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Fluxes of N_2O, CH_4 and soil respiration as affected by water and nitrogen addition in a temperate desert

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ABSTRACT

An experiment was conducted to investigate the effect of precipitation and N deposition on N_2O and CH_4 fluxes and soil respiration (R_s) in the Gurbantunggut Desert from September 2014 to August 2015. The desert was a weak sink for CH_4 (-0.92 kg C ha^{-1} yr^{-1}) and a small source of N_2O ($+0.13$ kg N ha^{-1} yr^{-1}) and the annual rate of R_s was 874 kg C ha^{-1}. Our work confirmed a relatively strong sink for CH_4 in desert soils. Significant impacts on N_2O, CH_4 fluxes and R_s were found by increasing precipitation, with pulses of CH_4 uptake and R_s accounting for 79.1% and 33.2% of annual CH_4 uptake and R_s, respectively. N_2O and CH_4 fluxes were significantly enhanced by 7.8–109.6% by N addition, but it had no significant effect on R_s. Statistical significant interactions of precipitation and N addition on N_2O and CH_4 fluxes were found, and on R_s was lower than any single factor. Our results indicate that the Gurbantunggut Desert is a weak sink for CH_4 and a small source of N_2O, and is sensitive to elevated precipitation and N deposition.

Desert soils, as a net sink of greenhouse gases (GHGs) (Zhuang et al., 2013), are profoundly affected by precipitation patterns and nitrogen (N) deposition (Huang et al., 2015). However, the impacts of precipitation and N deposition on N_2O, CH_4 and soil respiration (R_s) are uncertain largely in desert soils. Previous studies (Zhang et al., 2008; Huang et al., 2015) investigating precipitation and N addition impacts on GHGs have primarily focused on the effect of single factor in grassland and forest, while the interaction effects in desert soils are very scarce.

Temperate desert, covering approximately one third of the global land area, is dynamically sensitive to precipitation and N deposition (Li et al., 2015). Climate change in Northwest China is for an increase in precipitation of 30%, with an increases of 3–5 mm yr^{-1} since 1979 (Li et al., 2015), and N deposition has increased significantly since 1980 to total deposition of 35.2 kg N ha^{-1} yr^{-1} (Song, 2015). These changes are important for soil biological processes because of the extreme limits of soil N and water in such deserts (Huang et al., 2015). However, information on the responses of N_2O, CH_4 fluxes and R_s to precipitation and N deposition in this ecosystem is scarce and merits research.

We therefore conducted an experiment from September 2014 to August 2015 in the Gurbantunggut Desert (44°26′–43°65′N, 84°31′–90°00′E). Weather and soil conditions are shown in Fig. 1(a, b). N addition rates were 0 (N0), 30 (N1) and 60 (N2) kg N ha^{-1} yr^{-1}. Precipitation was 'natural' (W0) and 'natural' plus 60 mm yr^{-1} (equivalent to 30% of annual precipitation) (W1). There were six treatments: W0 N0 (the control), W0 N1, W0 N2, W1 N0, W1 N1 and W1 N2. Four plots were established for each treatment, each plot 10 m × 10 m with a 5 m-wide buffer zone; a total of 24 plots. The enhanced precipitation was sprayed onto the plots as an extra 10% (i.e. 20 mm) in Autumn (September), Spring (April), and Summer (July) in four doses of 5 mm per week in September, April and July using a petrol-driven, single-nozzle spray. Nitrogen was applied as NH_4NO_3 directly (in W0 N1 and W0 N2) or just after the extra precipitation (in W1 N1, W1 N2) in all treatments.

N_2O, CH_4 fluxes and R_s were measured using static chambers in all 24 plots. Gas samples were collected from the headspace of each static chamber at 0, 10, 20 and 30 min after closing the chamber between 10:00 and 12:00 (GMT + 8). Gas samples were collected once or twice a week. Samples were measured using a gas chromatograph (GC; Agilent 7890A, Agilent Technologies, Santa Clara, CA). Fluxes were calculated according to Chen et al. (2013). Effects of precipitation and N deposition on R_s, N_2O and CH_4 fluxes were analyzed by two-way

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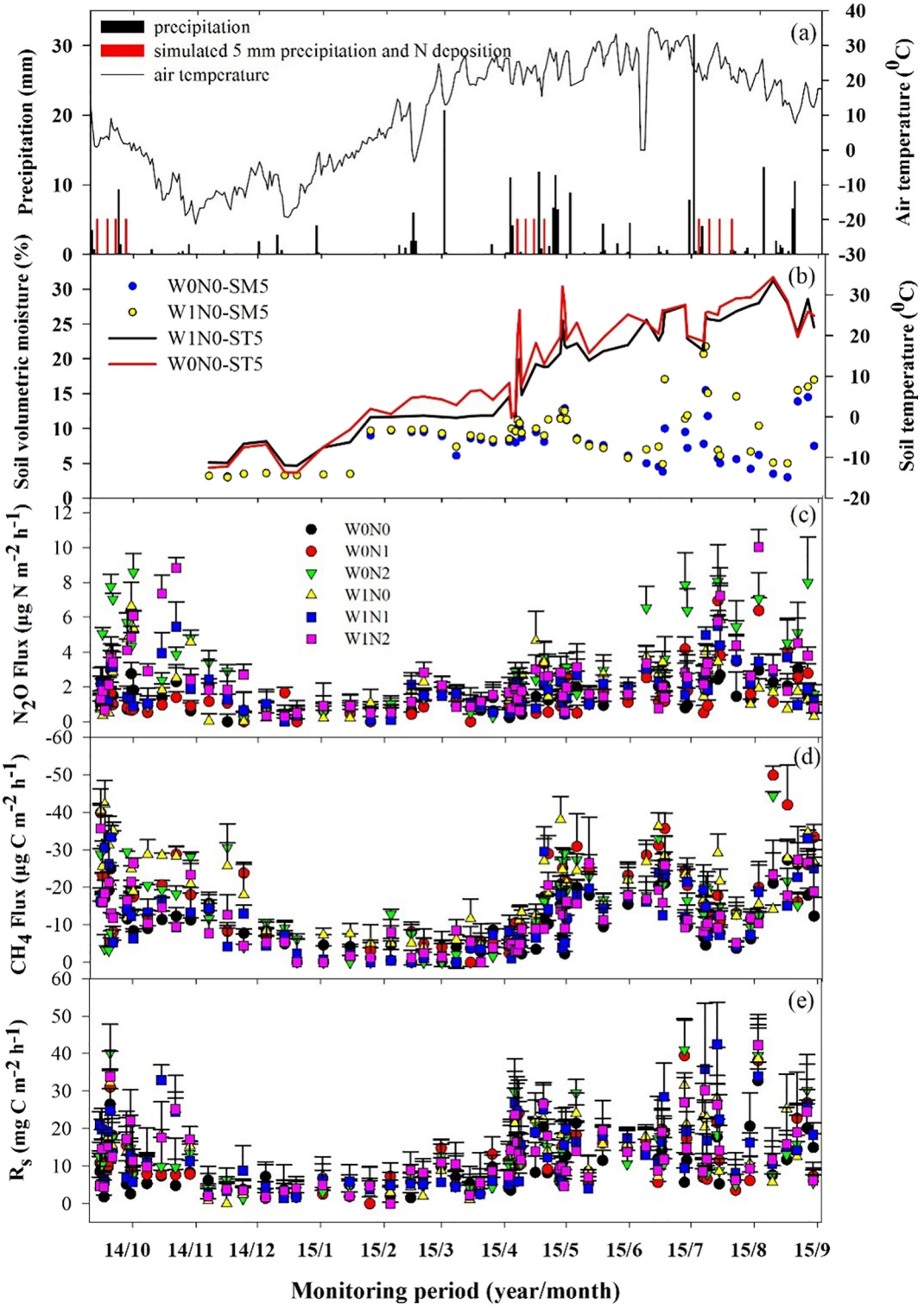

Fig. 1. Precipitation and air temperature and extra water treatment during the experimental period (a), and measured changes in soil moisture and soil temperature (b). The responses of fluxes (mean ± SE, n = 4) of N_2O (c), CH_4 (d) and soil respiration (R_s, e) to treatments. SM5 is soil moisture at the 5 cm depth; ST5 is soil temperature at the 5 cm depth.

repeated measures ANOVA. All statistical analyses were conducted using SPSS (version 20.0) with statistically significant differences set at $P < 0.05$.

N_2O emissions under the control (W0 N0) were small (0–3.46 μg N m^{-2} h^{-1}), being highest in March and lowest in December and January, with a weak emission peak occurring during the spring thaw (Fig. 1c). The annual cumulative N_2O emission was 0.13 kg N ha^{-1}, which was close to that of temperate semiarid grasslands (0.15 kg N ha^{-1}) (Chen et al., 2013), but far lower than that in forests (Zhang et al., 2008). N_2O emissions were significantly increased with N addition (Fig. 1c). For instance, W0 N2 caused the maximum flux being 10.03 ± 3.25 μg N m^{-2} h^{-1} and increased annual N_2O emission by 109.6%. N_2O emissions were significant increased by precipitation and interactions of precipitation and N deposition

Table 1
Tests of significance of precipitation (W) and nitrogen deposition (N) on N_2O, CH_4 fluxes, and R_s by two-way ANOVA (df, F and P values). Significant levels (P values < 0.05) are shown in bold.

Two-way ANOVA	N_2O flux			CH_4 flux			R_s		
	df	F	P	df	F	P	df	F	P
W	1	8917	**0.003**	1	20.584	**0.000**	1	4.286	**0.039**
N	2	29.086	**0.000**	2	18.467	**0.000**	2	2.448	0.118
W*N	2	7.817	**0.005**	2	23.158	**0.000**	2	1.849	0.175

(Table 1).

A weak CH_4 uptake was found (0–27.3 μg C m^{-2} h^{-1}) in the control. The annual cumulative uptake of CH_4 was 0.92 kg C ha^{-1} yr^{-1} in the control, slightly lower than that in a degraded steppe (1.4 kg C ha^{-1} yr^{-1}) (Chen et al., 2013) and the Mojave Desert (2.41 kg C ha^{-1} yr^{-1}) (Striegl et al., 1992). These temperate deserts are therefore weak sinks for atmospheric CH_4, whereas previous research found desert soils to be large sinks for CH_4 (Striegl et al., 1992). CH_4 uptake were significantly increased by precipitation and N addition (Fig. 1d), with an increase in annual uptake by 50.1–79.1% (Fig. 1d, Table 1S). Significant interactions of precipitation and N deposition on CH_4 uptake were found (Table 1), but the effects (+16.0–20.3%) were lower than those of any single-factor (+50.1–79.1%) (Table 1S).

A low annual R_s (9.98 ± 2.34 mg C m^{-2} h^{-1}) was observed in W0 N0. Significant impact on R_s was found by increasing precipitation but not by N addition (Table 1). R_s was significantly increased by the interaction of precipitation and 30 kg N ha^{-1} yr^{-1} (Table 1S). R_s was increased by the interaction of treatments less than by any single factor (Table 1S). Thus soil N and water content are the co-limiting factors in this desert ecosystem.

In summary, N_2O, CH_4 fluxes and R_s in desert soils are extremely sensitive precipitation and N deposition, and our results highlight the importance of a full understanding of the impacts and interactions of climate and environmental change on GHGs balance in desert ecosystems.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.geoderma.2018.10.020.

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