Grazing and GHG fluxes in steppe environments – how grazing reduces N_2O emissions and CH_4 uptake

K. Butterbach-Bahl[A], B.Wolf[A], W. Chen[B], X. Zheng[B], X. Han[C], H. Wu[C], Z. Yao[B], M. Dannenmann[A], M. A. Sutton[D] and N. Brüggemann[A]

[A]Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research (IMK-IFU), Germany. Email Klaus.butterbach-bahl@kit.edu
[B]Institute of Atmospheric Physics, Chinese Academy of Sciences (CAS), China.
[C]State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, 100093 Beijing.
[D]Centre for Ecology and Hydrology, Bush Estate, Penicuik, Midlothian, EH26 0QB, Scotland, UK.

Abstract
The interactions between grazing, livestock management and freeze/thaw and their impact on the exchange of N_2O and CH_4 steppe soils in steppe soils of Inner Mongolia were examined. Increases in stocking rate in steppe environments do not necessarily lead to increased annual N_2O emissions. Livestock grazing reduces CH_4 uptake significantly due to effects on soil aeration, and, thus CH_4 diffusion to sites with an active methanotrophic bacterial population.

Key Words
N_2O, CH_4, grassland.

Introduction
The greenhouse gas nitrous oxide (N_2O) is estimated to contribute about 6% to global warming (IPCC, 2007). Its atmospheric concentration has increased by 20% since pre-industrial times, mainly due to increased agricultural production (Mosier *et al.* 1998; Kroeze *et al.* 1999). Livestock production and associated manure management has contributed about 38% with regard to anthropogenic N_2O emissions. Temperate grasslands, such as steppe, cover approximately 8% of the terrestrial land surface and are widely used as pastures. High stocking rates as well as the addition of faeces have been reported to increase soil N_2O emissions (Yamulki *et al.* 1998; Ma *et al.* 2006; Saggar *et al.* 2007). On the other hand, grazing has been reported to strongly reduce the uptake of atmospheric CH_4 (Liu *et al.* 2007), another greenhouse gas for which upland grassland soils act as a significant sink. Most temperate grasslands are characterized by cold winters giving rise to distinct freeze/thaw cycles. The latter episodes can endure from days to months, and freeze thawing periods have been shown to contribute significantly to annual budgets of N_2O (Rover *et al.* 1998; Brumme *et al.* 1999; Papen and Butterbach-Bahl 1999). For CH_4, it is assumed that winter fluxes in such regions are close to zero, i.e. do not contribute significantly to annual fluxes. However, N_2O as well CH_4 flux measurements are often short term and periods with peak exchange rates may be missed. This study concentrates on the interactions of grazing, livestock management and freeze/thaw cycles on the exchange of N_2O and CH_4 between steppe soils of Inner Mongolia and the atmosphere.

In our study we hypothesized that (i) freeze/thaw episodes dominate the annual N_2O budget, (ii) N_2O fluxes increase with increasing grazing intensity and (iii) feedlots are significant point sources for N_2O on regional scales. With regard to CH_4 uptake we hypothesized (iv) that winter fluxes are not marginal and need to be considered for calculating annual fluxes.

Materials and methods
Our experimental sites were situated in the Xilin river catchment, Inner Mongilia, PR China and managed by the Inner Mongolian Grassland Ecosystem Research Station, IMGERS (43°33'N, 116°42.3'E). The growing season is from May to October, with mean annual air temperature and precipitation of 0.7°C and 335mm (reference period 1982-2005), respectively. Most of the precipitation, fell between June and August. Our study focused on three ungrazed sites (UG99, UGfl, UGsl); two lightly, moderately and heavily grazed sites (Lfl, Lsl, Mfl, Msl, Hfl, Hsl); and one site which was grazed moderately during winter only (WG). Measurements were either performed using an automated system for estimating fluxes in sub-daily resolution or by a manual system using the static chamber method and gas chromatography for analysis.

Results

Compared to ungrazed sites, grazing increased the amplitude of soil temperature and decreased the winter snow cover due to changes in the roughness length (Figure 1). As a consequence, soil moisture at the grazed sites was reduced during snow melt. Values on UG99 reached up to 90% water filled pore space (WFPS) while on WG values they did not exceed 60% (Figure 1). Differences in soil temperature and moisture regimes significantly affected soil microbial N cycling, with higher rates being found at the ungrazed sites. N_2O fluxes were mostly <5 µg N/m^2/h at all sites during the entire year. Higher fluxes were only observed either during freeze-thaw events or during periods with increased soil moisture contents during the vegetation period. N_2O fluxes during spring thawing period dominated the annual fluxes on the ungrazed sites while they were insignificant or entirely missing at grazed sites. This indicated that grazing decreases freeze/thaw fluxes. Observations at the lightly, moderately and heavily grazed sites revealed that freeze-thaw fluxes gradually decreased with increasing grazing intensity.

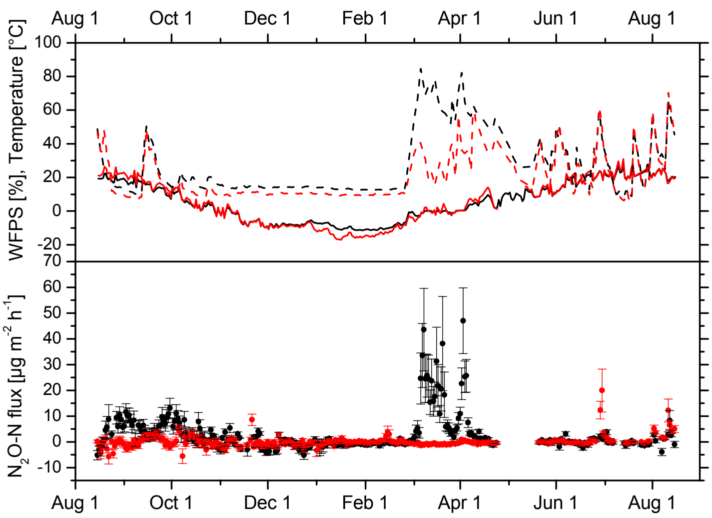

Figure 1. Top panel: temperature (solid) and moisture (dotted) for UG99 (black) and WG (red), bottom panel: N_2O-N fluxes for UG99 (black) and WG (red).

Based on our results a general mechanism can be identified which drives the interaction between grazing and freeze-thaw N_2O emissions. It is well established that under ungrazed conditions tall vegetation accumulates snow and that, with increasing snow cover, the soil is effectively insulated from low winter temperatures. The temperature effect is of importance for supporting microbial growth during winter, since a critical threshold seems to exist at approximately -10°C. Above this temperature a vital microbial community can survive, which is further activated by the onset of thawing in spring. This is consistent with our observations that microbial gross N turnover rates were significantly higher during winter and during spring-thaw at the ungrazed site as compared to the WG site. Our data as well as earlier studies (e.g. Koponen *et al.* 2004) demonstrate that freeze-thaw N_2O emissions increase with increasing soil moisture values and are highest around 60% WFPS. Since reduction of background emissions due to grazing are not considered in current IPCC methodology, our results suggest that N_2O emissions from semi-arid, cool temperate pasture systems may be severely overestimated.

With regard to CH_4 fluxes, soils of typical semi-arid steppe are a significant sink for atmospheric CH_4, not only during the vegetation period, but also during winter when soil temperatures were well <-10°C. The seasonal variation of CH_4 uptake was primarily determined by soil temperature. Soil moisture affected CH_4 uptake of steppe soil only when temperature was suitable for CH_4 oxidation and during spring thaw. Approximately one third of the annual CH_4 uptake was not during the growing season and cannot be ignored in estimates of annual CH_4 uptake in semi-arid steppe. However, grazing significantly reduced CH_4 uptake by the soil and was associated with increased soil compaction and reduced soil aeration which contributed to reduced CH_4 diffusion from the atmosphere to the soil layers with active CH_4 uptake.

Conclusions

Our study indicates that increases in stocking rate in steppe environments do not necessarily lead to increased annual N_2O emissions. This is due to a decrease of freeze/thaw N_2O fluxes with increasing stocking rate. Current methodologies may systematically over-estimate the importance of grazing for N_2O

emissions from cool temperate pasture systems. An integrated view of fluxes from livestock farming systems fluxes should be taken into account.

In our study the average difference in annual N_2O budgets between ungrazed and grazed sites is about 110g N_2O-N per ha/yr, whereas sheep related N_2O emissions from sheepfolds, urine patches and dry faeces were 36 g/(sheep yr). This indicates that net increases in emissions from grazed steppe systems as compared to ungrazed systems can be expected if stocking rates > 3 sheep/ha. With respect to CH_4 it is important to estimate off-season fluxes to fully understand and calculate annual budgets. Livestock grazing reduces CH_4 uptake significantly due to effects on soil aeration, and, thus CH_4 diffusion to sites with an active methanotrophic bacterial population.

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