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Methane fluxes on boreal arable soils

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Abstract

Methane (CH_4) oxidation in soils is the only known biological sink of CH_4. The sink strength of agricultural soils is known to be affected by soil properties and agricultural practices. We studied fluxes of CH_4 in southern and northern Finland in arable soils with different texture and crops. The annual fluxes ranged from uptake of -1.2 kg CH_4 ha^{-1} to emission of 40 kg CH_4 ha^{-1}. The CH_4 oxidation decreased in the order loamy sand > well drained peat > clay > poorly drained peat. The more there were macropores or the less there were micropores in the soil, the higher was the mean annual CH_4 oxidation rate. Calculated on the basis of the soil type specific CH_4 flux rates from our study and the soil type distribution of Finnish agricultural soils, the total agricultural area in Finland would form an annual CH_4 sink of -19 Gg CO_2 equiv., which is 0.3% of the total reported greenhouse gas emissions from agriculture in 2004.

Keywords: Methane uptake; Mineral soils; Organic soils; Soil porosity; Agriculture

1. Introduction

Methane (CH_4) emissions originate both from natural (e.g. wetlands, termites) and anthropogenic (e.g. energy production, cattle, rice cultivation and landfills) sources (IPCC, 2001). The largest sinks for CH_4 are chemical reactions in the atmosphere and oxidation by methanotrophic bacteria in soils. Due to a global imbalance of the production and consumption rates of CH_4, its concentration in the atmosphere is clearly increasing. The concentration of CH_4 has increased by 150% since 1750 and the annual increase is currently about 0.4% (IPCC, 2001). Human activities have both increased the emissions of CH_4, and diminished the sinks of CH_4 (e.g. by converting forest soils to arable soils) (Hütsch, 2001). Aerated soils act as sinks of CH_4, and their sink strength has been estimated to be 3–9% of the global annual removal of CH_4 from the atmosphere (Smith et al., 2000).

In agricultural soils the CH_4 oxidising capacity is about two-thirds lower than in forest soils (Smith et al., 2000). The reduction has mainly been attributed to the inhibition of the activity of CH_4 oxidising bacteria by ammonium ions and tillage (Hütsch et al., 1994; Hütsch, 1998). Ammonium ions are able to inhibit CH_4 oxidation both by competitive inhibition of the enzyme methane monooxygenase, and through the resulting decrease in pH when ammonium is applied to soil. The CH_4 oxidizers can be adapted to very different pH conditions; in arable soils the populations tend to have higher optimum pH than those in forest soils. Thus, a small change of pH in the range of 7.6–7.1 can cause a strong inhibition of CH_4 consumption in an agricultural soil (Hütsch, 1998) whereas in forest soils the optimum is often found in the range of 4–6.5 (Saari et al., 1994). Also nitrite ions reduce the activity of CH_4 oxidising bacteria (Hütsch, 2001). Physical disturbance of the soil structure by tillage may also reduce CH_4 oxidation by lowering the diffusion of CH_4 from the atmosphere into the soil, a mechanism which is the sole source of CH_4 to the CH_4 oxidisers (Ball et al., 1999). Tillage breaks down part of the soil microsites of high CH_4 oxidation activity, and the recovery of this activity is

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thought to be a slow process. The recovery of the CH_4 oxidation rate of a reforested agricultural soil to the predisturbance level may take more than 100 years (Smith et al., 2000). Soil compaction due to tractor traffic has been found to reduce the activity of CH_4 oxidizers (Ruser et al., 1998) since soil structure regulates CH_4 oxidation by determining the rate of CH_4 and oxygen diffusion into the soil (Dörr et al., 1993; Saari et al., 1997; Ball et al., 1997) and the available surface area suitable for the colonization by methanotrophic bacteria (Bender and Conrad, 1994). Other factors reducing CH_4 oxidation in agricultural soils are the use of pestisides (Topp, 1993; Prieme and Ekelund, 2001) and irrigation (Kessavalou et al., 1998).

There are some reports available on CH_4 oxidation in boreal forest soils (Kasimir-Klemedtsson and Klemedtsson, 1997; Saari et al., 1997, 2004; Maljanen et al., 2003a), but fewer on CH_4 oxidation rates in boreal arable soils (Nykänen et al., 1995; Maljanen et al., 2003a). If the greenhouse gas inventories are to be extented to cover also CH_4 fluxes from soils in the future as the IPCC Good Practice Guidance (IPCC, 2003) suggests, data on the sink strength of CH_4 in agricultural soils in different climatic zones and agricultural practises is needed. The aim of this study was to give an overview of CH_4 oxidation rates in boreal agricultural soils of different textures and crop production intensity, and to increase knowledge on the factors controlling CH_4 oxidation in boreal arable soils.

2. Materials and methods

2.1. Sites

Field experiments to study the fluxes of CH_4 on mineral and organic agricultural soils were established on clay, sandy and peat soils in Jokioinen, southern Finland (60°49′N, 23°30′E), and on a peat soil in Rovaniemi, northern Finland (66°35′N, 26°01′E) in 1999. The southern peat field has been in cultivation for 100 years whereas the northern field was drained for agriculture 50 years ago. The soil properties are shown in Table 1. The experimental areas consisted of nine 10 × 10 meter plots, where grass (*Phleum pratense* and *Festuca pratensis*), spring barley (*Hordeum vulgare*) and potato (*Solanum tuberosum*) were grown on three replicate plots organized as latin squares since 1999. The potato plots were as bare fallow after 2000. The fields were conventionally managed and fertiliser application was done as synthetic NPK fertiliser. The grass plots were fertilized with 120–160 kg N ha^{-1} on peat soils and 250 kg N ha^{-1} on mineral soils (Regina et al., 2004; Syväsalo et al., 2004). On the barley plots the N fertilization was 60 kg ha^{-1} on the peat soils and 100 kg ha^{-1} on the mineral soils. The grass was cut and fertilized twice a year. The barley plots were ploughed in the autumn (to 20–25 cm depth), harrowed once in spring before sowing, fertilized and sowed with a combined drill, herbicide sprayed in summer and harvested in August or September. The fallow plots were treated chemically twice a year and tilled in the autumn.

2.2. Physical and chemical analysis

Soil moisture, depth of the water table and soil temperature were determined in conjuction with the gas flux measurements when the soil was not frozen. For the determination of soil moisture soil samples from three bulked 0 to 25 cm cores with a diameter of 3 cm were oven-dried at 105 °C. The depth of the water table at each corner of the peat fields (Jokioinen) or in each plot (Rovaniemi) was measured in perforated plastic dipwells. Soil temperatures at 5 and 25 cm depths close to each chamber were measured with a 50 cm steel probe attached to a Fluke 52 II thermometer. Soil bulk density was determined three times during summer 2001 from three replicate oven-dried 15 cm soil cores (diameter 5 cm) from each plot (Blake and Hartge, 1986a). Since no significant variation or trend in the soil bulk density was found during these samplings, only one soil sampling was done in the northern field in 2002. The mean bulk density for each plot was used to calculate the water-filled pore space (WFPS) of the soils during the growing season. Particle densities of the soils were determined once during the monitoring period using the pycnometer method (Blake and Hartge, 1986b). Total porosity of each soil was calculated from the particle density and bulk density. WFPS was calculated by dividing volumetric soil water content by total porosity.

Pore size distribution was determined for the sites in southern Finland in May 2000 after seedbed preparation and sowing of barley. Undisturbed 200 cm^3 (height 4.9 cm, diameter 7.2 cm) soil core samples were taken from the 10 to 15 cm and 15 to 20 cm soil from each plot. Soil pore size distribution was estimated from the drying limb of the water-retention curve (pF-curve). Before measurements, the samples were moistened thoroughly at −0.15 kPa matric potential (ψ). They were then equilibrated at potentials of −0.25, −0.5, −1 and −10 kPa on pressure plates (air entry value 100 kPa) by using hanging water columns. Wilting point (suction of 1500 kPa) was analyzed with osmotic method by placing a small soil sample in a cellulose acetate bag and using a polyethylene glycol (PEG, molecular weight 20,000) solution according to Aura (1975). The pore size distribution and the proportion of micro- and macropores were determined from water retention curves as the proportion of pores filled with water at set water potentials. Pores with a diameter 30 μm (water potential −10 kPa, pF 2) or larger were classified as macropores and pores with a diameter 0.2 μm (water potential −1500 kPa, pF 4.2) or less were classified as micropores.

Soil pH was determined in suspensions of 30 ml of soil and 50 ml of water once a month during the growing season. Analysis of organic C and total N was done once during the monitoring period from air-dried samples on a CN analyser