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LETTERS

Grazing-induced reduction of natural nitrous oxide release from continental steppe

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Atmospheric concentrations of the greenhouse gas nitrous oxide (N_2O) have increased significantly since pre-industrial times owing to anthropogenic perturbation of the global nitrogen cycle[1,2], with animal production being one of the main contributors[3]. Grasslands cover about 20 per cent of the temperate land surface of the Earth and are widely used as pasture. It has been suggested that high animal stocking rates and the resulting elevated nitrogen input increase N_2O emissions[4–7]. Internationally agreed methods to upscale the effect of increased livestock numbers on N_2O emissions are based directly on per capita nitrogen inputs[8]. However, measurements of grassland N_2O fluxes are often performed over short time periods[9], with low time resolution and mostly during the growing season. In consequence, our understanding of the daily and seasonal dynamics of grassland N_2O fluxes remains limited. Here we report year-round N_2O flux measurements with high and low temporal resolution at ten steppe grassland sites in Inner Mongolia, China. We show that short-lived pulses of N_2O emission during spring thaw dominate the annual N_2O budget at our study sites. The N_2O emission pulses are highest in ungrazed steppe and decrease with increasing stocking rate, suggesting that grazing decreases rather than increases N_2O emissions. Our results show that the stimulatory effect of higher stocking rates on nitrogen cycling[4,7] and, hence, on N_2O emission is more than offset by the effects of a parallel reduction in microbial biomass, inorganic nitrogen production and wintertime water retention. By neglecting these freeze–thaw interactions, existing approaches may have systematically overestimated N_2O emissions over the last century for semi-arid, cool temperate grasslands by up to 72 per cent.

In temperate ecosystems with long frost periods, distinct freeze–thaw periods can occur. These periods can contribute significantly to annual N_2O budgets[10–12] and need to be better understood in relation to alterations in land use and agricultural practice. To address these interactions, we deployed several N_2O flux measurement systems in the steppe grassland of Inner Mongolia. Our measurement strategy was designed to address both sub-daily and seasonal dynamics, and to consider the relationships between N_2O fluxes, grassland management and the underlying plant and soil processes.

The data set we report represents year-round (August 2007–August 2008) N_2O flux measurements at high and low temporal resolution at ten sites differing in stocking rate (Table 1). All sites are typical steppe grasslands belonging to the Inner Mongolia Grassland Ecosystem Research Station, Chinese Ecosystem Research Network (43° 33′ N, 116° 42.3′ E). At two of the sites, fluxes were measured every three hours using an automatic system combining triplicate automatic chambers with online analysis. These two sites compared grassland that had been ungrazed since 1999 (UG99) with grassland that was grazed only during winter (WG). At the remaining eight sites, manual replicated chambers were deployed, allowing samples to be taken weekly. Supporting measurements included soil temperature and water-filled pore space (WFPS), gross rates of nitrogen mineralization and soil microbial-biomass nitrogen.

Our automated N_2O flux measurements show that N_2O fluxes at both the ungrazed and the winter-grazed sites were low and close to the detection limit during both the growing season and most of the winter. However, at the end of the winter, during the spring thaw, a large pulse of N_2O emissions, lasting for approximately eight weeks, was observed at the ungrazed site. Contrary to expectations, there was no matching pulse of N_2O emissions at the winter-grazed site (Fig. 1a, b). Our sub-daily measurements also showed pronounced diurnal variations

Table 1 | Annual and seasonal cumulative fluxes of N_2O

Site	Number of chambers	Grazing intensity*; stocking rate (sheep per hectare)	Duration of grazing period (d)	AE ± s.e. (kg N ha^{-1})	SE ± s.e. (kg N ha^{-1})	Group mean of SE ± s.e. (kg N ha^{-1})	GE ± s.e. (kg N ha^{-1})	Ratio of SE to AE (%)
UG99	3	Ungrazed; 0	—	0.22 ± 0.07	0.15 ± 0.04	0.17 ± 0.01†	0.06 ± 0.03	68
UG1	3	Ungrazed; 0	—	0.28 ± 0.05	0.23 ± 0.06		0.02 ± 0.01	81
UG2	3	Ungrazed; 0	—	0.17 ± 0.03	0.11 ± 0.03		0.04 ± 0.01	66
L1	4	Light; 0.92	93	0.20 ± 0.03	0.15 ± 0.03	0.10 ± 0.01†‡	0.01 ± 0.01	77
L2	4	Light; 0.51	93	0.10 ± 0.02	0.03 ± 0.1		0.04 ± 0.02	35
M1	4	Moderate; 1.45	93	0.15 ± 0.05	0.09 ± 0.03	0.06 ± 0.01‡§	0.04 ± 0.05	60
M2	4	Moderate; 0.99	93	0.11 ± 0.04	0.04 ± 0.02		0.05 ± 0.01	34
WG	3	Heavy; 2.05	166	0.01 ± 0.03	−0.01 ± 0.003	0.01 ± 0.01§	0.03 ± 0.01	0
H1	4	Heavy; 2.24	93	0.12 ± 0.01	0.02 ± 0.01		0.06 ± 0.02	16
H2	4	Heavy; 1.94	93	0.17 ± 0.03	0.01 ± 0.001		0.11 ± 0.03	9

$N = 3$ for UG99, UG1, UG2, WG; $N = 4$ for other sites. AE, annual emission; GE, growing-season emission; SE, spring-thaw emission.
* Grazing intensity classes derived from herbage allowance. Herbage allowance (HA; kilograms of dry biomass per kilogram of life weight) is a measure of the amount of biomass available per mass of grazing animal. Classes are as follows: heavy grazing (HA < 2.5); moderate grazing (2.5 < HA < 7.5); light grazing (HA > 7.5).
†‡§ Quantities marked with different symbols differ significantly ($P < 0.05$) with respect to grazing intensity.

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