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Emission of CO_2, CH_4 and N_2O from lakeshore soils in an Antarctic dry valley

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Abstract

We measured soil profile concentrations and emission of CO_2, CH_4 and N_2O from soils along a lakeshore in Garwood Valley, Antarctica, to assess the extent and biogeochemical significance of biogenic gas emission to C and N cycling processes. Simultaneous emission of all three gases from the same site indicated that aerobic and anaerobic processes occurred in different layers or different parts of each soil profile. The day and location of high gas concentrations in the soil profile corresponded to those having high gas emission, but the pattern of concentration with depth in the soil profile was not consistent across sites. That the highest gas concentrations were not always in the deepest soil layer suggests either limited production or gas diffusion in the deeper layers. Emission of CO_2 was as high as $47\,\mu mol\,m^{-2}\,min^{-1}$ and was strongly related to soil temperature. Soil respiration differed significantly according to location on the lakeshore, suggesting that factors other than environmental variables, such as the amount and availability of O_2 and nutrients, play an important role in C mineralization processes in these soils. High surface emission (maximum: $15\,\mu mol\,m^{-2}\,min^{-1}$) and profile gas concentration (maximum: $5780\,\mu L\,L^{-1}$) of CH_4 were at levels comparable to those in resource-rich temperate ecosystems, indicating an active indigenous population of methanogenic organisms. Emission of N_2O was low and highly variable, but the presence of this gas and NO_3 in some of the soils suggest that denitrification and nitrification occur there. No significant relationships between N_2O emission and environmental variables were found. It appears that considerable C and N turnover occurs in the lakeshore soils, and accurate accounting will require measurements of aerobic and anaerobic mineralization. The production and emission of biogenic gases confirm the importance of these soils as hotspots of biological activity in the dry valleys and probable reservoirs of biological diversity.

Keywords: Carbon dioxide; Methane; Nitrous oxide; Biogenic gases; Gas emission; Antarctic dry valleys; Polar desert; Mineralization; Microbial mat

1. Introduction

Antarctic dry valleys are resource-poor desert ecosystems with extremely low biological activity and biodiversity (Burkins et al., 2001; Barrett et al., 2005). Growing attention is being directed to the function and dynamics of these ecosystems, with a number of studies indicating considerable heterogeneity of resource distribution and utilization (Courtright et al., 2001; Barrett et al., 2002, 2004; Gooseff et al., 2003; Moorhead et al., 2003). Productivity in these heterogeneous landscapes is now known to result from a strong interaction between abiotic and biological factors (Parsons et al., 2004).

Biogenic gas emissions are an indicator of the biological activity and C and N cycling in soils. Although CO_2 efflux has received attention (e.g. Burkins et al., 2001; Elberling et al., 2006), we are not aware of any studies on production

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and emission of N_2O and CH_4 in Antarctic dry valleys. Arctic studies, however, have shown that CH_4 emission from tundra soils depends on moisture, vegetation, and microrelief (Kutzbach et al., 2004); release of N_2O is likewise a product of physical, chemical, and biological interactions (Müller et al., 2002, and references therein), including freeze–thawing and proximity to plants (Grogan et al., 2004). Although land plants are largely absent from Antarctica's McMurdo dry valleys, Lake Colleen in the Garwood Valley harbours considerable benthic microbial biomass, which may represent a similar source of energy and nutrients for soil microbes on the lakeshore.

It is thought that the main limitation on resource use in Antarctic dry valleys is extreme desiccation (Treonis et al., 2002) and that considerable resources appear to be available to soil biota from adjacent water bodies in the dry valleys (Elberling et al., 2006; Hopkins et al., 2006). On the basis of these factors and recent studies of soil organic C and CO_2 emission (Moorhead et al., 2003; Elberling et al., 2006), we hypothesized that relatively high rates of C and N cycling occur in the wet lakeshore soils, that this cycling should be detectable by efflux of CO_2, CH_4, and N_2O, and that their characterization with depth would provide further information on the biological processes occurring in the soil profile.

2. Materials and methods

2.1. Study site

The study area is located in Garwood Valley (78°01′S, 163°53′E) on the shore of a partly ice-covered lake (Lake Colleen) that is fed by seasonal melt streams and drained in the summer by one stream running to the Ross Sea. Sampling sites were located on the southeast shore of the lake (see Fig. 1 in Elberling et al., 2006) in a transect perpendicular to the lake edge.

2.2. Sampling

In January 2003 three circular steel rings (20 cm high and 15 cm in diameter) were installed 10 cm into the soil and 2 m apart along a transect perpendicular to the water edge. In 2005 three rings were installed within 1 m of the transect established in 2003. Site A was located about 6 m from the lake's edge, site B was located directly on a strand line of lacustrine detritus (comprising mostly dried foam and cyanobacterial mat) about 4 m from the lake's edge, and site C was located in an area of living and dried mat about 2 m from the lake's edge. Two plastic gas sampling tubes (0.20 m length, 6.35 mm outer diameter, and 3.18 mm internal diameter) were inserted into the soil outside the rings at each sampling site. The tubes were inserted at a 45° angle to depths of 5 and 10 cm, which correspond to about the middle and the bottom of the active soil layer (above the permafrost, which was about 11–12 cm below the soil surface). The upper end of the sampling tube was fitted with a two-way Luer-type stopcock valve (Cole Parmer, Vernon Hills, IL, USA) and a silicone septum (male Luer-lock stopper with injectable membrane, Vygon, Ecouen, FR) at the surface end, and the lower end was covered with nylon gauze to reduce blockage by soil particles. In 2003 gas samples of surface fluxes and profile gas concentrations were collected for six consecutive days beginning on January 24; in 2005 gas samples were collected for seven consecutive days beginning also on January 24. On some sampling dates the soil water content was too high to allow for an adequate volume of gas to be collected in the soil profile for analysis.

2.2.1. Gas sampling

Surface gas measurements commenced more than 24 h after the metal rings and tubes were installed in the soil. In 2003, soil CO_2 efflux measurements were made using an infrared (non-dispersive) gas analyser system (LiCor 6200 System, LiCor Inc., Lincoln, USA), and N_2O and CH_4 fluxes were measured by collecting gases in evacuated vials; in 2005 all three gases were measured by collecting gas samples in evacuated vials. Measurement of the soil CO_2 efflux using a LiCor is described by Elberling et al. (2006). Non-steady-state, non-flow-through vented chambers (Livingston and Hutchinson, 1995) were sealed over the rings to allow for collection of gas samples in vials; 15-cm^3 samples of the head-space gas were collected through a septum in the chamber using a syringe. The gas samples were injected into, and subsequently stored in, evacuated (−200 kPa) 12-cm^3 vials (Exetainers, Labco Inc., UK) containing approximately 3 mg of magnesium perchlorate as a drying agent (Rochette and Bertrand, 2003). An ambient air sample was collected above the ring, then the ring was covered with the chamber and three samples were collected, one every 4 min over a 12-min period, to determine the rate of gas emission.

Soil-surface gas fluxes (F; $\mu mol\,m^{-2}\,min^{-1}$) were calculated from the linear change in the chamber gas concentration during the 12 min that the ring was covered using the following equation:

$$F = dC/dt(V/A)Mm/Mv,$$

where dC/dt ($\mu mol\,mol^{-1}\,min^{-1}$) is the rate of change in gas concentration estimated from gas samples taken after 0, 4, 8, and 12 min; V (m^3) is the chamber headspace volume; A (m^2) is the surface area covered by the chamber; Mm ($mg\,mol^{-1}$) is the molecular weight of the gas; and Mv ($m^3\,mol^{-1}$) is the molecular volume ($0.0225\,m^3\,mol^{-1}$).

Gas samples were collected from the soil pore space at the two depths through the sampling tubes on the same day as flux measurements. After removing the air in the dead space in the tubes with a gas-tight syringe, 15 cm^3 of air from the tubes were removed and injected into previously evacuated vials. Samples were handled, stored, and analysed in the same way as the chamber air samples.

The gas samples were stored at ambient temperature and analysed using a gas chromatograph fitted to a catalytic