Agriculture, Ecosystems and Environment 213 (2015) 241–251

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Nitrous oxide emissions from an agro-pastoral ecotone of northern China depending on land uses

Xinming Yang[a], Haiqing Chen[a,*], Yuanshi Gong[a], Xunhua Zheng[b], Mingsheng Fan[a], Yakov Kuzyakov[c,d]

[a] College of Resource and Environmental Science, China Agricultural University, 100193 Beijing, China
[b] State Key Laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry, Institute of Atmospheric Physics, Chinese Academy of Sciences, 100029 Beijing, China
[c] Department of Soil Science of Temperate Ecosystems, University of Göttingen, 37077 Göttingen, Germany
[d] Department of Agropedology, University of Göttingen, 37077 Göttingen, Germany

ARTICLE INFO

Article history:
Received 14 January 2015
Received in revised form 9 August 2015
Accepted 11 August 2015
Available online 27 August 2015

Keywords:
Annual N_2O emissions
Land use change
Spring thaw
Grazing
Semi-arid grassland
Cropland

ABSTRACT

Overgrazing and intensive farming have led to severe land degradation in the past half century in the agro-pastoral ecotone of northern China. Currently, complete and periodical exclusions of grazing are commonly adopted for the restoration of these degraded grasslands. However, little is known about the effects of such land uses on nitrous oxide (N_2O) emission in this region. Using static chamber technique, we quantified annual N_2O emissions (from May 2012 to September 2013) from four land uses: summer-grazed grassland (SG), winter-grazed grassland (WG), ungrazed grassland since 1997 (UG) and oat cropland (OC). N_2O emissions occurred mainly after farmyard manure fertilization and during spring thaw periods. Annual N_2O fluxes from the SG, WG, UG and OC were 0.19, 0.15, 0.43 and 0.98 kg N ha^{-1} yr^{-1}, respectively. The spring–thaw N_2O emissions from UG and OC dominated the annual emission and accounted for 70% and 65% of the annual fluxes, respectively. In contrast, the contributions of spring thaw fluxes to total annual N_2O emissions for SG and WG were only 32%. N_2O fluxes during spring thaw season were positively related to soil $NH_4^+ + NO_3^-$ content accounting for 80% of N_2O flux variability across all land uses. Land use conversion from the native grassland to cropland increased N_2O flux both during growing and spring thaw seasons due to farmyard manure application. Instead, grazing has the potential to decrease annual N_2O losses mainly through reducing spring–thaw N_2O emissions.

1. Introduction

Nitrous oxide (N_2O) is one of the important greenhouse gases with a global warming potential 265 times that of CO_2 and an atmospheric lifetime of about 121 years (IPCC, 2013). Moreover, N_2O plays a role in the destruction of ozone in the stratosphere. In viewed of atmospheric N_2O concentration increase of about 0.3% per year, it can be expected that the contribution of N_2O to global warming will further increase in the future (Wu et al., 2010). Soils are the dominant source of N_2O worldwide, releasing an estimated 9.5 Tg N yr^{-1} to the atmosphere (65% of global N_2O emissions), of which 3.5 Tg N yr^{-1} originate in agricultural soils and 1 Tg N yr^{-1} in temperate grasslands (Flechard et al., 2007).

Land use change is one of the major factors regulating soil N_2O emission (Skiba and Smith, 2000). Crop cultivation and grazing, main land uses, could profoundly impact N_2O emissions of grassland ecosystem through altering abiotic and biotic characteristics of soil (Holst et al., 2007; Mosier et al., 1997; Rafique et al., 2011; Ri et al., 2003). It has been generally recognized that conversion of grassland to croplands increases the emission of N_2O due to the impacts of agricultural practices, especially organic and mineral nitrogen (N) fertilization (Mosier et al., 1997; Wang et al., 2001). However, effects of grazing on N_2O emissions still remain controversial, with increases (Rafique et al., 2011; Saggar et al., 2007), decreases (Wolf et al., 2010; Xu et al., 2008), and no changes (Holst et al., 2007; Li et al., 2012) all being reported. The discrepancies between studies could be attributable to different grazing history, grassland type, climate regime and type of soil. Therefore, it is important to investigate N_2O emissions under site-specific land use patterns in order to draw regionally specific conclusions.

Although N_2O emissions from grasslands have been investigated worldwide, there are still high uncertainties in estimates of annual soil-atmosphere N_2O exchange of grassland ecosystem because most investigations have focused on the growing season (Holst et al., 2007;

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* Corresponding author. Fax: +86 10 62733596.
E-mail address: chenhq@cau.edu.cn (H. Chen).

http://dx.doi.org/10.1016/j.agee.2015.08.011
0167-8809/

Xu et al., 2008). Several studies have revealed that winter or spring–thaw N_2O loss can be of major importance for the annual N_2O loss in temperate ecosystems (Röver et al., 1998; Teepe et al., 2000; Wagner-Riddle et al., 2007; Wolf et al., 2010). In some cases up to 80% of the annual N_2O emissions were found in the spring–thaw period (Holst et al., 2008; Wolf et al., 2010). This phenomenon has been attributed to physical release of N_2O produced in unfrozen part of the soil and accumulated below the frozen soil layer (Burton and Beauchamp, 1994; Teepe et al., 2001) and/or enhanced microbial metabolism by substrate supply (Röver et al., 1998; Wolf et al., 2010). Moreover, the magnitude of spring–thaw N_2O emission may differ between land uses even at similar weather (Holst et al., 2008; Wagner-Riddle and Thurtell, 1998; Wolf et al., 2010). Clearly, long-term studies of at least one year or more are necessary for reliable estimates of annual N_2O release from soil.

The agro-pastoral ecotone in northern China covers 6.2×10^5 km^2 from the North China Plain to the Inner Mongolia Plateau (Liu and Gao, 2008). It is a transitional land use from livestock-grazing to farming in between semi-arid temperate steppe and semi-humid cropland. This region plays an important role in livestock farming and environmental conservation. However, overgrazing and intensive farming have led to severe land degradation in the past half century in this region. Currently, improved grassland management practices, complete and periodical exclusions of grazing are commonly adopted for the restoration of these degraded grasslands. Quantifying the effects of cultivation and grazing regimes on the greenhouse gas emissions is critical for the understanding of consequences of land use conversion including that on N_2O emissions. However, previous studies of N_2O emissions in the semi-arid grassland in China have primarily focused on the growing season (Holst et al., 2007; Xu et al., 2008) and on grazing management (Wolf et al., 2010). Limited evaluations of annual N_2O emissions and land uses including both cropland and grassland underscore the need for additional research.

In present study, we measured soil N_2O emissions, temperature, soil moisture and mineral N content ($NH_4^+ + NO_3^-$) over a 16-month period from four land uses in the agro-pastoral zone of northern China. The objectives were to: (1) investigate seasonal variations of N_2O fluxes depending on land uses; (2) quantify annual N_2O emissions depending on land uses and evaluate the contribution of spring–thaw N_2O emissions to annual N_2O losses; (3) examine the effects of soil temperature, water-filled pore space (WFPS) and mineral N content ($NH_4^+ + NO_3^-$) on N_2O fluxes from land uses.

2. Materials and methods

2.1. Study site

The study was carried out at the National Grassland Ecosystem Observation and Research Station (41°46′N, 115°40′E, 1460 m above sea level), which lies in the typical agro-pastoral ecotone in the Guyuan county, Hebei province, Northern China. The region has a semi-arid and temperate continental monsoon climate, with a frost-free period of 80–110 days. The 30 year (1979–2009) annual mean precipitation is 380 mm with 80% falling during the growing season from May to September. The annual mean temperature is 1.4 °C with the minimum monthly mean of −18.6 °C in January and the maximum of 17.6 °C in July. The soil is classified as a Kastanozem according to the FAO system.

Four land uses were selected for the study: a summer-grazed grassland (SG), a winter-grazed grassland (WG), an ungrazed grassland (UG), and a cropland (OC). The 15-ha SG has been moderately grazed (4–5 sheep ha^{-1}) from June to September since 2009. Before 2009, the grassland was mown at mid or late September once a year. A majority of the species in the SG site was *Leymus chinensis* (73% of the species composition) but *Stipa krylivii* (10%) and *Potentilla acaulis* (8%) also made significant contributions to the species composition. The remaining species were *Iris lactea* Var. *chinesis* and *Saussurea runcinata.* The 10-ha WG has been grazed from November to March by 5–6 sheep ha^{-1} since 2007. At 80% of the relative species composition, *L. chinensis* was the dominant species in the WG site. The remaining species composition was comprised of *S. krylivii* (12%), *Artemisia frigida* and *P. acaulis* (8%). The 3-ha UG was fenced in 1997 and since then grazing has been forbidden in this fenced site. There is a thin litter layer (about 4–5 cm) covering the ground surface because of long-term enclosure. The UG site was dominated by *L. chinensis* (90% of the species composition) while the remainder of the species were *S. krylivii* (8%), *Hordeum brevisubulatum* and *P. acaulis* (2%). Vegetation coverage was 45%, 60% and 90% for SG, WG and UG, respectively. The three grasslands have been extensively managed consistently without fertilizer, herbicides or irrigation since 1995. The 5-ha cropland has been reclaimed in part of the *L. chinensis* grassland since 1995. Oat (*Avena sativa*) was usually sown in late May and harvested in late September. Oat was grown under rainfed condition. The cropland was plowed to a depth of 15–20 cm using a mouldboard plough before oat sowing. A limited amount of farmyard manure (about 675 kg ha^{-1}, corresponding to 30 kg N ha^{-1}) was applied as the base fertilizer before sowing. After harvest, most of the crop residue was removed, and only a small amount of standing stubble of about 5–10 cm in height remained. Live aboveground biomass was measured by clipping live plants from five representative 1m x 1m quadrats in each land use in late August 2013. Live aboveground biomass was 56, 307, 426 and 336 g m^{-2} for SG, WG, UG and OC, respectively. Root biomass at 50 cm depth was taken with soil core method in the same quadrats that were used for aboveground biomass measurement. Root biomass was 1392, 1277, 1933 and 737 g m^{-2} for SG, WG, UG and OC, respectively. The OC, UG and SG sites were adjacent to each other and the WG site lay about 1800 m west of these sites.

2.2. N_2O flux measurements

N_2O fluxes were measured with an opaque static closed chamber method (Wang and Wang, 2003) from 25 May 2012 to 29 September 2013. Four gas flux measurement plots within each land use were established randomly. Stainless steel base frames (0.5 m × 0.5 m, height 0.1 m) were inserted 10 cm into the soil on 1st May 2012 and left there through the experiment. During sampling, an open-bottom stainless steel chamber (0.5 m × 0.5 m, height 0.5 m) was placed over the base frames, which had rubber seal in the upper end to ensure air-tightness. N_2O fluxes were generally measured twice per week during the growing season from May to September and during spring thaw from March to April, and twice per month from October to next February. The gas samplings were normally carried out between 8:00–11:00, because a preliminary experiment investigating diurnal variations in N_2O fluxes showed that the fluxes at this time represent average daily flux. Gas samples were taken with 60 ml plastic syringes attached to a three-way stopcock at 0, 15, 30, 45, 60 min following chamber closure, respectively. N_2O concentrations in gas samples were analyzed within 8 h after sampling with a gas chromatograph (GC, Agilent 7890A, Santa Clara, CA, USA) equipped with an electron capture detector (ECD). Details of the gas chromatograph configurations for N_2O analysis are referred to Wang et al. (2010) and Zheng et al. (2008). N_2O flux was calculated jointly from the linear or non-linear change in gas concentrations (Wang et al., 2013).

2.3. Auxiliary measurements

Weather variables (precipitation, air temperature, and atmospheric pressure) were measured continuously from the