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Annual methane budgets of sheep grazing systems were regulated by grazing intensities in the temperate continental steppe: A two-year case study

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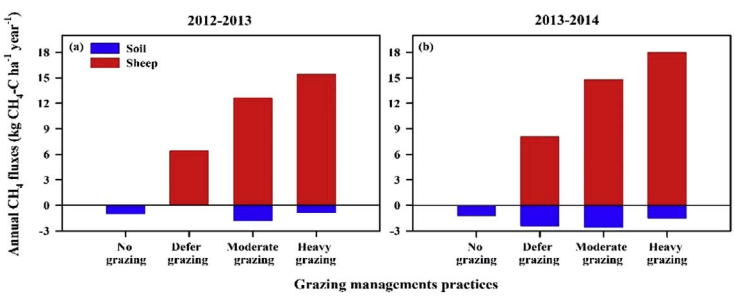
GRAPHICAL ABSTRACT



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ABSTRACT

Methane (CH_4) emission from animal husbandry accounts for a large percentage of anthropogenic contributions to CH_4 emissions. Fully understanding of grazing management effects on the CH_4 budget is essential for mitigating CH_4 emissions in the temperate grazing steppe systems. Annual CH_4 budgets for the sheep grazed steppes at various grazing intensities, un–grazing (UG, 0 sheep $ha^{-1}year^{-1}$), defer grazing (DG, 1.0 sheep ha^{-1} $year^{-1}$), moderate grazing (MG, 1.43 sheep $ha^{-1}year^{-1}$), and heavy grazing (HG, 2.43 sheep $ha^{-1}year^{-1}$) were assessed across 2012–2014 in the agro–pastoral region of northern China. Annual soil CH_4 uptake averaged across 2012–2014 were 1.1 ± 0.1, 2.4 ± 0.2, 2.2 ± 0.2, and 1.3 ± 0.1 kg CH_4–C ha^{-1} for UG, DG (only 2013–2014), MG and HG sites. Non–growing season CH_4 uptake comprised 50.0 ± 4.3% of annual CH_4 uptake in 2012–2013 and 37.7 ± 2.0% in 2013–2014. DG and MG significantly promoted annual soil CH_4 uptake ($P < 0.05$), while there was no difference between HG and UG ($P > 0.05$). Bell–shaped relationship was presented between stocking rates and soil CH_4 uptake ($r^2 = 0.59$, $P < 0.05$). Annual soil CH_4 uptake significant linearly and positively correlated with root biomass ($r^2 = 0.30$, $P < 0.05$). Annual CH_4 budgets for the grazed grasslands were −1.1 ± 0.1, 5.7 ± 0.6, 11.5 ± 1.5 and 15.5 ± 1.3 kg CH_4–C ha^{-1} $year^{-1}$ in UG, DG (only 2013–2014), MG and HG across 2012–2014. Soil CH_4 uptake could offset 29.7 ± 5.6, 15.9 ± 4.3 and 6.8 ± 1.0% of total annual CH_4 emissions from sheep, sheepfold and faeces in DG, MG, and HG. All grazed steppes are sources for atmospheric CH_4 and the magnitude is regulated by grazing intensities. Sheep CH_4 emissions for 1–g liveweight gain were 0.21, 0.32 and 0.37 g CH_4–C in DG, MG and HG, respectively. DG is the recommended grazing management in this region to achieve greater herbage mass, higher sheep performance and lower CH_4 emissions simultaneously.

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1. Introduction

Methane (CH_4) is a long–lived greenhouse gas that has 34 times greater global warming potential than CO_2 across a 100-year timescale (IPCC, 2013). Increase of atmospheric CH_4 concentrations from 722 ppbv in 1750 to 1845 ppbv in 2015 has a great impact on global warming (WMO, 2016). CH_4 emission from human activities contributes 50–65% of total CH_4 emissions (IPCC, 2013); 25% of this amount relates to domestic ruminant husbandry (Ghosh et al., 2015). Therefore, accurate evaluation of grazing management practices on CH_4 budgets is necessary for mitigating CH_4 emissions.

Temperate grasslands occupy vast areas of the earth's surface. They are critical resources for livestock grazing (Glindemann et al., 2009) and are an important component of the global CH_4 budget (Allard et al., 2007). The CH_4 budget for grazed grassland was determined by the difference between CH_4 emission of grazing ruminants during forage digestion and CH_4 consumed by soil methanotrophs (Dong, 1998; Hart et al., 2009). Numerous CH_4 flux measurements have been conducted using chambers (Mosier et al., 1991, 1996; Mosier and Delgado, 1997; Wang et al., 2005; Liu et al., 2007; Holst et al., 2008; Liebig et al., 2010; Chen et al., 2011a; Tang et al., 2013; Rong et al., 2015) and eddy covariance (Dengel et al., 2011; Merbold et al., 2014; Dumortier et al., 2017) on grassland–atmosphere CH_4 exchange in grazed grasslands. The results demonstrated that grazed grasslands were net sources for atmospheric CH_4 either in European grasslands (Flessa et al., 2002; Allard et al., 2007; Pinares–Patiño et al., 2007; Soussana et al., 2007; Dengel et al., 2011; Merbold et al., 2014; Dumortier et al., 2017) or in northern Great Plains (Liebig et al., 2010). The grazed steppe in Inner Mongolia emitted 1.5–3.6 kg CH_4–C ha^{-1} during the growing season (Liu et al., 2009) and 8.6 kg CH_4–C ha^{-1} for the entire year (Wang et al., 2009). Livestock grazing altered soil physical, chemical and biological conditions, which affected soil CH_4 consumption and production (Liu et al., 2007, 2017; Chen et al., 2011a; Wang et al., 2015). CH_4 emissions for animal enteric fermentation were significantly related to livestock grazing intensity (Soussana et al., 2007; Schönbach et al., 2012). To date, only Schönbach et al. (2012) estimated a CH_4 budget for different grazing intensities in Inner Mongolia, China. Therefore, more data are needed to evaluate grazing intensity effects on CH_4 budgets for the extensively grazed grasslands in this area.

In this study, annual soil CH_4 uptake for grasslands grazed at various intensities were measured in the agro–pastoral region of northern China during 2012–2014. CH_4 budgets were estimated using field soil CH_4 flux measurements and associated data from other studies in this region. Data for sheep CH_4 emissions, excreta emissions, organic matter intake and sheep liveweight gain were obtained from previous studies at these sites (Wang et al., 2013, 2015; Ma et al., 2014) and livestock sheepfold CH_4 emissions were obtained from the studies of Liu et al. (2009) and Chen et al. (2011b) conducted near our sites. The objectives were to assess the CH_4 budgets for various grazing management practices and identify the optimal grazing management practices. We hypothesized that CH_4 budgets for the grazed ecosystem would increase with increasing grazing intensities. Higher grazing intensity led to greater soil compaction and lower soil nutrients which inhibited soil CH_4 uptake, while increasing CH_4 emissions from ruminants enteric, excreta and livestock pens.

2. Materials and methods

2.1. Study site description

The study was conducted at the National Grassland Ecosystem Research Station (41°46′ N, 115°41′ E, elevation 1380 m), located in Hebei Province, China. Geographically this region is part of the southeastern edge of the Mongolian Plateau and is a temperate steppe. The local climate is temperate continental monsoon, with a frost–free period of 85–95 days. The vegetation growing season is relatively short (May through September) in comparison with the period of non–-growing season (Holst et al., 2008; Chen et al., 2011a; Fan et al., 2016; Liu et al., 2017). Mean annual temperature (T_a) is 1.0 °C, with a mean minimum temperature of −18.6 °C in January and mean maximum temperature of 17.6 °C in July. Mean annual precipitation is 350–400 mm of which ~80% is received between June and August. The low precipitation and strong winds during winter usually lead to a shallow and unevenly distributed snow–cover (Holst et al., 2008). Soil at the study site is classified as Kastanozem (FAO, 2006).

The vegetation is dominated by perennial grasses (*Leymus chinensis* [Trin.] Tzvel., *Stipa grandis* P. Smirn., *Phragmites communis* [Cav.] Trin. ex Steu., and *Cleistogenes chinensis* [Maxim.] Keng.); a sedge (*Carex duriuscula* C. A. Mey.); and several broadleaf species (*Taraxacum mongolicum* Hand.–Mazz., *Artemisia frigida* Willd. Sp. Pl., and *Polygonum sibiricum* Laxm.) (Ma et al., 2014). Total vegetation coverage is 60–70% with a mean height of 20–30 cm. The vegetation and soil characteristics at the grazed sites are listed in Table 1.

2.2. Experimental design

This experiment was conducted at four sites (1.5 ha each) within a 24–ha area maintained at four grazing intensities: un–grazing (UG), defer grazing (DG), moderate grazing (MG), and heavy grazing (HG) (Ma et al., 2014). The area encompassing the study sites was seriously degraded due to heavy grazing by beef cattle and sheep for more than five decades before 2009. The experimental area was closed to grazing

Table 1
The characteristics of vegetation and soil (mean ± SE) in un–grazing (UG), defer grazing (DG), moderate grazing (MG), and heavy grazing (HG) sites.

Parameters[1]	UG	DG	MG	HG
AGB (g m^{-2})	501 ± 9[a]		103 ± 3[b]	65 ± 2[c]
BGB (g m^{-2}) (0–12 cm)	652 ± 7[b]		706 ± 21[a]	394 ± 4[c]
Soil properties (0–12 cm)				
pH (H_2O)	9.15 ± 0.12[a]		9.21 ± 0.20[a]	9.03 ± 0.19[a]
BD (g cm^{-3})	1.34 ± 0.03[a]		1.35 ± 0.04[a]	1.41 ± 0.05[a]
SOC (g kg^{-1})	12.28 ± 1.96[c]	20.08 ± 0.13[a]	18.75 ± 2.28[ab]	13.46 ± 0.20[bc]
TN (g kg^{-1})	1.55 ± 0.07[b]		2.43 ± 0.13[a]	2.22 ± 0.20[a]
NH_4^+ (mg N kg^{-1} dry soil)	2.23 ± 0.32[a]	2.55 ± 0.38[a]	2.81 ± 0.65[a]	2.31 ± 0.61[a]
NO_3^- (mg N kg^{-1} dry soil)	0.73 ± 0.18[b]	0.80 ± 0.17[b]	1.37[a] ± 0.30[a]	1.37 ± 0.24[a]
Soil texture (%)				
Sand (0.05–2 mm)	47.31 ± 24.52[a]		50.02 ± 25.64[a]	53.92 ± 23.84[a]
Silt (0.002–0.05 mm)	49.51 ± 18.4[a]		46.74 ± 20.62[a]	43.04 ± 16.82[a]
Clay (< 0.002 mm)	3.21 ± 1.73[a]		3.22 ± 1.41[a]	3.11 ± 1.82[a]

Data within the same row with different letters indicate significance at $P < 0.05$.
[1]AGB = aboveground biomass, BGB = belowground biomass, BD = Bulk density, SOC = soil organic carbon, TN = soil total nitrogen.
The data in UG, MG, and HG were obtained in early August 2013 and in DG were obtained in early August 2014 with five spatial replicates in each site.