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Methane uptake by four land-use types in the agro-pastoral region of northern China

Yuping Rong [a,*], Lei Ma [a], Douglas A. Johnson [b]

[a] Grassland Institute of Animal Science and Technology College, China Agricultural University, Beijing 100193, China
[b] USDA-ARS Forage and Range Research Lab, Utah State University, Logan, UT 84322-6300, USA

HIGHLIGHTS

- CH_4 fluxes were monitored year-long at four land-use types in northern China.
- Land-use types affected soil sink activity for atmospheric CH_4.
- Annual CH_4 uptake was greatest in the cropland land-use type.
- Non-growing season CH_4 uptake represented 50% of annual uptake for grassland types.
- 21% of annual uptake during non-growing season for cropland and perennial pasture.

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ABSTRACT

Land-use types and management practices of temperate semiarid steppes may affect soil sink activity for atmospheric methane (CH_4). Most previous studies related to CH_4 have focused primarily on the growing season with only a few studies evaluating CH_4 fluxes throughout the entire year. With CH_4 exchange largely undocumented during the non-growing season, the annual CH_4 uptake in different land-use types under various management practices is uncertain. The aim of this study was to investigate the annual variation of CH_4 fluxes from four land-use types (ungrazed grassland, moderately grazed grassland, perennial pasture and cropland), which are the dominant land-use types in the agro-pastoral region of northern China. Fluxes of CH_4 were measured throughout the year in four land-use types using a mobile greenhouse gas analyzer. Results showed that soils were a sink for atmospheric CH_4 throughout the year for all land-use types. Annual CH_4 uptake patterns were similar (but with quite different magnitudes) for all land-use types with low, spiky uptake during the two freeze-thaw periods, low and constant uptake during the frozen period and highly variable uptake with some emission events during the growing season. Seasonality of CH_4 uptake was related to monthly mean temperature and precipitation. Monthly mean temperature and precipitation explained 56% (range: 40–83%) of the variability in monthly cumulative soil CH_4 uptake. Annual CH_4 uptake across all land-use types averaged 3.9 ± 0.3 kg C ha^{-1} yr^{-1} (range: 1.0–10.2). CH_4 uptake during the non-growing season represented about 50% (range: 41–59%) of annual CH_4 uptake for the grassland types and 21% (range: 20–22%) for the cropland and perennial pasture land-use types. Moderate grazing (stocking rate 1.43 sheep ha^{-1} yr^{-1}) significantly increased annual CH_4 uptake by 78% ($P < 0.05$) compared to ungrazed grassland. The highest annual CH_4 uptake was observed for cropland (10.2 ± 0.2 kg C ha^{-1} yr^{-1}), followed by 2.7 kg $\pm$ 0.1C ha^{-1} yr^{-1} for perennial pasture. Our results documented year-long CH_4 fluxes in four important land-use types in the expansive agro-pastoral region of northern China and contribute to our understanding of soil uptake levels of atmospheric CH_4.

1. Introduction

Natural methane (CH_4) emissions are an important component of the global CH_4 budget for terrestrial ecosystems, and the magnitude of these emissions are dependent on climate, ecosystem type and soil characteristics (Curry, 2007; Dutaur and Verchot,

* Corresponding author. Department of Grassland Science, China Agricultural University, 2 Yuanmingyuan West Rd., 100193 Beijing, China.
E-mail addresses: rongyuping@cau.edu.cn (Y. Rong), doug.johnson@ars.usda.gov (D.A. Johnson).

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2007; Spahni et al., 2011). Processed-based models provide a mechanistic understanding of the global terrestrial CH_4 budget and suggest that terrestrial CH_4 feedbacks will play an increasingly critical role in climate change (Potter et al., 1996; Curry, 2007; Spahni et al., 2011; Ito and Inatomi, 2012). CH_4 is a prevalent greenhouse gas with a global warming potential 25 times greater than that of CO_2, and oxidation of CH_4 by OH radicals in the troposphere is the primary sink for atmospheric CH_4 (IPCC, 2007). Atmospheric CH_4 is also consumed by methanotrophic microbes in aerobic soils. Estimates of the global soil sink for CH_4 vary from 20 to 45 Tg CH_4 yr^{-1} (Dutaur and Verchot, 2007).

Temperate grasslands account for a large fraction of the earth's vegetation (White et al., 2000), are important global soil sinks for C (Guo and Gifford, 2002) and play a critical role in the global C cycle. Soil CH_4 flux in terrestrial systems is sensitive to land-use practices such as livestock grazing and cropland production (Awasthi et al., 2005). The effects of CH_4 on global climate change and its relation to land use are particularly important for the vast areas of the agro-pastoral zone in northern China, which is one of the regions of the world where the impact of global climate change is predicted to be large (White et al., 2000).

In the past few decades, rapid population growth in northern China have increased demands on farmlands and grasslands for food production, which is leading to grassland overgrazing and conversion of grassland to cropland (Zhao et al., 2002). The prevailing semi-arid climate and sandy topography in the region make these agro-ecosystems vulnerable and less resilient to disturbances (White et al., 2000). The destruction of grassland ecosystems and their conversion to croplands can result in severe desertification (Wu and Tiessen, 2002; Yang et al., 2005; Wang et al., 2011), which can reduce soil C storage (Xie et al., 2007; Klumpp et al., 2007), decreased soil fertility (Guo and Glifford, 2002; Xie and Wittig, 2004) and rapid decomposition of accumulated soil organic matter (Wang et al., 2011). A number of studies have evaluated CH_4 fluxes on grasslands in northern China (Wu et al., 2010; Chen et al., 2010, 2011; Luo et al., 2013) and examined the influence of various management practices such as grazing (Chen et al., 2011; Wang et al., 2012; Tang et al., 2013) and fencing (Chen et al., 2011) on CH_4 fluxes. However, few studies have compared CH_4 fluxes of grazed and ungrazed grasslands to artificial perennial pastures and croplands throughout the entire year.

Soils both produce and consume CH_4 with net soil atmosphere CH_4 flux being the net result of two offsetting processes of microbial production and consumption. Soil temperature and water content are two physical factors that directly control CH_4 uptake in different ecosystems. Diffusivity of CH_4 in the soil profile also limits soil CH_4 uptake (Wu et al., 2010). Factors affecting soil aeration such as soil texture, soil water content and land-use practices significantly affect soil CH_4 uptake across the soil-atmosphere interface (Mosier et al., 1997; Smith et al., 2003; Maljanen et al., 2004). Data documenting CH_4 uptake in temperate and tropical grasslands are limited, especially as relates to different land-use practices.

To clarify the relationship between soil CH_4 exchange and land management practices in the agro-pastoral region of northern China on an annual basis, we obtained year-long measurements of CH_4 on ungrazed grassland, grazed grassland, perennial pasture and cropland. The objectives of this study were to: 1) determine seasonal changes in soil uptake of CH_4 in major land-use types, 2) evaluate the influence of soil water content (SWC) and temperature on soil CH_4 fluxes and 3) quantify annual soil CH_4 fluxes in these four land-use types.

2. Materials and methods

2.1. Site description

Experiments were conducted at the Guyuan National Grassland Ecosystem Research Station in the agro-pastoral transition region of northern Hebei Province in China (41°46′ N, 115°41′ E, elevation 1380 m). This area has a semiarid continental monsoon climate, which in summer is dominated by warm, moist air currents from the Pacific Ocean. Autumn, winter and spring seasons are dominated by cold, dry air currents from Mongolia. Mean annual precipitation is about 400 mm, nearly 79% of which is received between July and September. Mean annual temperature in the area is 1 °C with a mean minimum temperature of −18.6 °C (January) and mean maximum of 17.6 °C (July). Annual evaporation in the study area is about 1735 mm, which is more than four times the mean annual precipitation.

Guyuan County has 1,040,000 ha of permanent cropland and 1,117,330 ha of grassland. Our experiment was conducted in four land-use types: 1) ungrazed grassland (UG), 2) moderately grazed grassland (MG), 3) perennial pasture (PP) and 4) cropland (CL). The land-use types were 5–24 ha in size and were located within 50–500 m from each other. The UG and MG sites (1.5 ha each) were located about 100–150 m apart within a 24-ha area. The UG site was ungrazed since 2010, while the MG site was grazed at an intensity of 6.7 sheep/ha during the growing season with 50–55% biomass removal (equivalent to 1.43 sheep units/ha/year) (Ma et al., 2014). The vegetation in the UG and MG land-use types was dominated by C_3 perennial grasses (*Leymus chinensis*, *Stipa krylovii* and *Phragmites communis*), a C_4 perennial grass (*Cleistogenes squarrosa*), a C_3 sedge (*Carex duriuscula*) and several broad leaf species (*Taraxacum mongolicum*, *Artemisia frigida*, and *Polygonum sibiricum*). The PP land-use type included an area of 10 ha that was converted from native grassland to mainly *L. chinensis* in 2009. The PP land-use type is used for haying 10–20 Aug. each year with the remaining stubble grazed by sheep and cattle during autumn and winter. The CL land-use type was converted from native grassland to cropland in 1980 and has been plowed annually since then with a crop rotation of two years of *Avena nuda* and one year of *Linum usitatissimum*. No irrigation was applied to any of the land-use types, and fertilizers were applied only to the CL type at a rate of 100 kg/ha manure each year before sowing and 40 kg/ha urea at sowing. Soils for all four land-use types are chestnut soil (Chinese classification) or a Calci orthic Aridisol (USA classification).

In early August 2013, vegetation and soil properties in each land-use type were measured. Aboveground biomass was measured using 0.5 m × 0.5 m quadrat with five replications. Plants were clipped to a 1-cm height and dried in an oven at 80 °C for 48 h to constant weight. Belowground biomass was determined at the sampling locations where aboveground biomass was determined using a soil auger (6.5-cm inside diameter) to a 12-cm depth. Belowground samples were placed in a 0.02-mm nylon mesh bag, dried in an oven at 80 °C for 48 h and weighed. Soil bulk density was determined from five replicate samples using the ring-knife method (ISSCAS, 1978). For analysis of soil characteristics, five soil samples (each sample consisting of a mixture of five sampling points) were collected at each site to a 12-cm soil depth and dried at room temperature prior to analysis (Table 1).

2.2. CH_4 flux measurements

In September 2012 (about one week before measurements commenced), five PVC collars (20-cm diameter, 15-cm height, 1.5–2-mm thickness) were inserted 12 cm into the soil of each land-use type. During the growing season about 48 h before each measurement period, aboveground biomass was removed from the area inside the PVC collars.

A mobile Greenhouse Gas Analyzer (LGR-9080010, Los Gatos Research Inc., USA), which used off-axis integrated-cavity output spectroscopy (laser spectrum technology), was used to measure