Effects of Simulated Nitrogen Deposition on Greenhouse Gas Emissions from Alpine Meadows in Northern Tibet (Postprint)

Authors: Liang Yan, Ganzhu Zhabu, Cao Xujuan, Zhang Weina, Zhang Yong, Li Wenhan, Gao Qingzhu, Wan Yunfan, Li Yu' e, Danjiu Luobu, He Shicheng

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Abstract

Currently, the contribution of alpine meadows to the global greenhouse effect remains uncertain, and greenhouse gas emissions from this system will inevitably change with increasing N deposition. To reveal the response mechanisms of alpine meadows to N deposition and explore their feedback effects on global change, we established different N addition gradients (0, 7, 20 kg hm^{2}a^{1} and 40 kg hm^{2}a^{1}) using artificial nitrogen addition methods during the 2014 growing season (June–September) in Nagqu County, Nagqu Prefecture, to simulate the effects of increased nitrogen deposition on greenhouse gas emissions from alpine meadows in northern Tibet. The one-year study results showed: 1) Nitrogen addition significantly promoted CO emissions but had no significant effect on CH uptake or N O emissions. Overall, nitrogen addition significantly increased total greenhouse gas emissions, with the N20 treatment producing the highest total emissions from alpine meadows. 2) Regression analysis indicated that CO was linearly correlated with NPP (total biomass) and TOC (soil organic carbon) ($P < 0.05$) but showed no significant correlation with TN (total nitrogen), NH -N, or NO -N ($P > 0.05$). CH showed no significant correlation with TN/NPP/TOC/NH -N/NO -N ($P > 0.05$). N O was significantly linearly correlated with NPP/TOC/NO -N ($P < 0.05$) but not with TN/NH -N. Based on these preliminary findings, greenhouse gas emission fluxes from alpine meadows in northern Tibet may increase significantly under future conditions of increased nitrogen deposition, thereby producing important feedback effects on climate change.

Full Text

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**LIANG Yan[1], HASBAGAN Ganjurjav[1,2,*], CAO Xujuan[1,2], ZHANG Weina[1], ZHANG Yong[3], LI Wenhan[1,2], GAO Qingzhu[1,2], WAN Yifan[1], LI Yu' e[1], DANJIU Luobu , HE Shicheng **

[1]Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing 100081, China
Key Laboratory for Agro-Environment & Climate Change, Ministry of Agriculture, Beijing 100081, China
[2]School of Environment, Beijing Normal University, Beijing 100875, China
Nagqu Grassland Station, Nagqu 852100, Tibet, China

Abstract

The contribution of alpine meadows to the global greenhouse effect remains uncertain. As nitrogen deposition continues to increase, greenhouse gas emissions from this ecosystem will inevitably change. To reveal the response mechanisms of alpine meadows to nitrogen deposition and explore their feedback effects on global change, we established a nitrogen addition experiment with four fertilization levels (0, 7, 20, and 40 kg N hm^{2}) in Nagqu County, Tibet during the 2014 growing season. Our results showed that nitrogen addition significantly increased total greenhouse gas emissions. The highest emissions occurred under the 40 kg N hm^{2} treatment (N40). CO emissions were significantly enhanced by nitrogen addition, while CH absorption and N O emissions showed no significant response. Regression analysis revealed that CO was significantly linearly correlated with net primary productivity (NPP) and total organic carbon (TOC) ($P < 0.05$), but not with total nitrogen (TN), NH -N, or NO -N ($P > 0.05$). CH flux showed no significant correlation with TN, NPP, TOC, NH -N, or NO -N ($P > 0.05$). N O exhibited significant linear correlations with NPP, TOC, and NO -N ($P < 0.05$), but not with TN or NH -N ($P > 0.05$). Under future scenarios of increased nitrogen deposition, greenhouse gas fluxes from northern Tibetan alpine meadows may increase significantly, potentially creating important feedback effects on climate change.

Keywords: nitrogen deposition; alpine meadow; greenhouse gas; soil nutrients; biomass

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1. Study Area Overview

The experimental site was located at the Nagqu Agricultural Environment Observation and Experiment Station, Ministry of Agriculture, in Nagqu County, northern Tibet (31.441°N, 92.017°E). The vegetation is dominated by *Kobresia pygmaea* (alpine sedge) as the constructive species, with *Stipa orientalis* as the main grass species. Common forbs include *Astragalus peduncularis*, *Potentilla saundersiana*, and *Potentilla tanacetifolia*. During the 2014 growing season, the monthly average temperature at 5 cm soil depth was 12.35°C, with 90% of precipitation concentrated in this period. The average volumetric water content was [Figure 1: see original paper].

2. Plot Setup and Sampling Methods

Nitrogen addition rates were determined based on China' s nitrogen deposition distribution patterns. The current nitrogen deposition rate in Tibet is 7 kg N hm ^{2} yr ^{1}, which is projected to reach 40 kg N hm ^{2} yr ^{1} in the future. This experiment established four nitrogen addition gradients: control (0 kg N hm ^{2}), low nitrogen (7 kg N hm ^{2}, N7), medium nitrogen (20 kg N hm ^{2}, N20), and high nitrogen (40 kg N hm ^{2}, N40), representing 1×, 3×, and 6× the natural deposition rate, respectively. The study plots were established in a flat, long-term fenced *Kobresia pygmaea* meadow community.

Plot Design: Each experimental plot measured 3 m × 3 m, with buffer zones > 46.4% between adjacent plots. Nitrogen fertilizer was sprayed at the beginning of each month. Control plots received equal amounts of water.

Greenhouse Gas Flux Measurement: Gas fluxes were measured using the conventional static chamber method. Measurements were conducted monthly during the growing season at 11:00 and 19:00. The static chamber (150 mm height, 250 mm diameter) was placed on permanently installed bases inserted into the soil. After covering the base with the chamber, air samples were collected from the surrounding area and injected into sealed glass vials at 0 and 15 minutes. Samples were then transported to the laboratory for analysis.

Gas Chromatography Analysis: CO and CH concentrations were measured using a gas chromatograph (HP6890N, Agilent) with a flame ionization detector (FID) at 200°C, using a Porapak Q column at 70°C. N O concentrations were measured with an electron capture detector (ECD) at 330°C, also with a Porapak Q column at 70°C. Fluxes were calculated based on concentration differences between closing and opening times [20].

Biomass Measurement: During the growing season, plant species composition and coverage were surveyed in each plot. Aboveground biomass was harvested from 0.5 m × 0.5 m quadrats outside the experimental area, sorted by species, oven-dried at 70°C for 0.5 h, then dried to constant weight. A linear regression equation was developed between species height, coverage, and biomass to estimate biomass for each treatment.

Soil Sampling and Analysis: At the end of the growing season, soil samples were collected from 0–20 cm depth using a soil auger. Samples were transported to the laboratory, sieved to remove gravel and roots. Soil TN, NH -N, and NO -N were analyzed using a continuous flow injection analyzer (Bran Luebbe, Germany) after extraction with 2 mol/L KCl.

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3. Calculation Formulas

Gas Flux Calculation:

$$F = \frac{V \times M}{A \times \Delta t} \times \frac{\Delta c}{\Delta t}$$

Where:
- F = greenhouse gas flux at time t (mg m ^{2} h ^{1})
- V = chamber volume (m^3)
- M = molar mass of the gas (g mol ^{1})
- A = chamber base area (m^2)
- Δc = concentration difference between closing and opening
- Δt = time interval between measurements (h)

Positive values indicate emission, negative values indicate absorption.

Global Warming Potential (GWP):
The comprehensive greenhouse effect was estimated using CO -equivalents based on GWP values [21]:

$$\text{CO}_2\text{-e} = 25 \times R_{\text{CH}_4} + 298 \times R_{\text{N}_2\text{O}}$$

Where CO -e (kg CO -e hm ^{2}) is the daily CO -equivalent emission per hectare, and R_{CH_4} and $R_{\text{N}_2\text{O}}$ are the daily emissions of CH and N O during the growing season.

Biomass Linear Regression Equation:

$$\text{Biomass} = 0.585 + 1.282 \times h + 0.059 \times c$$

Where biomass is in grams, h is species height (m), and c is species coverage (%).

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4. Data Analysis

Data were pre-processed using Excel 2010. IBM SPSS Statistics software was used for one-way ANOVA, regression analysis, and repeated measures ANOVA. Significance was determined at $P < 0.05$.

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1. Diurnal Variation of Greenhouse Gas Fluxes Under Different Nitrogen Addition Levels

Nitrogen addition levels significantly affected the diurnal emission patterns of greenhouse gases. The variation patterns were generally consistent across treatments. [Figure 2: see original paper]

CO emissions showed significant differences across different times and treatments in June, July, and August ($P < 0.05$), with significant interactions between treatment and time. Under nitrogen addition, CO fluxes differed significantly across diurnal periods, with consistent patterns across treatments and significant treatment-time interactions ($P < 0.05$). Nitrogen addition altered the diurnal pattern of CO emissions.

CH fluxes showed no significant differences between treatments ($P > 0.05$), but varied across different time periods. In June, July, and August, CH absorption both decreased and increased. The most pronounced increase in absorption occurred in July and August under N20 treatment, with daily mean values increasing by 39.39% and 68.55% respectively compared to the control. Under N40 treatment, absorption increased by 191.52% in July and 225.38% in August. The effects of nitrogen addition on CH flux varied by time period.

N O emissions were highest at 13:00 under N7 treatment and at 15:00 and 19:00 under N20 treatment. Emissions at 17:00 under N40 treatment increased by 169.04% in July and 203.42% in August compared to the control. However, there were no significant differences between treatments ($P > 0.05$).

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2. Seasonal Variation Characteristics of Greenhouse Gas Fluxes Under Different Nitrogen Addition Levels

The seasonal patterns of greenhouse gas fluxes were generally consistent across nitrogen addition treatments. CO emissions showed significant differences across dates and treatments ($P < 0.05$), but without significant date-treatment interactions. A peak occurred at the end of July.

CH fluxes fluctuated slightly around zero, showing significant differences across dates and treatments ($P < 0.05$) with significant date-treatment interactions. Nitrogen addition significantly increased CH absorption in June, July, and August, with monthly mean values increasing by 100.84% under N20 and 64.07% under N40 compared to the control ($P < 0.05$). However, short-term nitrogen addition had no significant effect on monthly mean values in other months.

N O emissions showed no significant differences between treatments ($P > 0.05$). [Figure 3: see original paper]

Total greenhouse gas emissions across all treatments were higher than the control, with the highest total emissions occurring under N20 treatment.

3. Changes in Plant Community Biomass and Soil Nutrients Under Different Nitrogen Addition Levels

Nitrogen addition did not significantly increase total vegetation biomass in alpine meadows ($P > 0.05$), although an increasing trend was observed. Aboveground biomass under N20 and N40 treatments increased by 22.65% and 26.93% respectively compared to the control ($P < 0.05$). [Figure 4: see original paper]

Nitrogen addition significantly increased soil TN content, which increased by 26.40% under N40 treatment compared to the control ($P < 0.05$).

4. Effects of Biotic and Abiotic Factors on Greenhouse Gas Emissions

Stepwise regression analysis showed that CO was significantly linearly positively correlated with NPP and TOC ($P < 0.05$), but not with TN, NH -N, or NO -N ($P > 0.05$). CH showed significant linear positive correlations with TN, NPP, TOC, NH -N, and NO -N ($P < 0.05$). N O showed significant linear positive correlations with NPP, TOC, and NO -N ($P < 0.05$), but not with TN or NH -N ($P > 0.05$).

3. Discussion

CO emissions from grassland ecosystems primarily originate from ecosystem respiration, including autotrophic and heterotrophic respiration. Heterotrophic respiration is mainly influenced by environmental factors such as temperature, moisture, and nutrient conditions, as well as biotic factors including soil fauna and microorganisms [22]. Nitrogen deposition alters soil nutrient conditions and microbial activity [23]. Most studies have shown that nitrogen deposition promotes CO emissions from Tibetan Plateau grasslands [22-24], though the mechanisms vary, including increased microbial activity [22-23], increased biomass [22-24], and increased soil available nitrogen [22,24]. Some studies suggest nitrogen addition may alter the temperature sensitivity of soil respiration, leading to reduced CO emissions [13]. Our results showed that nitrogen addition significantly promoted CO emissions, which were significantly positively correlated with NPP and TOC, but soil TN content did not change significantly under nitrogen addition. The increased CO emissions may result from enhanced soil microbial activity under nitrogen addition [22-23]. Future research should focus on soil microbial quantity and activity responses to nitrogen addition.

For alpine meadow ecosystems, CH absorption is primarily influenced by soil temperature and moisture [27], vegetation patterns, and nitrogen form [28]. Zhang et al. [26] found that low nitrogen addition promoted CH absorption in Tibetan alpine meadows, while medium and high nitrogen addition inhibited it, as soil moisture is a key factor affecting CH absorption. Our results showed that nitrogen addition had no effect on CH absorption diurnal patterns, and its impact on global warming potential was minimal [13].

N O emissions from grassland ecosystems depend mainly on nitrification and denitrification processes, which are strongly influenced by soil temperature, moisture, and microorganisms [25,27,29-30]. Previous studies show inconsistent effects of nitrogen addition on N O emissions. Hu et al. [31] found nitrogen deposition did not alter seasonal patterns of N O flux in a north subtropical deciduous broadleaf forest, possibly due to short treatment duration. Jiang et al. [13] found short-term nitrogen addition during the growing season increased N O emissions in Tibetan alpine meadows, likely by promoting denitrification. Our study found alpine meadows were weak N O sources, consistent with Wei et al. [25] in Tibetan alpine steppe. Nitrogen addition did not significantly change N O emissions, possibly due to the semi-arid climate, low soil organic carbon content, and cation exchange capacity in this high-altitude region [32].

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