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*Research Article*

# Effects of Mixed-Grazing on Greenhouse Gas Fluxes During the Growing Season in Desert Steppe

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## Abstract

We studied the effects of different grazing species (cattle grazing (CG), sheep grazing (SG) and mixed-grazing of cattle and sheep (MG)) on fluxes of carbon dioxide ($CO_2$) and methane ($CH_4$) during the growing season in a desert steppe of Inner Mongolia, China. The static chamber method was used to measure fluxes of $CO_2$ and $CH_4$ from June to October, 2013. Results indicate that the grazed desert steppe was a net source of soil atmospheric $CO_2$ exchange and a net sink of soil atmospheric $CH_4$ exchange during the growing season. Grazing species did not alter the $CO_2$ or $CH_4$ flux direction. $CO_2$ flux in the MG plot (256.66 mg $m^{-2}$ $h^{-1}$) was lower than that in CG (351.18 mg $m^{-2}h^{-1}$) and SG (315.38 mg $m^{-2}$ $h^{-1}$) plots. $CH_4$ flux in the MG plot (-0.1330 mg $m^{-2}$ $h^{-1}$) was higher than in the CG (-0.1120 mg $m^{-2}$ $h^{-1}$) and CK (-0.1099 mg $m^{-2}$ $h^{-1}$) plots. Binomial regression equations of the fluxes of $CO_2$ ($R^2 = 0.509$) and $CH_4$ ($R^2 = 0.327$) on soil temperature and moisture were developed. These findings imply that MG reduced $CO_2$ emission by 26.9 % and 18.6 %, and increased $CH_4$ uptake by 18.8 % and 14.7 % compared with CG and SG, respectively, in a desert steppe of Inner Mongolia.

**Keywords:** Greenhouse Gas Flux; Mixed-Grazing; Growing Season; Inner Mongolia Desert Steppe

**Abbreviations:**

CG: Cattle Grazing;
SG: Sheep Grazing;
MG: Mixed-Grazing of Cattle and Sheep;
GHG: Greenhouse Gas

## Introduction

Soil-atmosphere greenhouse gas (GHG) exchange in terrestrial ecosystems has an important effect on global climate change. The carbon dioxide ($CO_2$) concentration in the atmosphere has reached 400 ppm and the average global temperature has increased by 0.85 °C from 1880 to 2012 [1]. Although methane ($CH_4$) flux from the soil-atmosphere is usually smaller than $CO_2$ flux, the global warming potential on a molar basis of $CH_4$ over a 100-year timeframe is 34 times greater than $CO_2$ [2]. Factors affecting the sources and sinks of GHGs in terrestrial ecosystems are therefore an important topic of study. Several studies of $CO_2$ and $CH_4$ fluxes from soils have focused on agricultural and forest ecosystems in the temperate zones of Europe and North America [3-5], and there are more limited reports for semi-arid grassland ecosystems in the Eurasian steppe [6-8].

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Approximately 28 % of the Eurasian steppe and 91 % of the North American prairies (the two historically dominant temperate grassland ecosystems) have already been converted to arable land or other land uses [9]. Livestock grazing is the main land use for remaining steppe and prairie. Over a quarter of the global potential for soil C storage may be influenced by grazing [10]. Direct grazer impact on plant production, and thereby on potential soil C inputs, is likely mediated by grazing intensity, and has been extensively studied by means of theoretical models [11] and through experimentation [12]. Grazers can also indirectly alter plant community composition through their diet selectivity [13,14], and consequently influence soil C inputs [15].

Animal excreta is an important source of GHG [16-19]. Sheep and cattle excreta patches are different in nature by the area covered, nutrient concentration in soil, and the height of fall of excreta [20]. It has been reported that in Inner Mongolian grassland grazing changes soil moisture holding capacity, which in turn affects GHG fluxes [8,21,22]. [23] found that soil water content and temperature were the main factors driving GHG fluxes. Other studies reported that grazing changes the community of soil methanotrophs in typical steppe [24]. [24] found that population of methanotrophs in the topsoil of desert steppe was higher under light grazing and moderate grazing sites than in non-grazed and heavily grazed sites. In tropical conditions, [25] reported that the average biomass of the experimental area was lower with mixed grazing animals (cattle and goats) compared with goat grazing alone, but the average daily gain of goats in mixed grazing conditions was higher than goat grazing alone, suggesting better use of the sward. Grazer type has also been found to influence some characteristics of alfalfa-orchard grass pasture, with mixed grazing promoting a more homogenous harvest than grazing with heifer only, due to lower rejection of dung-contaminated forage [26]. Therefore, the amount of soil C storage may be higher than other grazing species, for example cattle and sheep grazing.

Previous studies on mixed grazing have seldom researched soil-atmosphere GHG exchange in the study region. Therefore, our aims here were to 1) assess the effects of the different grazer species (sheep grazing, cattle grazing, and cattle and sheep mixed-grazing) on $CO_2$ and $CH_4$ fluxes during the growing season in an Inner Mongolian desert steppe; and 2) analyze the relationship between GHG exchange and environmental parameters (soil temperature and moisture). We hypothesized that 1) the different intake behaviors of cattle and sheep grazing affect vegetative characteristics, which in turn affects soil properties and respiration, and 2) soil moisture content and temperature are the principal factors controlling the fluxes of $CO_2$ and $CH_4$.

## Materials and Methods

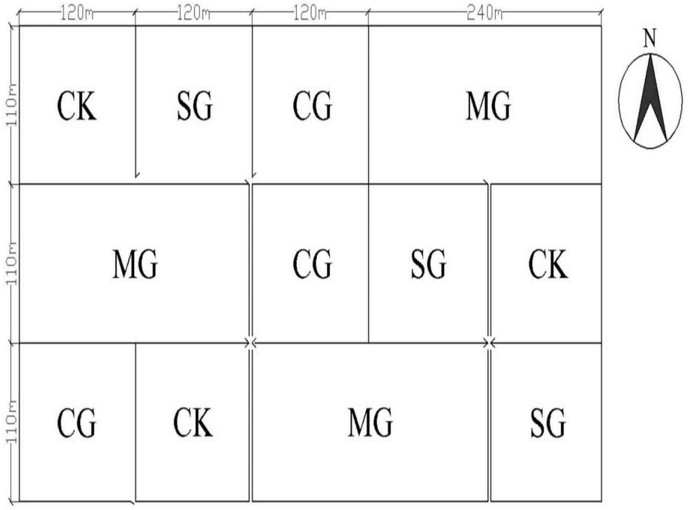
### Study site

The study was conducted in Xilamuren desert steppe, located at 41° 21′ N, 111° 112′ E, at an elevation of approximately 1,602 m above sea level. The regional climate is temperate continental, characterized by a short growing season and long cold winter, with a frost-free period of 83 d. The average annual precipitation is approximately 284 mm, of which nearly 75 % falls from July to September, and evaporation is 2305 mm. The average annual temperature is 2.5 °C and there are 3100–3300 sunshine hours. The dominant soil types are Kastanozem (FAO soil classification) or Brown Chernozem (Canadian Soil Classification) with a loamy sand texture. The steppe is dominated by *Stipa krylovii Griseb*, *Artemisia frigida* Willd, and accompanied by L*eymus chinensis Tzvel, Stellera chamaejasme* Linn, *Leynus secalinus* Tzvel, and *Heteropappus altaicus* Novopokr.

### Experimental design

The fluxes of $CO_2$ and $CH_4$ were measured in twelve grazing plots in 2013. Before a grazing experiment began on these plots in 2012, the area had been under free grazing. The grazing experiment that started in 2012 was composed of four treatments of cattle grazing (CG, 3 cattle per plot), sheep grazing (SG, 15 sheep per plot), mixed-grazing of cattle and sheep (MG, 3 cattle and 15 sheep per plot), and no grazing (CK) with three replicates for each treatment (Figure. 1). Each plot was grazed in the first seven days from June to September only. During this period, sheep and cattle grazed 24 h per day. Then sheep and cattle were moved to other grazing areas after 7 days of grazing. The grazed sheep and cattle were all 1.5 years old. The stocking rate was considered a moderate grazing intensity based on livestock intake, species composition and ground cover in the growing season.

**Figure.1** Schematic diagram of the experimental area. CG: cattle grazing; SG: sheep grazing; MG: mixed-grazing of cattle and sheep



### Measurements of GHGs and environmental factors

Fluxes of $CH_4$ and $CO_2$ were measured using the closed static chamber method [27]. The chamber had a dimension of 50 × 50 × 50 (cm) made of stainless steel. A 9 VDC fan was fixed to the top wall of each chamber to mix the chamber atmosphere. The chamber was covered with a shroud made of camel hair, aluminum foil and white canvas to limit heating of the chamber atmosphere during sampling. Three points were randomly selected in each plot. At each point, the chamber was placed on a steel base frame driven 10 cm into the soil one month prior to the start of the experiment. The base frame had a channel in which the chamber was inserted and the channel was filled with water to seal the chamber atmosphere. During gas flux determination, a disposable syringe (100 ml) with a 3-way valve was used to collect 200 ml of chamber atmosphere into a sample gas bag (Dalian Hede Technologies Co., Ltd., Dalian, China) at 10 min intervals over a 30 min period. The gas samples were taken between 9:30–10:30 am, which are times that are representative of the average rate of $CH_4$ and $CO_2$ fluxes over a 24-h cycle [28]. Soil temperature and moisture (0–10 cm) were measured by thermocouples, a hand-held reader (HH-25TC, OMEGA Engineering Inc., Stamford, CT) and a portable TDR probe (HH2, Delta-T Devices, Cambridge, UK) at the same time as the measurement of GHG fluxes. The concentrations of $CO_2$ and $CH_4$ in the gas samples were analyzed using a cavity ring-down spectrophotometer (Picarro G1301, Santa Clara, USA). Gas fluxes were calculated using the following equation:

$$F = \rho \cdot \frac{V}{A} \cdot \frac{\Delta c}{\Delta t} \qquad (1)$$

where F is the flux (mg $m^{-2}2\ h^{-1}$) of $CO_2$ or $CH_4$; ρ is the density of 1 mol $CO_2$ or $CH_4$ (kg $m^{-3}$ ); $\Delta c\ \Delta t^{-1}$ is the rate of change in gas concentration ($h^{-1}$); V and A are the volume ($m^3$) and the chamber base area ($m^2$), respectively.

### Statistical Analysis

The fluxes of $CO_2$ and $CH_4$ were analyzed using the MIXED procedure of the Statistical Package for Social Science (SPSS 13.0 for Windows, 2003), to test the significance of differences in $CO_2$ and $CH_4$ fluxes. Replicate flux measurements were averaged over sampling points for each grazing plot. Grazer species, period and their interactions were treated as fixed effects, with plot as a random effect, and sampling date as the repeated measure with the grazing plot used as the subject. The data were examined for homogeneity of variances and for normal distribution before analysis. Where necessary, data were transformed using log transformation. Paired means of significant differences in treatments were determined using the least significant difference (LSD) statistic. To test the correlations between soil temperature moisture and the fluxes of $CO_2$ and $CH_4$, Pearson's correlation analysis was performed. The $R^2$ (square of Pearson correlation coefficient) value was used to identify the best fit function (i.e. linear or quadratic). All significances mentioned in the paper are at the p = 0.05 level unless otherwise noted.

## Results

### Effect of grazing system on GHG fluxes

The dynamic feature of $CO_2$ fluxes for CG, SG, MG and CK are shown in Figure. 2. The measured mean $CO_2$ fluxes for CG, SG, MG and CK were 351.18, 315.38, 256.66 and 369.96 mg $m^{-2}$ $h^{-1}$, respectively, which indicates that the experimental plots were a net source of soil-atmospheric $CO_2$ exchange during the entire measurement period (Table 1). $CO_2$ emission occurred mainly in August.

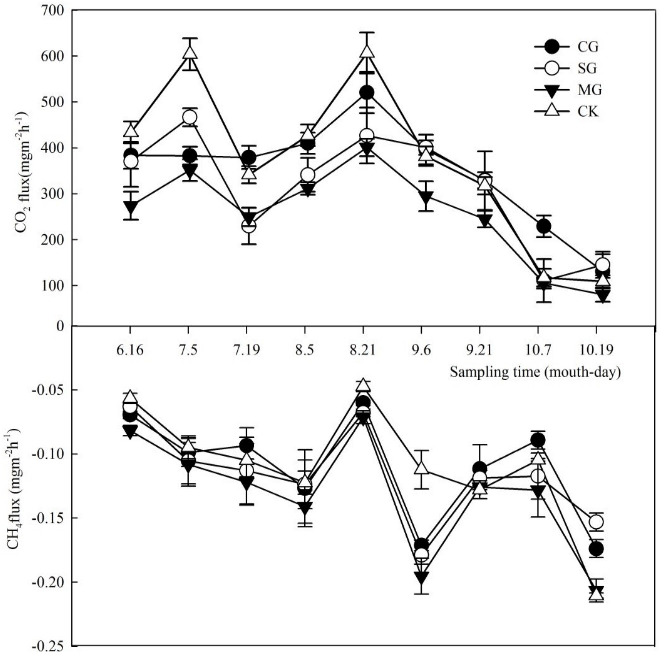


**Figure 2.** Seasonal variation of carbon dioxide ($CO_2$) and methane ($CH_4$) fluxes in different grazing species CG: cattle grazing; SG: sheep grazing; MG: mixed-grazing of cattle and sheep

The measured mean $CH_4$ fluxes for CG, SG, MG and CK were -0.112, -0.116, -0.133 and -0.110 mg $m^{-2}$ $h^{-1}$, respectively, which indicates that the experimental plots were a net sink of soil-atmospheric $CH_4$ exchange during the entire measurement period.

The pure carbon (C) flux converted from flux of $CO_2$ and $CH_4$ is shown in Table 1. The measured mean C flux for CG, SG, MG and CK were 348.87, 315.27, 262.49 and 367.01 mg $m^{-2}$ $h^{-1}$, respectively, which indicates that the grazed desert steppe is a net source of soil-atmospheric C exchange during the growing season. There was lower C emission in the MG plot compared with CG, SG and CK plots during the growing season.

**Table 1.** Comparison of greenhouse gas emission in different grazing species.

| Item | Treatment | | | | | |
|---|---|---|---|---|---|---|
| | CG | SG | MG | CK | SEM | P value |
| $CO_2$ flux ($mg\ m^{-2}\ h^{-1}$) | 351.17±14.51 | 315.38±15.73 | 256.66±15.40 | 369.96±25.63 | 9.452 | 0.967 |
| $CH_4$ flux ($mg\ m^{-2}\ h^{-1}$) | —0.112±0.006 | —0.116±0.005 | —0.133±0.007 | —0.110±0.007 | 0.003 | 0.745 |
| C flux ($mg\ m^{-2}\ h^{-1}$) | 348.87±15.30 | 315.27±15.73 | 262.49±15.57 | 367.01±25.80 | 9.594 | 0.891 |

CG: cattle grazing; SG: sheep grazing; MG: mixed-grazing of cattle and sheep; CK: non-grazing; SEM: standard error of mean; P: probability.
$F_{CO2}$-C + $FCH_4$-C = F•MC /$M_{CO2}$ + F•MC /$MCH_4$

## Relationship between GHG fluxes and environmental factors

The relationship between soil temperature and moisture and the measured fluxes $CO_2$ and $CH_4$ under the four grazing treatments are shown in Figure. 3. The results indicate that $CO_2$ flux was positively correlated with topsoil (0–10 cm) temperature ($R^2 = 0.540$, $p < 0.01$) and moisture ($R^2 = 0.523$, $p < 0.01$). $CH_4$ flux was negatively correlated ($R^2 = 0.532$, $p < 0.01$) with topsoil moisture, whereas no significant relationship between $CH_4$ flux and topsoil temperature was observed ($R^2 = 0.162$, $p > 0.05$) in this study. Considering the combined effect, binomial regression equations of the fluxes of $CO_2$ ($R^2 = 0.509$) and $CH_4$ ($R^2 = 0.327$) on soil temperature and moisture were developed in this study (Table 2).

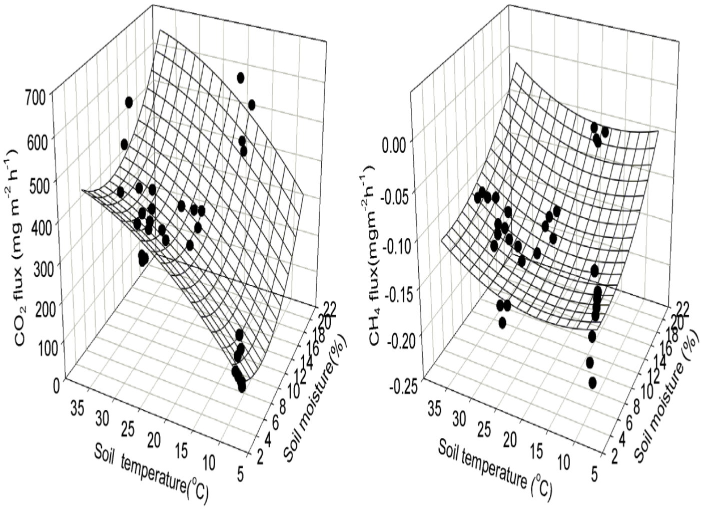


**Figure 3.** Correlation between carbon dioxide ($CO_2$) and methane ($CH_4$) fluxes with soil temperature and soil moisture

**Table 2.** Binomial regression equation between $CO_2$ and $CH_4$ fluxes with soil temperature and soil moisture

| | $F = y_0 + aM_s + bT_s + cM_s^2 + dT_s^2$ | | | | | |
|---|---|---|---|---|---|---|
| Item | $y_0$ | a | b | c | d | n | $R^2$ |
| $CO_2$ | 70.435 | −35.035 | 24.410 | 1.870 | −0.304 | 96 | 0.509 |
| $CH_4$ | −0.117 | −0.0031 | −0.0034 | 0.0004 | 0.0003 | 96 | 0.327 |

Ms: soil moisture; Ts: soil temperature;

## Discussion

Grassland ecosystems play a key role in C and N cycles, and are also sensitive to the impact of grazing [29]. Grazing is a complex event and improper grazing practices have led to grassland degradation in Inner Mongolia, China. Grassland degradation has a significant feedback to biosphere-atmosphere C exchange because grasslands can serve either as a source or sink. Overgrazing reduces below ground net primary production and thereby the C storage capacity and turnover via the volatilization and dislocation by erosion of a huge amount of C previously stored in the ecosystem [30]. Thus, it was urgent to identify suitable grazing practices for management of grassland ecosystems and prevention of ecosystem degradation.

The grazed desert steppe in Inner Mongolia is a net source of soil atmospheric C exchange during the growing season, when measured as the sum of soil and plant respiration. At the same time, grassland soil where methanotrophic activity occurs is an important natural sink for $CH_4$. In MG sites, $CO_2$ flux was lower and $CH_4$ flux was higher that in the other grazing systems. This finding suggests that planned adjustment of grazer species can reduce $CO_2$ emission and increase $CH_4$ sequestration. This maybe caused by glomalin, a secretion of arbuscular mycorrhizal fungi, which the study [31] has shown is an important source of the active soil organic carbon pool. Total glomalin storage under MG has been found to be higher than under grazing by single species (i.e. SG and CG) [32].

Soil carbon storage was higher in grazed area than in ungrazed areas in our study, which is similar to results reported by the study [33], who showed that grazed rangelands in mountain meadows had a greater proportion of active C in total soil C pools. This is attributed to the effects of grazing on plant biomass, regrowth, community structure, soil biotic, and abiotic factors [34]. Therefore, grazing affects both the physical and chemical properties of soil. The chemical composition and rate of decomposition of plant residues are important determinants of C accumulation in the soil [35]. [36] reported that high grazing intensity reduced $CH_4$ uptake significantly by 37.9 % compared with non-grazed steppe, while [7] did not detect significant differences in $CH_4$ uptake between grazed and non-grazed steppes. This discrepancy in the literature stems from the differences in soil characteristics, degree of degradation associated with grazing, age of exclosures, contribution of manure to the overall nutrient balance in the ecosystem, climatic conditions, and original and post-grazing vegetation communities.

Our study found that the magnitude of GHG fluxes was strongly influenced by soil moisture, as has also been observed in other studies [4,37-39] These studies also reported that soil temperature is an important factor affecting microbial activity. [40] observed that the daily $CH_4$ flux and topsoil temperature followed an exponential trend during grazing in a semiarid grassland, with soil temperature explaining 66–82 % of the variation in the daily $CH_4$ uptake. We did not find a significant correlation between $CH_4$ flux and topsoil temperature, which is similar to findings reported by [41,42]. This is ascribed to the effects of soil moisture, as rainfall in the study area is low. [43] reported that $CH_4$ oxidation was limited due to low microbial activity at low soil moisture conditions, while it was mainly determined by temperature for wet soils. In our study, there were correlation and regression relationships between soil environmental factors (temperature and moisture) and GHG fluxes.

## Conclusion

The grazed desert steppe grassland soil was a $CO_2$ source and a $CH_4$ sink for soil-atmospheric exchange. Mixed grazing species (i.e. cattle and sheep) reduced $CO_2$ emission by 26.91 % and 18.62 %, and increased $CH_4$ uptake by 18.75 % and 14.66 % compared with CG and SG, respectively. The interaction of soil moisture and temperature was the principal factor controlling soil-atmosphere GHG exchange in the grazed desert steppe in Inner Mongolia, China.

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