Science of the Total Environment 612 (2018) 799–808

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

# Response of soil methane uptake to simulated nitrogen deposition and grazing management across three types of steppe in Inner Mongolia, China

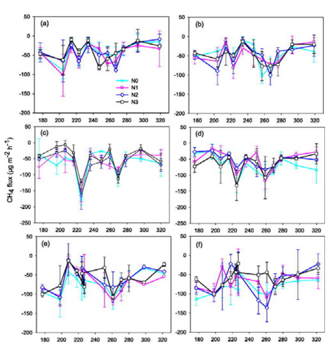
Xianglan Li [a,b,*], Hong He [a,b], Wenping Yuan [c,d], Linghao Li [e], Wenfang Xu [d,f], Wei Liu [c,e], Huiqiu Shi [e,f], Longyu Hou [g], Jiquan Chen [h], Zhiping Wang [e]

[a] College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China
[b] Joint Center for Global Change and China Green Development, Beijing Normal University, Beijing 100875, China
[c] School of Atmospheric Sciences, Sun Yat-Sen University, Guangzhou 519082, Guangdong, China
[d] State Key Laboratory of Cryospheric Sciences, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, Gansu 730000, China
[e] State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China
[f] University of the Chinese Academy of Sciences, Beijing 100049, China
[g] Department of Grassland Science, China Agricultural University, Beijing 100193, China
[h] College of Social Science, Department of Geography, Michigan State University, East Lansing, MI 48824, United States

## HIGHLIGHTS

- The interaction of nitrogen deposition, steppe types, and fencing management on $CH_4$ uptake was studied.
- The steppe was a significant sink for $CH_4$, significantly decreased ($P < 0.05$) with increasing N deposition rates.
- Soil $CH_4$ uptake was the highest in desert steppe, intermediate in typical steppe, and the lowest in meadow steppe.

## GRAPHICAL ABSTRACT



The response of soil methane ($CH_4$) uptake to increased nitrogen (N) deposition and grazing management was studied in three types of steppe (i.e., meadow steppe, typical steppe, and desert steppe) under grazed and fenced management in Inner Mongolia, China. Results showed that the continental steppe was $CH_4$ sink (Fig. 2) with the values of 1.12–3.36 kg $ha^{-1}$ over the grass growing season, which was significantly ($P < 0.05$) decreased with increasing N deposition rates. The soil $CH_4$ uptake rates were highest in the desert steppe, moderate in the typical steppe, and lowest in the meadow steppe. Compared with grazed plots, fencing increased the $CH_4$ uptake by 4.7–40.2% with a mean value of 20.2% across the three different steppe types. The responses of soil $CH_4$ uptake to N deposition in the continental steppe varied depending on the N deposition rate, steppe type, and grazing management. A significantly positive correlation between $CH_4$ uptake and soil temperature was found in this study. Our results may contribute to the improvement of model parameterization for simulating biosphere-atmosphere $CH_4$ exchange processes and for evaluating the climate change feedback on $CH_4$ soil uptake.

Fig. 2 Seasonal variation in $CH_4$ fluxes as affected by increasing N deposition in three different types of continental steppe under grazed and fenced conditions during the growing season from May to October 2012, i.e., meadow steppe grazed (a) and fenced (b), typical steppe grazed (c) and fenced (d), and desert steppe grazed (e) and fenced (f). Error bars indicate standard errors (n = 3) of the mean.

* Corresponding author at: College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China.
*E-mail address:* xlli@bnu.edu.cn (X. Li).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.236

A R T I C L E I N F O

*Article history:*
Received 31 May 2017
Received in revised form 22 August 2017
Accepted 22 August 2017
Available online xxxx

Editor: Jay Gan

*Keywords:*
$CH_4$ exchange
Meadow steppe
Typical steppe
Desert steppe
Inner Mongolia

A B S T R A C T

The response of soil methane ($CH_4$) uptake to increased nitrogen (N) deposition and grazing management was studied in three types of steppe (i.e., meadow steppe, typical steppe, and desert steppe) in Inner Mongolia, China. The experiment was designed with four simulated N deposition rates such as 0, 50, 100, and 200 kg N $ha^{-1}$, respectively, under grazed and fenced management treatments. Results showed that the investigated steppes were significant sinks for $CH_4$, with an uptake flux of 1.12–3.36 kg $ha^{-1}$ over the grass growing season and that the magnitude of $CH_4$ uptake significantly ($P < 0.05$) decreased with increasing N deposition rates. The soil $CH_4$ uptake rates were highest in the desert steppe, moderate in the typical steppe, and lowest in the meadow steppe. Compared with grazed plots, fencing increased the $CH_4$ uptake by 4.7–40.2% with a mean value of 20.2% across the three different steppe types. The responses of soil $CH_4$ uptake to N deposition in the continental steppe varied depending on the N deposition rate, steppe type, and grazing management. A significantly positive correlation between $CH_4$ uptake and soil temperature was found in this study, whereas no significant relationship between soil moisture and $CH_4$ uptake occurred. Our results may contribute to the improvement of model parameterization for simulating biosphere-atmosphere $CH_4$ exchange processes and for evaluating the climate change feedback on $CH_4$ soil uptake.



## 1. Introduction

Anthropogenic nitrogen (N) deposition, mainly originating from fertilizer application, fossil fuel combustion, and legume cultivation, has drastically increased around the world since the industrial revolution (Matson et al., 2002; Galloway et al., 2008; Pan et al., 2012). It is thought that this increasing trend will accelerate over the next few decades (Galloway et al., 2004). Elevated N deposition induced by human activities contributes to many negative effects on terrestrial ecosystems, such as reducing biodiversity and causing soil acidification (Liu et al., 2011; Song et al., 2011). In addition, atmospheric N deposition affects a range of biogeochemical processes in terrestrial ecosystems that control the production and consumption of greenhouse gases (GHGs) (Matson et al., 2002; Templer et al., 2012). Recently, the effect of anthropogenic N deposition on GHG fluxes has caused great concern due to the important role that GHGs play in regulating global climate change.

Continental steppe soils are commonly sinks for $CH_4$ because of their well-aerated mineral soils that support methanotrophic activity, and because the magnitude of the $CH_4$ sink is affected by steppe type, grazing management, and simulated N depositions rate (Tang et al., 2013; Zhang et al., 2012, 2016). A number of field experiments have been carried out to investigate the individual impact of N deposition (Wei et al., 2014; Zhao et al., 2017), steppe type (Li et al., 2015), and grazing management (Tang et al., 2013; Zhu et al., 2015) on $CH_4$ efflux in semiarid grasslands. As we know, N deposition was an important factor that controls the potential of steppe soils to act as sinks for atmospheric $CH_4$ (Ambus and Robertson, 2006; Jassal et al., 2011; Jiang et al., 2010; Li et al., 2012; Mosier et al., 2003; Templer et al., 2012; Chen et al., 2013). The impact of grazing management on $CH_4$ uptake has been widely investigated in grasslands, showing different impacts of grazing management on $CH_4$ uptake (Wei et al., 2014; Tang et al., 2013; Zhao et al., 2017). Most studies of soil-atmospheric $CH_4$ exchange have been conducted in typical steppes in Inner Mongolian steppe (Wang et al., 2005; Liu et al., 2007; Chen et al., 2011a, 2011b, 2013). Across different steppe types, $CH_4$ uptake in the desert steppe increased 20.4% and 51.2% compared with the typical steppe and meadow steppe, respectively (Tang et al., 2013). However, to the best of our knowledge, few reports are available on soil-atmospheric $CH_4$ exchanges to study the interaction of steppe types, N deposition, and grazing management. The interactive effect of these three factors on the absorption of $CH_4$ is not well understood and has not been thoroughly evaluated in Inner Mongolia, China.

Chinese steppes, covering approximately 41.7% of China's land area, are distributed mainly in Inner Mongolia, Xinjiang, Gansu, and the Qinghai-Tibet Plateau (NSBC, 2002). They are part of a continuous expanse of approximately 12.5 million $km^2$ of temperate grasslands, >8% of the earth's total land surface area (Tang et al., 2013). The aims of this study are to (1) investigate soil-atmosphere $CH_4$ exchange during the growing season in the three dominant types of steppe ecosystems in Inner Mongolia, China; (2) assess the interactive effects of the N deposition rate, grazing management, and steppe type on the dynamic variation in $CH_4$ fluxes; and (3) evaluate the relationship between $CH_4$ uptake and environmental factors.

## 2. Materials and methods

### *2.1. Site description*

The experiment examined three types of steppe, meadow steppe (120.3 N, 45.1E), typical steppe (116.7 N, 43.6E), and desert steppe (111.9 N, 41.8E), along a 1200-km grassland transect located in Inner Mongolia, China (Fig. 1). The altitudes of these three sites are 656, 1453, and 1428 m, respectively (Cheng et al., 2009). This transect covers a mean annual precipitation (MAP) gradient from 120 to 450 mm and a mean annual temperature gradient from 0.5 to 7.1 °C, and rainfall was the main driving factor of steppe type (Cheng et al., 2009). All three investigated types of steppe were among the dominant steppe types in this region. Experiment site #1 was located on private land rented from local farmers who gave permission to conduct the study at this site. Experiment site #2 was located at a long-term experimental station for the Inner Mongolia grassland ecosystem operated by the Chinese Academy of Sciences. Experiment site #3 was conducted another long-term experimental station for the grassland ecosystem in Siziwang Banner (Fig. 1). None of the field studies involved endangered or protected species.

The meadow steppe is located in the northeastern of Xilingol of Inner Mongolia (120.3 N, 45.1E). The climate is the temperate continental. The mean annual temperature and precipitation is 1.2 °C and 370 mm, respectively, with frost-free period of 106 days (Tang et al., 2013). The annual precipitation mostly occurred during July through August. The soil type is typical kastanozem with soil pH of 6.31 and soil bulk density of 1.06 g $cm^{-3}$. Soil C and soil N ranged from 0.16–0.27% and 1.46–2.77%, respectively (Table 1). The grassland is dominated by *L. chinensis* (Trin.) Tzvel., *Stipa baicalensis* Roshev., and *Filifolium sibiricum* (L.) Kitam. The ground coverage of vegetation is 60–75% (Tang et al., 2013).

The typical steppe is located in the Xilingol of Inner Mongolia (116.7 N, 43.6E). The climate is the temperate continental and semi-arid. The growing season starts in early May and ends in late September. The annual average temperature is 0.7 °C with a frost-free period of 98 days (Liu et al., 2007). Annual mean precipitation is 330 mm with 60–80% falling between June and August. Soil type is Kastanozem (FAO soil classification), with soil pH of 7.06 and soil bulk density of 1.07 g $cm^{-3}$. Soil C and soil N ranged from 0.14–0.20% and 1.26–1.52%, respectively (Table 1). The constructive species is *L. chinensis*