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Growing season in situ uptake of atmospheric methane by desert soils in a semiarid region of northern China

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ABSTRACT

Despite vast areas of desert soils distributed extensively in arid and semiarid regions of northern China, methane (CH_4) uptake was sparsely observed in these soils. In this study, we selected a fenced sand land of the Xilin River basin in Inner Mongolia as a case to understand in situ CH_4 uptake by desert soils. A set of measurements was made using a static chamber technique both to quantify temporal and spatial CH_4 uptake and to examine the effect of environmental factors on the uptake. The CH_4 uptake had large temporal and spatial variability during the growing seasons of both years 2009 and 2011, with a mean rate of $-48.5\ \mu g\ m^{-2}\ h^{-1}$. Vertical CH_4 uptake coincided with the change in CH_4 concentrations along various soil horizons, with the most active in the 5–30 cm soils. The dependence of CH_4 uptake on soil temperature and moisture was well established in these desert soils. The CH_4 uptake was temporarily enhanced over brief periods when desert soils were wetted. In order to more availably estimate in situ annual CH_4 sink in arid and semiarid regions of northern China, it is suggested that year-round measurements should be centralized on the effect of soil temperature and moisture on the CH_4 uptake.

1. Introduction

The global atmospheric concentration of methane (CH_4) has increased from a pre-industrial value of about 715 nl l^{-1} to 1774 nl l^{-1} in 2005 (IPCC, 2007). The change in atmospheric CH_4 concentration depends upon its sources and sinks. The two principal sinks that remove CH_4 from the atmosphere are reactions in the troposphere and CH_4 uptake by bacteria in soils. The latter process is estimated to be responsible for about 5% of the annual global CH_4 sink (Dunfield, 2007).

The estimate of the global strength for CH_4 uptake by aerated soils is highly uncertain due to the large variability measured spatially and temporarily in the field. CH_4 uptake has been observed in nearly all types of aerated soils, such as in tundra (Whalen and Reeburgh, 1990), forests (Reay et al., 2005; Steudler et al., 1989), grasslands (Mosier et al., 1991), and deserts (Angel and Conrad, 2009; McLain and Martens, 2006; McLain et al., 2008; Peters and Conrad, 1996; Striegl et al., 1992). The global sink generally assumes weak CH_4 uptake by desert soils (Potter et al., 1996). Available data, however, suggest desert soils may have substantial CH_4 uptake. For example, CH_4 uptake was observed up to $-182.5\ \mu g\ m^{-2}\ h^{-1}$ by desert soils following wetting (Striegl et al., 1992). Sandy soil moisture accounted for variability in CH_4 uptake (McLain and Martens, 2006; McLain et al., 2008). Desert soils are distributed extensively in arid and semiarid regions that account for about 30% of the Earth's surface (Middleton and Thomas, 1997). Their great area coverage suggests a potentially marked contribution in the global soil CH_4 sink. However, desert soils have been largely overlooked in greenhouse gas inventories.

There are vast areas of deserts and deserted lands in China (Fig. 1), accounting for about a quarter of the territory (Feng et al., 2001; Piao et al., 2010; Qu et al., 1990). Inner Mongolia consists of a significant part in arid and semiarid northern China. Many in situ CH_4 flux measurements have been conducted in aerated soils of the Inner Mongolia steppes (see Z.P. Wang et al., 2009). However, these measurements have almost not investigated in situ CH_4 flux in desert soils. Most recently, CH_4 uptake was investigated under the laboratory incubations using intact desert soil cores sampled from the desert steppes of Inner Mongolia (Wu et al., 2010; Yao et al., 2010). The effect of increasing soil temperature and nitrogen on CH_4 flux was investigated in desert soils of Inner Mongolia (Wang et al., 2011). However, in situ CH_4 uptake was sparsely measured in desert soils of Inner Mongolia and should therefore be prioritized for additional research.

The general objective of this study was to understand in situ CH_4 uptake by desert soils in a semiarid region of Inner Mongolia. Hence we carried out field measurements of CH_4 uptake by desert soils in the Xilin River basin. Specifically, CH_4 uptake was measured spatially and temporarily. Meanwhile, the effects of soil temperature and moisture on CH_4 uptake were examined.

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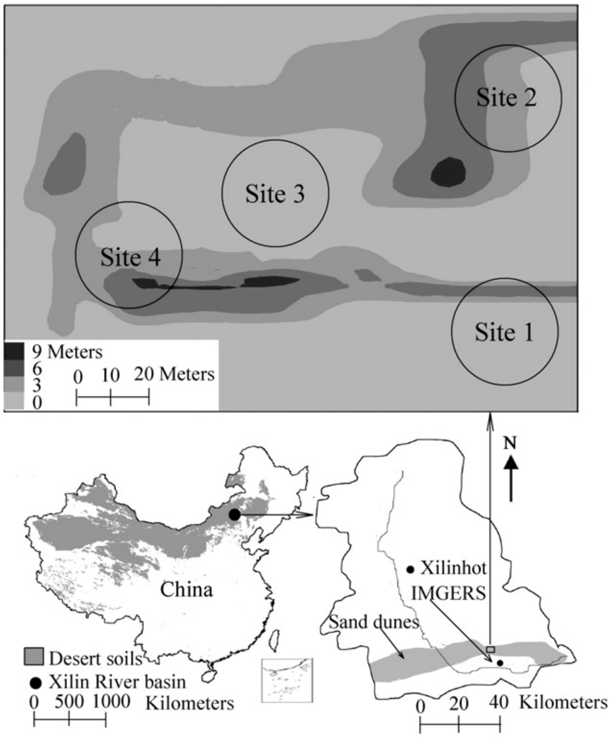

Fig. 1. Geographic distribution of desert soils in China and the objective area in this study. The four sampling sites are located in about 200 m north of IMGERS (Inner Mongolia Grassland Ecosystem Research Station), Chinese Academy of Sciences.

2. Methods and materials

2.1. Site description

This study selected a fenced sandy land of the Xilin River basin in the eastern Inner Mongolia Plateau (Fig. 1). The basin (43°26′–44°39′ N, 115°32′–117°12′ E; 902–1506 m above sea level; 10,786 km^2) is within the semiarid temperate zone with a mean annual temperature of approximately 0.6 °C (see Z.P. Wang et al., 2009). Desert soils in the basin had been wind-deposited during the drought desertification period of late Pleistocene and are presently existed in the form of sand dunes. The soils are Arenosols according to WRB classification (IUSS Working Group WRB, 2006). Plants usually grow from late April to early October. Dominant plant species are *Artemisia frigida*, *Artemisia arenaria*, *Poa attenuata*, *Prunus padus*, and *Ulmus macrocarpa*.

2.2. Experimental design

A series of experiments were conducted in the four sites of sand dunes (Fig. 1), since one site cannot simultaneously meet all measurements without disturbance. Specifically, diurnal and seasonal CH_4 uptake were measured in site 1, while vertical CH_4 concentrations and uptake in sites 1 and 2. The effects of rainfall and water application on CH_4 uptake were investigated in sites 2 and 4, respectively, while plant species in site 3. These experiments were conducted in the growing seasons of 2009, 2010, and 2011 (see figure legends). A few of chamber base plots were randomly determined in each site, a circle with about 30 m diameter.

Static chamber technique was used for measurements of in situ CH_4 uptake. Bases were installed 10 cm into desert soils 1 week prior to formal measurements and were left in place throughout the measurement period. Each base is a white polyvinyl chloride frame (10 cm in height, 50 cm in inner width, and 50 cm in inner length) with a channel on the top. Water was irrigated into the channel to form a gastight seal via placing a 25-cm-tall stainless steel chamber. The chamber was covered with white plastic foam to block light and minimize internal heating. Plants inside and outside each base plot were not noticeably different. Chamber headspace gas samples were collected at 0, 10, 20, and 30 min using 50-ml polypropylene syringes fitted with three-way nylon stopcocks. Mercury thermometers were installed into desert soils in various horizons. Chamber headspace air temperature was recorded during gas sampling. Soil temperature was measured nearby the plots. Soil moisture was determined using the soils outside the plots sampled by a stainless steel corer (3.5 cm in diameter) and oven-dried at 105 °C to constant weight.

A gas sampling corer method (Angel and Conrad, 2009) was used to determine vertical CH_4 profile. Stainless steel needles were temporarily inserted into various soil horizons. Each needle (3.5 mm in inner diameter, 6 mm in outer diameter) held three side ports (2 mm diameter) close to sealed end. Rudimental air held in the needle was extracted slowly before gas sampling. 30 ml soil gas was slowly sampled from the midpoint of each soil horizon by gastight syringe fitted with three-way nylon stopcock directly connected with the needle. After gas sampling, desert soils in various horizons were immediately collected and transported to the laboratory and then stored at 4 °C refrigerator in the dark. Potential CH_4 uptake was measured by the use of these desert soils within three days. Specifically, fresh desert soils were incubated in 300-ml bottles under ambient atmosphere of 25–27 °C in the dark for approximately 24 h.

In natural rainfall experiment, half of plots were exposed to rainfall whereas other plots were covered by the use of 1-m^2 sheet irons that were supported 30 cm height from surface soils by four steel needles. All plots were exposed to the atmosphere during no rainfall. In water application experiment, water amount was determined at 100%, 50%, and 150% levels that represent a multi-year mean rainfall in local area, a 50% decrease than the mean, and a 50% increase than the mean. Mean multi-year rainfall was 66 mm in August at Inner Mongolia Grassland Ecosystem Research Station. This water amount is assumed to equably distribute in August in three times. Thus, water of 11, 22, and 33 mm were artificially applied in the three treatments, respectively. Intact soil cores (80 cm in depth, 50 cm × 50 cm in top area) were formed by driving 80-cm-long anti-rust iron tubs (50 cm × 50 cm in top area) into soils. Bases were connected and sealed to the soil cores by the use of adhesive tape and fenced with desert soils. Although intact soil cores were not sealed at bottoms, these tubs availably prevented soil moisture exchange between core soils and outer soils. In situ core soils were equilibrated one week prior to formal measurements.

2.3. CH_4 measurement

CH_4 concentration was analyzed by use of a Hewlett-Packard 5890 Series II Gas Chromatograph within 24 h of sampling. The GC running conditions were described previously (Wang and Han, 2005). Certified CH_4 standard in 2.03 $\mu l\,l^{-1}$ (China National Research Center for Certified Reference Materials, Beijing) was used for calibration. The single-point calibration was valid since measured CH_4 concentrations had a narrow range such as 1.0–2.0 $\mu l\,l^{-1}$.

2.4. Soil and plant characteristic analysis

For analyzing soil characteristics, desert soils were sampled using a stainless steel corer (3.5 cm in diameter). The soils were processed briefly in the field such as removing gravels and litters, and then taken to the laboratory. Air-dried soils were sieved through 2 mm mesh and ground to fine powder (mesh number 100) with a pestle and mortar. Soil characteristics were determined following standard procedures (Liu, 1996). Soil pH was determined by shaking air-dried soil of 5 g in 25 ml deionized water, using a glass combination electrode (PH B-4, Leici Ltd., Shanghai). Soil organic carbon was determined using the combustion method. First, 5 ml 0.8-M $K_2Cr_2O_7$ solution and 5 ml H_2SO_4 were added into the weighed soils and then