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A lysimeter study on the effect of temperature on 
CO₂ 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 CO₂ 
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. CO₂ emission 
was measured weekly from the vegetated lysimeters and the 
results were compared with data from incubation experiments. 
The CO₂ 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 
CO₂ emission rates between soils (483 mg ± 6.9 CO₂ m⁻² h⁻¹ 
from the Örke soil and 360 ± 7.5 mg CO₂ m⁻² h⁻¹ from the 
Majnegården soil) were presumably due to soil quality 
differences. Q₁₀ 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. CO₂ 
emission data fitted well to a semi-empirical equation relating 
CO₂ emissions to air temperature. The lysimeter method 
proved to be well suited for CO₂ 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 CO₂. Drainage 
and cultivation of peat soils increase soil aeration and reverse 
the carbon flux into net CO₂ 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 CO₂ from agricultural land in 
Sweden (Eriksson, 1991; Kasimir-Klemedtsson et al., 1997). 
The effect of temperature on the release of CO₂ from soils has 
been widely investigated and quantified for many types of 
sounds (Kirschbaum, 1995). Silvola et al. (1996) found that 
temperature was the most important factor controlling CO₂ 
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 CO₂ emissions 
from peat soil in a laboratory experiment. Q₁₀ values (the Q₁₀ 
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 Thorlow, 
1996, 1998; Nieven 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 CO₂ 
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-Amblystegiüm, 
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 Eutic Terric 
Haplofibrist (Majnegården) and a Eutic 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
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)

<table>
<thead>
<tr>
<th>Site and depth (cm)</th>
<th>Field</th>
<th>Loss on ignition (%)</th>
<th>Bulk density (g cm(^{-3}))</th>
<th>Density of solids (g cm(^{-3}))</th>
<th>Tot-C (%)</th>
<th>Tot-N (%)</th>
<th>CaCO(_3) (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>6-10</td>
<td>7.8</td>
<td>32</td>
<td>0.64 (0.03)</td>
<td>2.07</td>
<td>214 (0.14)</td>
<td>1.5 (0.04)</td>
<td>32</td>
</tr>
<tr>
<td>10-20</td>
<td>7.8</td>
<td>29</td>
<td>0.62 (0.01)</td>
<td>2.12</td>
<td>214 (0.14)</td>
<td>1.5 (0.04)</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>3.4</td>
<td>30</td>
<td>0.53 (0.03)</td>
<td>2.16</td>
<td>253 (0.64)</td>
<td>1.5 (0.01)</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>30-40</td>
<td>1.2</td>
<td>53</td>
<td>0.21 (0.01)</td>
<td>1.80</td>
<td>275 (4.88)</td>
<td>1.3 (0.36)</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>1-2</td>
<td>48</td>
<td>0.21 (0.02)</td>
<td>1.87</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>7.7</td>
</tr>
<tr>
<td>Örke</td>
<td>6-10</td>
<td>9-10</td>
<td>86</td>
<td>0.31 (0.02)</td>
<td>1.62</td>
<td>37.7 (0.14)</td>
<td>2.6 (0.01)</td>
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</tr>
<tr>
<td>10-20</td>
<td>9-10</td>
<td>86</td>
<td>0.28 (0.02)</td>
<td>1.57</td>
<td>37.7 (0.14)</td>
<td>2.6 (0.01)</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
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<td>9-10</td>
<td>86</td>
<td>0.22 (0.01)</td>
<td>1.59</td>
<td>39.3 (0.00)</td>
<td>2.6 (0.02)</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>30-40</td>
<td>8-9</td>
<td>83</td>
<td>0.22 (0.02)</td>
<td>1.60</td>
<td>38.0 (1.48)</td>
<td>2.3 (0.04)</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>8-9</td>
<td>87</td>
<td>0.18 (0.00)</td>
<td>1.59</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>5.7</td>
</tr>
</tbody>
</table>

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

of 150 meters water column) and particle density (ethanol method described by Andersson (1955)) were determined on

of soils

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 hours (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).

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

To allow the watertable level 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) 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\(_2\)PO\(_4\))\(_2\), 4 g K as K\(_2\)SO\(_4\) 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
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 CO₂ Probe (GMP343, Vaisala Ltd., Vantaa, Finland) where CO₂ 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 CO₂ concentration and time in Microsoft Excel 2003 sp3, discarding samples with R² 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 CO₂ 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...
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
model describing emission as a function of temperature (Eqn. 1) (Lloyd and Taylor, 1994).

\[ R_e = R_{10} e^{\frac{308.56}{56.02} - \frac{T_s}{227.13}} \]  

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 water table 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.
Table 2. Q10 values (CO2 emissions) from incubation experiments with undisturbed soil cores from Majnegården and Örke. 4 or 5 replicates

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Majnegården 13-25°C</th>
<th>Majnegården 2-13°C</th>
<th>Örke 13-25°C</th>
<th>Örke 2-13°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-15</td>
<td>3.8</td>
<td>2.6</td>
<td>3.9</td>
<td>4.2</td>
</tr>
<tr>
<td>20-30</td>
<td>3.3</td>
<td>1.9</td>
<td>4.5</td>
<td>2.9</td>
</tr>
<tr>
<td>30-40</td>
<td>3.2</td>
<td>2.9</td>
<td>3.7</td>
<td>4.1</td>
</tr>
</tbody>
</table>

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). Q10 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). Q10 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, Q10 was 3.8 for the lower temperature range and 3.1 for the higher range. Decreasing Q10 values for CO2 with increasing temperature have also been reported in other studies (Lloyd and Taylor, 1994; Pietikäinen et al., 2005). There is some evidence that CO2 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 R² 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 CO2 emission modelling. The statistical analysis showed that CO2 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 CO2 m⁻² h⁻¹ from Örke soil and 360 ± 7.5 mg CO2 m⁻² h⁻¹ from Majnegården soil. These CO2 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 CO2 m⁻² h⁻¹, while Kasimir-Klemedtsson et al. (1997) reported that CO2 flux from Majnegården measured in the field, including root respiration of 38%, was 276 mg CO2 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, CO2 emissions were overestimated by 7-36%. To investigate the temporal variation in our experiment, measurements of CO2 emissions were made at 3-hour intervals during 24 hours. During the summer the...
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 CO₂ 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 R² values for linear regression but the emission rate calculated from the short-interval measurement was much higher (Figure 7). This indicates that CO₂ 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 CO₂ 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. CO₂ emissions measured in the lysimeter experiment (360-480 mg CO₂ m⁻² h⁻¹) were within the range reported in the literature and increased with temperature in both the lysimeter and incubation experiments. CO₂ 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.

Acknowledgements

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References


Talme, O. and Almén, K.E. 1975. Jordartsanalys. Laboratorieanvisningar, del 1, Department of Quaternary Research, Stockholm University, 133.

