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Moderate grazing has little effect on global warming potential in the temperate steppes of northern China

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ABSTRACT

Grazing has been reported to significantly affect the flux of three greenhouse gases (GHGs: CO_2, CH_4 and N_2O) in grasslands, but its effect on total global warming potential (GWP) is still unclear. To assess the effect of grazing on GWP, we simultaneously measured the flux of these three GHGs using static chambers in meadow, typical, and desert steppes under no grazing (NG) and summer grazing (SG) conditions during the 2012-14 growing seasons. We aimed to examine the impact of grazing on total GWP across different steppes and to assess the relative contribution of different environmental factors to changes in GWP. Our results showed that total GWP values were almost entirely negative in all steppe environments and displayed high spatio-temporal variability. Net ecosystem exchange was the most important predictor of total GWP in all three steppes, and the positive GWP induced by N_2O emission was approximately equal to the negative GWP induced by CH_4 uptake. Steppe type and sampling year—but not grazing treatment—were found to affect GWP. Air temperature and precipitation were the major factors driving total GWP change under the no grazing treatment. In contrast, soil temperature, soil moisture, and precipitation explained a significant percentage of variation in total GWP under the summer grazing treatment. Our study suggests that moderate grazing does not change the role of temperate steppe's function in mitigating climate change; however, multi-year GWP data are necessary for extrapolation to a regional scale.

1. Introduction

The increased atmospheric concentration of greenhouse gases (GHGs) plays a dominant role in climate change and global warming (Mu et al., 2013; IPCC, 2013). Since 1990, the Intergovernmental Panel on Climate Change (IPCC) has used Global Warming Potential (GWP) as an index to integrate the potential impact of the fluxes of different GHGs on climate (IPCC, 2013). Carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O) are the three most important greenhouse gases (GHGs), and contribute 64, 17, and 6%, respectively, of the total global warming potential of all GHGs (IPCC, 2013). Total GWP was determined as the total of all potential tradeoffs and/or synergisms of all GHG fluxes. Therefore, understanding changes in total GWP due to different land use regimes is important to evaluate whether differences in ecosystem usage contribute to global climate change.

GHG fluxes and their respective contributions to total GWP vary among different ecosystems and soils (Mosier et al., 2005; Wang et al., 2011; Mu et al., 2013), as do the particular contributions of each GHG to total GWP (Mosier et al., 2005). For instance, the main contributors to total GWP in paddy soils, intensively managed grasslands in Switzerland, and vegetable croplands in south China were CH_4, N_2O, and CO_2, respectively (Mu et al., 2013; Xu et al., 2017). Moreover, even within the same ecosystem or soil type, the production or uptake of different GHGs can be determined by different environmental factors (Yao et al., 2010; Shi et al., 2017). Any single environmental factor can induce different—and even opposite—effects on GHG flux. For example, soil moisture has been shown to have opposing effects on soil CH_4 uptake and soil respiration (Morgan et al., 2011; Dijkstra et al.,

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2013). Different GHG fluxes also have interactive effects on global warming potential. For example, N_2O and CO_2 fluxes have been shown to produce significant interactions in meadow steppe (Holst et al., 2008; Yao et al., 2010; Shi et al., 2017). In addition, the mechanisms that regulate the relationship between CH_4 uptake and N_2O emission have been shown to be different among steppe types (Shi et al., 2017). Thus, evaluating total GWP and how it changes with various environmental factors in a specific ecosystem will advance our understanding of how feedback in that ecosystem may contribute to climate change.

Grasslands cover about 20 percent of the temperate land surface of the Earth and are widely used as pastures (Wolf et al., 2010). Previous studies have shown that changes in CO_2, CH_4, and N_2O fluxes depend on grazing intensity and steppe type (Buchmann et al., 2011; Imer et al., 2013; Hou et al., 2016). These studies also identified different factors causing the production and consumption of different greenhouse gases (Merbold et al., 2014; Li et al., 2015). However, these studies only focused on individual GHG fluxes without quantifying the total GWP. To assess the total potential impact on climate change, it is necessary to simultaneously investigate the contributions of each of the GHGs over a long (i.e. multiple-year) time scale.

In this study, we obtained measurements of CO_2, CH_4, and N_2O fluxes in 3 years at three temperate steppe sites (i.e. meadow, typical, and desert steppes) with both no grazing and summer grazing treatments. From these data, the total GWP was calculated using the calculation method specified by the IPCC (2013). The objectives of this study were (1) to test the effects of grazing and steppe type on total GWP across years, and (2) to analyze the relative contributions of different environmental factors in driving changes in GWP by studying interannual and spatial variations in these factors as well as in total GWP.

2. Materials and methods

2.1. Site and experimental description

Temperate steppe is one of the largest terrestrial biomes worldwide, and is widely used for grazing and other economic activities related to livestock production. The Inner Mongolian steppe is part of a continuous expanse of approximately 12.5 million km^2 of temperate grasslands that make up more than 8% of the earth's land surface area (Tang et al., 2013). This steppe has a temperate continental monsoon climate, and the growing season starts in early May and ends in late September (Hou et al., 2016). In 2011, we created east-west transects of the Inner Mongolia grassland, and identified meadow steppe, typical steppe, and desert steppe environments. These three steppe types were defined based on the humidity of the steppe climate. The meadow steppe site receives 350–500 mm of annual precipitation, has a mean annual temperature of 1–4 °C, and *Stipa baicalensis* is the dominant species. The typical steppe site was characterized by having 300–400 mm of annual precipitation range, a mean annual temperature between −2.3 and 5 °C, and *Stipa grandis* and *Stipa krylovii* as dominant species. The desert steppe site receives only 135–311 mm of annual precipitation, has an annual temperature of 0.8–5.3 °C, and contains the dominant species *Stipa klemenzii*, *Stipa breviflora*, and *Stipa glareosa* (Miao et al., 2016). The typical steppe site for this experiment is located at the Inner Mongolia Grassland Ecosystem Research Station of the Chinese Academy of Sciences. The desert steppe site was at the Siziwang Experimental Station of the Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences. The meadow steppe also determined after comparing a huge of meadow steppe. The characteristics of the experimental sites are shown in Table 1. The basic properties of the soil were measured in May 2012 and are described in detail in a previous study (Hou et al., 2016).

First, summer grazing plots were 1 ha (100 m × 100 m) and were stocked at a rate of 0.5 sheep per ha during the growing season, which approximated the grazing intensity of the Inner Mongolian grasslands (0.38–0.75 sheep per ha) (Hou et al., 2015). Second, the plots were grazed by one sheep from Jun to September but the sheep was fed by foraging for other foods during the non-growing season. Third, more than 90% of the grassland was degraded in Inner Mongolia, and this grazing intensity is therefore widely used for sustainable management of grassland in this area (Tang et al., 2013).

Table 1
Site specific characteristics and climates in the meadow, typical, and desert steppe sites.

Parameter	Meadow steppe		Typical steppe		Desert steppe	
	NG	SG	NG	SG	NG	SG
Latitude/ Longitude	120.3° N, 45.1° E		116.7° N, 43.6° E		111.9° N, 41.8° E	
Altitude (m)	656		1268		1428	
Soil type	Typical Kastanozem		Calcia Chernozem		Light-colored Chernozemic	
MAP (1971-2000) (mm)	395		293		175	
MAT (1971-2000) (°C)	2.1		−0.3		3.1	
Grazing density (sheep hm^{-2})		0.5		0.5		0.5
Areas (hm^2)	1	1	1	1	1	1
Grazing period		Jun-Sep		Jun-Sep		Jun-Sep
Air temperature (°C)						
2012	20.8		17.3		19.7	
2013	21.5		18.0		19.2	
2014	21.0		17.6		19.6	
Relative humidity						
2012	61.6		54.8		54.8	
2013	58.2		49.6		55.6	
2014	59.7		51.3		50.1	
Soil temperature (°C)						
2012	22.5	23.7	16.6	16.5	20.4	21.4
2013	20.0	20.3	15.8	17.0	22.0	22.6
2014	18.3	18.9	17.0	17.5	23.8	24.4
Soil moisture (v/v%)						
2012	56.8	46.3	33.3	31.5	24.6	25.4
2013	47.8	33.0	19.2	22.0	19.8	18.6
2014	39.6	29.5	17.3	19.3	11.3	12.3

MAP and MAT are the means from 1971 to 2000.
Air temperature and relative humidity values listed are the means of May to September and were supplied by the local meteorological station.
Soil temperature and moisture values are the means of May to September measured in this study.

In 2012, we established paired summer grazing (SG) and no grazing (NG) treatment plots in each of the three steppe types to measure the net ecosystem exchange (NEE, CO_2 flux), CH_4 and N_2O fluxes. The NG plots had been enclosed for more than 15 years. At each site, six bases (0.5 m × 0.5 m) for each treatment (SG vs NG) were installed in the soil at a depth of 10 cm ten days prior to GHG measurement. Of these, three bases were used for NEE measurement and the other three for the measurement of CH_4 and N_2O fluxes.

2.2. GHG sampling and analysis

NEE, CH_4 and N_2O fluxes were measured every ten days from May to September in 2012 and monthly in 2013 and 2014. NEE was measured by transparent chambers (length × width × height = 0.5 m × 0.5 m × 0.4 m), and CH_4 and N_2O were measured by opaque chambers (length × width × height = 0.5 m × 0.5 m × 0.25 m). A detailed account of the transparent and opaque chamber method has been presented in previous studies (i.e. Zhang et al. (2014) and Hou et al. (2012)). GHGs were collected using 100-ml air-tight plastic syringes at 0-, 1-, 2- and 3-min intervals for transparent chambers and at 0-, 10-, 20- and 30-min for opaque chambers after manually closing the chamber (Zhang et al., 2014; Hou et al., 2012). The gas samples were