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Nitrous oxide emissions from different land uses affected by managements on the Qinghai-Tibetan Plateau

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ABSTRACT

We evaluated the N_2O emissions from four land use types (a native alpine meadow with winter grazing (NAM), an abandoned pasture (APL), a perennial *Elymus nutans Griseb.* pasture (PEN) and an annual *Avena sativa* L. pasture (AAS)) with and without three management practices (nitrogen (N) fertilizer, sheep manure and no tillage (NT)) in a Gelic Cambisol soil underlying an alpine meadow on the Qinghai-Tibetan Plateau in 2009 and 2010. Our results show that, compared with NAM, APL had significantly higher cumulative-average seasonal N_2O emissions. Converting unmanaged APL to PEN or AAS significantly increased cumulative-average seasonal N_2O emissions by 35% and 75%, respectively. Sheep manure and N fertilizer application significantly increased N_2O emissions due to increased soil inorganic N concentration. The effect of sheep manure addition on N_2O emissions was lower than that of N fertilizer. For AAS, tillage significantly decreased the effect of sheep manure application on N_2O emissions. Compared with tillage, NT significantly decreased N_2O emissions from AAS. Therefore, our results suggest that cultivating natural grassland would increase N_2O emissions, and fertilizer application would amplify the magnitude of emissions, whereas NT could mitigate the fertilizer impact on N_2O emission. Furthermore, the structural equation analysis revealed that land use change affected N_2O emissions directly by influencing the number of plant species and soil characteristics. There were two different underlying mechanisms regulating N_2O emissions in response to N fertilizer and sheep manure addition.

1. Introduction

The atmospheric concentration of nitrous oxide (N_2O), which has a global warming potential approximately 300 times that of carbon dioxide (CO_2), has increased from 271 ppbv before the Industrial Revolution to 324 ppbv in 2011, and has been responsible for 6% of the enhanced greenhouse effect (IPCC, 2013). Global emissions of N_2O from managed grasslands are estimated at $\sim$0.81 Tg N_2O-N yr^{-1}, accounting for 32% of total N_2O emissions from grassland sources (Ussiri and Lal, 2013).

Nitrous oxide emissions depend on the balance between the production and consumption of N_2O and its diffusion from the soil to the atmosphere (Qin et al., 2014). Nitrous oxide is mainly produced in soils by denitrifying microorganisms which convert NO_3^- or NO_2^- to N_2O and N_2 under anaerobic conditions, and by nitrifying bacteria, which create N_2O as an intermediate product of the oxidation of NH_4^+ to NO_2^- or NO_3^- under aerobic conditions (Khalil et al., 2004; Hamonts et al., 2013; Denk et al., 2017). Denitrification by reduction to N_2 is the major microbial process of N_2O consumption under low oxygen (Flechard et al., 2007; Liu and Graver, 2009). Land use change alters N_2O emissions by altering plant community composition and soil characteristics that are indirectly and directly associated with N_2O production, consumption and diffusion processes (Merbold et al., 2014; Liu and Greaver, 2009; Fig. 1). Management (such as N fertilizer

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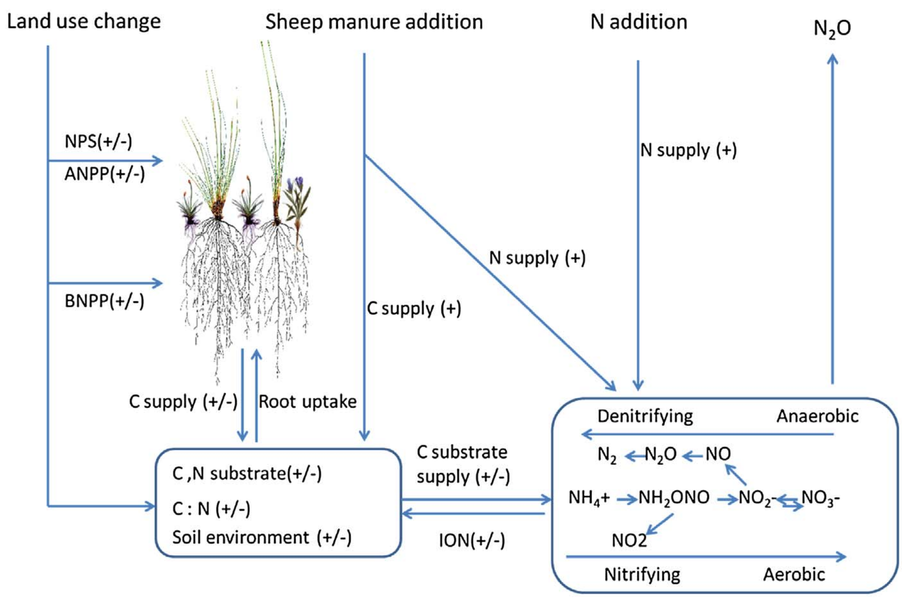

Fig 1. A conceptual model of how land use change and management practices regulate N_2O production and consumption processes (Liu and Greaver, 2009). NPS: the number of plant species; ANPP: aboveground net primary productivity; BNPP: belowground net primary productivity; C:N, soil C/N ratio; ION, soil inorganic N.

application and no-tillage (NT)) has been found to amplify or sometimes modify the effects of land use change through regulation of plant and microbial activities (van Groenigen et al., 2005; Hamonts et al., 2013; Du et al., 2016; Molina-Herrera et al., 2017). Nitrous oxide emissions from grasslands are strongly dependent on soil texture and the availability of mineral N and organic C (Khalil et al., 2004; van Kessel et al., 2013; Abalos et al., 2014; Merbold et al., 2014). The conversion of native grasslands to cultivated pasture is expected to increase the availability of soil C and N by altering plant community composition and soil characteristics (such as soil temperature, moisture, bulk density and N availability), and to result in increased N_2O emissions (Simona et al., 2004; Merbold et al., 2014). However, the potential mechanisms that regulate N_2O emissions under different management practices are still not well understood. The NT practice is widely used to conserve water and reduce soil organic matter losses in cultivated croplands. Some studies have shown an increase in N_2O emissions from NT soils, because of compaction, reduced porosity and increased denitrification in humid climate conditions (Rochette et al., 2008). However, others have reported lower emissions under NT than tillage (T) due to improvements in soil structure and lower soil temperature in dry climate conditions (Ruan and Robertson, 2013). The effect of tillage on N_2O emissions is probably highly dependent on the local environmental conditions (van Kessel et al., 2013). Results from manipulative field experiments indicate that chemical fertilizer or livestock manure increases N_2O emissions, but the magnitude of increase varies widely across grassland ecosystems, environmental conditions, fertilizer rates (0–300 kg^{-1} N ha^{-1} y^{-1}), type of fertilizer (manure organic fertilizer, chemical fertilizer), and application time (preplanting, sidedressing) (Meng et al., 2005; Jones et al., 2005; Flechard et al., 2007; Lu et al., 2011). Livestock manure, which has a high concentration of easily mineralizable organic C, could reduce C constraints on denitrification while at the same time increasing supply of labile N, which could stimulate microbial activity and emit more N_2O than chemical fertilizer (Del Grosso, 2010). Above all, there is high uncertainty in N_2O emission rates from individual fields and regions with different management. Even though an increasing number of models have been used to assess the characteristics of N_2O emissions and develop efficient mitigation strategies for reducing N_2O emissions (Du et al., 2008), the prediction of N_2O emissions in grassland under different land use types and management is difficult without an improved understanding of the potential mechanisms.

As one of the most important dominant vegetation types on the Qinghai-Tibetan Plateau, alpine meadows cover an area of about 2.5 million km^2 and emit an average of 0.3 Tg N_2O annually (Du et al., 2008). Because livestock numbers have increased by more than 200% since 1978, actual livestock numbers have greatly exceeded the theoretical carrying capacity (Cui et al., 2006). Large areas of native grassland have been converted into pasture and cultivated cropland to improve herbage production to meet the forage demand of the livestock population. With economic and social development, fertilizer application has now become the main management practice adopted by herders in this area to increase the productivity of cultivated pasture. Since the early 2000's, a number of government programs have been implemented, aiming to restore grassland vegetation on formerly cultivated land. Therefore, to reduce uncertainty in the estimation of N_2O emissions from the Qinghai-Tibetan Plateau, field quantification of N_2O emissions and the determination of model parameters for accurate model simulations are urgently needed for alpine grasslands under different land uses and managements. Previous studies reported that plowing could accelerate soil N transformation rates and decrease soil organic C in an alpine meadow on the Qinghai-Tibetan Plateau (Sun et al., 2005; Li et al., 2006). Given that N_2O emissions are mainly dependent on soil texture and the availability of soil N, organic C, we hypothesized that the conversion of abandoned pasture to cultivated pasture would increase N_2O emissions due to increased soil N and C transformation rates and a decreased number of plant species, and that natural restoration following the abandonment of cropland would decrease N_2O emissions. In addition, we hypothesized that N_2O emissions would increase in response to N fertilizer, sheep manure addition and tillage due to the increased mineral N, and we expected that sheep manure addition would cause more N_2O emissions than chemical fertilizer application. To test these hypotheses and study the potential mechanisms that regulate the N_2O emissions under different land uses and with different management practices, we set up experiments to measure N_2O emissions from four types of land use with three management practices in an alpine meadow on the Qinghai-Tibetan Plateau in 2009 and 2010.

2. Materials and methods

2.1. Site description and experimental design

Details about the experimental site were previously reported (Zhang et al., 2012). In brief, the experiment was conducted at the Haibei Alpine Grassland Ecosystem Research Station, Northwest Plateau Institute of Biology, Chinese Academy of Sciences, in Qinghai province (37°36′N,