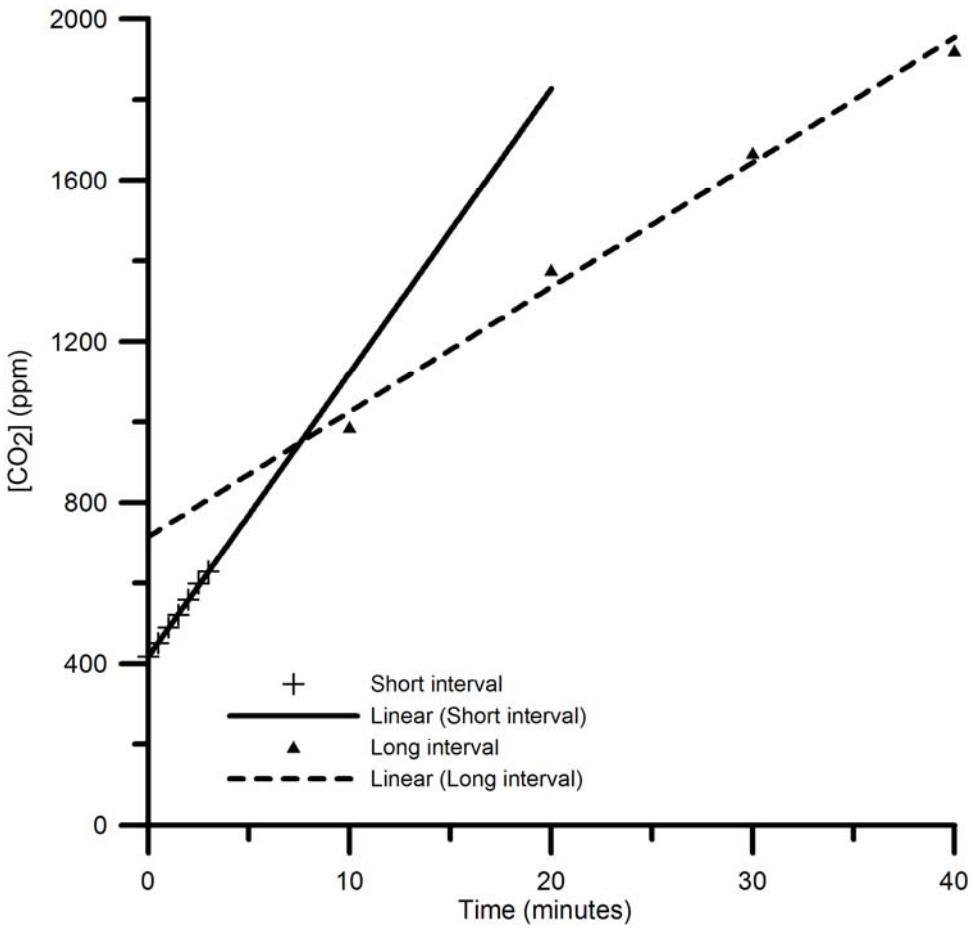

Figure 7. Comparison of direct measurement of CO_2 emissions with the Vaisala probe during a short period (3 minutes) and gas sampling 10, 20, 30 and 40 minutes after closure of the chamber in the lysimeter experiment.

emission rates at noon were almost double those at midnight. Most of our measurements were made between 9 am and 3 pm, which might have resulted in an overestimation of the average emission rate for the whole day (24 hours) of 15% at Örke and 23% at Majnegården.

A comparison was made in the lysimeter experiment between direct measurement of CO_2 emissions with the Vaisala probe during a short period after closure of the chamber and point measurements at longer intervals (10, 20, 30 and 40 minutes after closure). Both methods gave very high R^2 values for linear regression but the emission rate calculated from the short-interval measurement was much higher (Figure 7). This indicates that CO_2 emission could be underestimated if longer sampling intervals are used, which is often the case when gas samples are collected for gas chromatography analysis. Bekku et al. (1995) suggest avoiding sampling intervals longer than 20-25 minutes, while Pumpanen et al. (2004) report that non-steady state non-throughflow chambers underestimate the soil CO_2 flux by about 15% when using 30-minute sampling intervals compared with 10-minute intervals. In our very limited investigation, the underestimation was 56% (Figure 7), but this is a dynamic number dependent on emission rate.

Conclusions

The lysimeter method worked very well in these emission studies. CO_2 emissions measured in the lysimeter experiment (360-480 mg CO_2 m^{-2} h^{-1}) were within the range reported in the literature and increased with temperature in both the lysimeter and incubation experiments. CO_2 emissions could be modelled with a general model correlating emission rate to air temperature. With climatic and drainage conditions being the same for both soils in the lysimeter experiment, differences in daytime emissions are presumably due to soil quality differences. The lysimeter method resembles natural conditions well and makes it possible to work with undisturbed soil cores. Climatic conditions are easy to monitor and the experimental set-up is flexible.

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