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Short Communication

The effect of increased atmospheric carbon dioxide concentration on emissions of nitrous oxide, carbon dioxide and methane from a wheat field in a semi-arid environment in northern China

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ABSTRACT

There are no reports on the effects of elevated carbon dioxide [CO_2] on the fluxes of N_2O, CO_2 and CH_4 from semi-arid wheat cropping systems. These three soil gas fluxes were measured using closed chambers under ambient (420 ± 18 μmol mol^{-1}) and elevated (565 ± 37 μmol mol^{-1}) at the Free-Air Carbon dioxide Enrichment experimental facility in northern China. Measurements were made over five weeks on a wheat crop (*Triticum aestivum* L. cv. Zhongmai 175). Elevated [CO_2] increased N_2O and CO_2 emission from soil by 60% and 15%, respectively, but had no significant effect on CH_4 flux. There was no significant interaction between [CO_2] and N application rate on these gas fluxes, probably because soil N was not limiting. At least 22% increase in C storage is required to offset the observed increase in greenhouse gas emissions under elevated [CO_2].

The atmospheric concentration of carbon dioxide [CO_2] has increased from 280 μmol mol^{-1} in 1800 to around 385 μmol mol^{-1} now, and is expected to reach around 700 μmol mol^{-1} by the end of 21st century (Houghton et al., 2001). The effect of elevated [CO_2] on the fluxes of nitrous oxide (N_2O), CO_2 and methane (CH_4) from wheat based cropping systems is not well documented, nor is its interaction with nitrogen (N) and water inputs, especially in intensively fertilized semi-arid cropping systems. The present study was conducted on a wheat field in northern China using the Free-Air Carbon dioxide Enrichment (FACE) facility to investigate the interaction among elevated [CO_2], fertilizer N application rate and irrigation on the fluxes of N_2O, CO_2 and CH_4 from soil.

The FACE experiment at Changping (40°10′N, 116°14′E), Beijing, China consists of six elevated (565 ± 37 μmol mol^{-1}) and six ambient (420 ± 18 μmol mol^{-1}) experimental areas, each 4 m in diameter. The soil (0–20 cm) is a clay loam, with a pH (1:5 soil: water) of 8.4 and contained 1.1% organic carbon (C), 0.1% total N and 94.8 mg kg^{-1} available N. Winter wheat (*Triticum aestivum* L. cv. Zhongmai 175) was sown on 10 October 2008. The long term average rainfall and temperature during the wheat growing season is 165 mm and 7.9 °C, respectively. The experimental areas were fertilized with granular urea and diammonium phosphate at a total N rate of 84 and 188 kg N ha^{-1} for the low-N (LN) and high-N (HN) areas, respectively. The data reported here were collected from early May to mid June in 2009, which corresponded to the booting stage to maturity of the wheat crop. The experiment was a completely randomized block design, with treatments of two [CO_2], two rates of N application and three replications. One hour prior to sampling, water was applied to the microplots on 7 and 10 June equivalent to rainfall of 75 mm and 25 mm, respectively.

Gas samples for N_2O, CO_2 and CH_4 analysis were taken from closed flux chambers (0.15 m height by 0.16 m diameter) on 5, 15 and 25 May and 4, 7 and 10 June between 1200 and 1500 h. In each treatment plot, one chamber was inserted in the soil to a depth of 70 mm between wheat rows on 4 May, and remained *in situ* throughout the experimental period. On each sampling day, the

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Table 1
Emission of N_2O, CO_2, CH_4 and CO_2 equivalent ($n = 36$, mean ± SE) as affected by ambient and elevated [CO_2], averaged across N application rates and irrigation events.

[CO_2] (μmol mol^{-1})	Gas flux							
	N_2O (μg N m^{-2} h^{-1})		CO_2 (mg C m^{-2} h^{-1})		CH_4 (μg C m^{-2} h^{-1})		CO_2 equivalent (mg C m^{-2} h^{-1})	
420	24.0 ± 6.6	*	37.3 ± 5.0	*	−5.6 ± 1.2	ns	44.3 ± 6.8	*
565	38.4 ± 11.1		42.8 ± 5.7		−4.2 ± 0.9		54.1 ± 8.8	

ns: not significant; *$p < 0.05$; CO_2 equivalent (mg C m^{-2} h^{-1}) = N_2O (mg N m^{-2} h^{-1}) × 296 + CO_2 (mg C m^{-2} h^{-1}) × 1 + CH_4 (mg C m^{-2} h^{-1}) × 23, where 296, 1 and 23 are global warming potentials (relative to CO_2) for N_2O, CO_2 and CH_4, respectively (Houghton et al., 2001).

chamber headspace was sampled at 30, 40 and 50 min after closure by removing a 30 mL gas sample with a gas-tight syringe and transferring it to a vacutainer (Labco, Exetainer). The gas samples were transported to the laboratory the same day for analysis by gas chromatography (Agilent Technologies 7890 GC). Gas diffusion into the headspace within 1 h was linear. The rates of emission of N_2O, CO_2 and CH_4 were calculated from the linear change in gas concentrations in the chamber according to Ruser et al. (1998). Two auger samples of the 0–0.1 m layer of soil from each microplot within each treatment plot were bulked. Subsamples (10 g) of the fresh soil were extracted by shaking for 1 h with 50 mL 2 M KCl (Russell et al., 2006). The concentrations of ammonium (NH_4^+) and nitrate (NO_3^-) in the filtered extract were determined colorimetrically by continuous flow analysis (FOSS Fiastar 5000). Data were analysed with MINITAB 14 statistical package using a General Linear Model analysis of variance.

1. Nitrous oxide flux

Positive N_2O fluxes (1.2–179.0 μg N m^{-2} h^{-1}) were observed for all treatments, with an overall increase of 60% ($p < 0.05$) in N_2O emission under elevated [CO_2] (Table 1). This is in agreement with a 40% increase in N_2O emissions in a mixed perennial ryegrass/white clover sward in a FACE experiment (Baggs et al., 2003). The hypothesis that elevated [CO_2] increased N_2O flux as a result of increase in root biomass and root exudation that was used by denitrifiers (Arnone and Bohlen, 1998; Kettunen et al., 2007) is supported by the positive correlation between N_2O and CO_2 fluxes ($r = 0.88$, $p < 0.001$) in the present study. Therefore, C cycling was increased and the increased C was the energy source for denitrification in this system. The interaction between elevated [CO_2] and N application rate on N_2O flux was not significant ($p = 0.117$) in the present study. In contrast, in perennial ryegrass swards where estimated N requirement was 290 kg N ha^{-1} yr^{-1} (Richter, 2003), elevated [CO_2] significantly increased N_2O emissions at application rate of 560 kg N ha^{-1} yr^{-1}, but not for 140 kg N ha^{-1} yr^{-1} (Baggs et al., 2003). The findings of Baggs et al. (2003) suggest that insufficient N supply limited N_2O emissions despite the greater C availability under elevated [CO_2]. In the present study, elevated [CO_2] increased overall N_2O emissions by 27% and 75% from both LN and HN plots, respectively (Fig. 1a), which suggests that excessive N application would enhance N_2O emission in this wheat cropping system. Indeed, soil from HN plots contained more NH_4^+–N (34%; $p < 0.05$) and NO_3^-–N (260%; $p < 0.001$) than the LN counterparts (Fig. 2). If fertilizer application rate is reduced in this system, the percentage stimulation of N_2O emission by elevated [CO_2] could possibly be reduced, especially after irrigation (Fig. 1a). We found significant interaction ($p < 0.001$) between N application rate and irrigation, with higher N_2O flux recorded from HN than LN plots on 7 June (37%) and 10 June (1812%) after the addition of 75 and

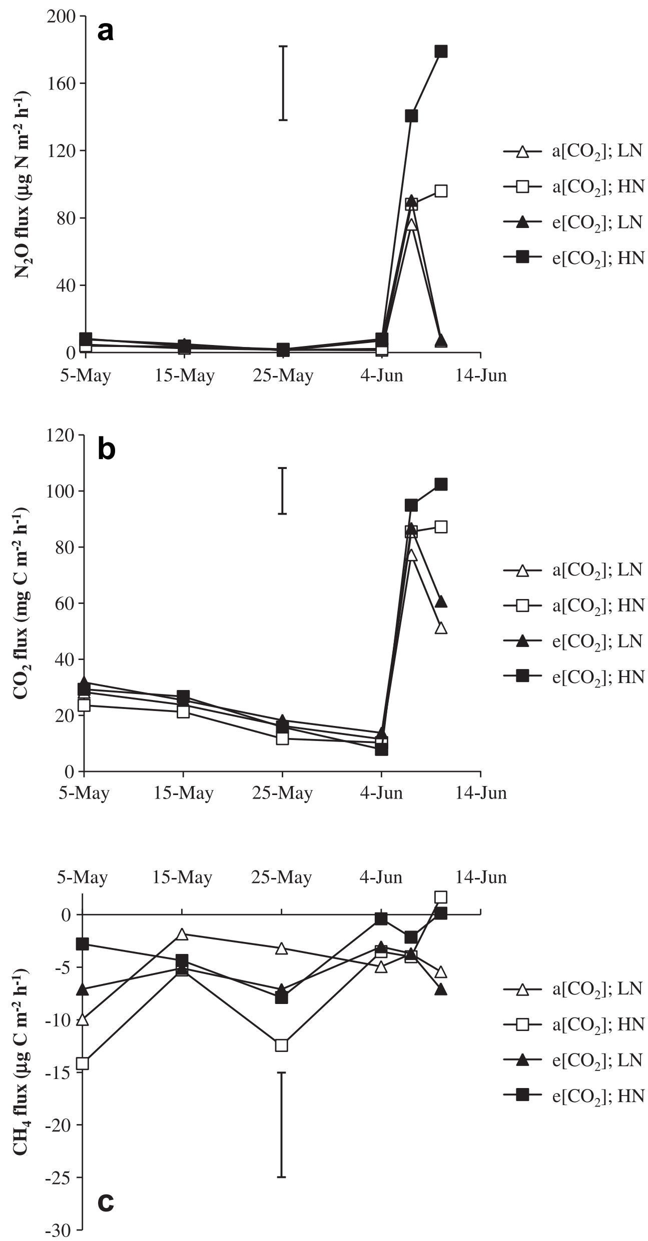

Fig. 1. The fluxes of (a) nitrous oxide, (b) carbon dioxide and (c) methane as affected by elevated [CO_2], nitrogen application rate and irrigation. On 7 and 10 June fluxes were measured 1 h after irrigation of plots with 75 mm and 25 mm water, respectively. Each data point represents the mean of three replicates. Vertical bars indicate LSD ($p < 0.05$). a[CO_2]: ambient [CO_2]; e[CO_2]: elevated [CO_2]; LN: low N plots; HN: high N plots.