The impact of free-air CO_2 enrichment (FACE) on N leaching from paddy soil

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Abstract
China FACE (Free-air Carbon Dioxide Enrichment) system was used to study the effects of elevated CO_2 on N leaching from paddy soil in the rice season. The results showed that elevated CO_2 had different effects on NH_4^+-N concentration in the till-layer soil solution at different stages. FACE condition increased NO_3^--N concentration in soil solution at 5 cm, 15 cm, 30 cm, 60 cm and 90 cm depth, by 46.5%, 36.8%, 23.3%, 103.7% ($P<0.01$) and 42.7% ($P<0.05$), respectively. Elevated atmospheric CO_2 can increase N loss via leaching from paddy soil. It is indicated that the amount of N in paddy soil will decrease faster under elevated atmospheric CO_2 due to larger N loss via leaching and uptake by rice plant, and there will need to be higher N inputs to maintain N balance in paddy soils in the future.

Key Words
Elevated CO_2; nitrogen; leaching; rice season; paddy soil

Introduction
Atmospheric [CO_2] has risen from approximately 280 mmol/mol in pre-industrial times to 387 mmol/mol in 2009 (IPCC 2001; IPCC 2009). CO_2 enrichment usually stimulates crop growth and yield (Rogers 1993). Elevated [CO_2] can reduce carbon mineralization in soil, and increase the amount of DIC (dissolved inorganic carbon) in the leachate while it has no significant effect on the amount of DOC (dissolved organic carbon) in the leachate (Marhan 2008). Elevated CO_2 increases nitrogen fixation and decreases soil nitrogen mineralization in Florida scrub oak (Hungate 1999). So the responses of different ecosystems to elevated [CO_2] in atmosphere are different. Rice (Oryza sativa L.) is one of the most important plants in the world and the first staple food in Asia, providing nutrition to a large proportion of the world's population. The response of rice ecosystem to atmospheric [CO_2] enrichment in China is a research hotspot. There have been many studies involving rice yield, elements in plant, soil respiration and soil microflora under elevated [CO_2](Xu 2006; Yang 2008; Liu 2008). The research about nitrogen dynamics in paddy soils under elevated [CO_2] is relatively lacking. It is very important to know the response of nitrogen dynamics to elevated [CO_2]. On the one hand, nitrogen is one of the most important elements to rice plant growth, yield as well as quality. On the other hand, nitrogen via runoff and leaching can enter into the water bodies, and increase the water eutrophication and groundwater pollution. Using FACE (Free-air Carbon Dioxide Enrichment) experiment, we studied nitrogen leaching loss from paddy soil under atmospheric [CO_2] enrichment by determining the concentrations of NH_4^+-N and NO_3^--N at different soil depth. Our objective is to understand nitrogen geochemical behaviour under future climates and provide theoretical support to nitrogen fertilizer application conditions in paddy fields.

Materials and methods
Experiment site description and meteorology
The FACE experimental system of rice-wheat rotation was established in Xiaoji town, Yangzhou city, Jiangsu Province, China (119°42'0''E, 32°35'5''N). The soil is Shajiang Aquic Cambosols with a sandy-loamy texture. Relevant soil properties are as follows: soil organic C (SOC) 18.4 g/kg, total N 1.45 g/kg, total P 0.63 g/kg, total K 14.0 g/kg, available P 10.1 mg/kg, available K 70.5 mg/kg, and pH(H_2O) 7.2. The station, 5 m above sea level in elevation, sits in the subtropical marine climatic zone with mean annual precipitation being 980 mm, annual evaporation 1100 mm, annual mean temperature 14.9 ^oC, annual sunshine hours 2100 h and frost free period 220 days.

Face system
The FACE system has six octagonal plots located in different paddies having similar soils and agronomic histories. Three plots were randomly allocated for the elevated CO_2 treatments (hereinafter called FACE plots) and the other three for the ambient treatments (hereinafter referred to as ambient plots). In the FACE plots, the plants were grown within 14-m-diameter 'rings' which sprayed pure CO_2 both day and night

throughout the growing season except for a few days during transplantation towards the plot centre from eight peripheral emission tubes (5mlong) located about 0.5m above the canopy (Okada, 2001). The ambient plots had no ring structures, and plants were grown under ambient [CO_2] without ring structures. The target [CO_2] in the FACE plots throughout the rice growth season was controlled to 200 mmol/mol above that of ambient by computer system platform. Adjacent plots were buffered to avoid treatment cross-over. Details of the design, rationale, operation, and performance of the CO_2 exposure system used in this study can be found in Okada (2001) and Liu (2002).

Crop cultivation

A japonica cv. Wuxiangging 14 was tested in the experiment. Standard cultivation practices as commonly performed in the area were followed in all experimental plots. Rice seeds were sown under ambient [CO_2] conditions on 18 May. On 14 June 2007, the seedlings were manually transplanted at a density of three seedlings per hill into the FACE and ambient plots. Spacing of the hills was 16.7 cm × 25 cm (equivalent to 24 hills/m^2). The amount of nitrogen (N) was 25 g N/m^2, which was supplied as urea (N, 46%) and compound chemical fertilizer ($N:P_2O_5:K_2O$ = 15:15:15,%). Phosphorous (P) and potassium (K) fertilizers were applied as compound fertilizer at rates of 7 g P_2O_5/m^2 and 7 g K_2O/m^2, respectively. N was applied as a basal dressing 1 day prior to transplanting and as side dressing at early-tillering on 21 June (60% of the total) and at panicle initiation (PI) on 28 July (40%),while P or K was both applied as basal dressing 1 day prior to transplanting.

Soil solution sampling and measurements

On 18 June 2007, soil solution samplers (RHIZON SMS-MOM, Netherlands Eijkelkamp Agrisearch Equipment) were inserted at 5cm, 15cm, 30 cm, 60 cm and 90 cm depths. There are 2 replicates at same soil depth in each plot. The soil solution at different soil depths was sampled on 30 June, 22 July, 15 August and 10 September. NH_4^+-N and NO_3^--N in soil solution samples were measured colorimetrically by the indophenol blue method and ultraviolet spectrophotometry (Lu 2000), respectively.

Statistical analysis

Data were analyzed with the statistical package SPSS15.0 and EXCEL2007 for Windows.

Results

NH_4^+-N concentration in soil solution

Due to NH_4^+ -N concentrations in soil solution at 30 cm, 60 cm and 90 cm depths on 30 June were very low (data not shown), the NH_4^+ -N concentrations in soil solution at 30cm, 60cm and 90cm depths on 22 July, 15 August and 10 September were not determined. Figure 1 show dynamics of NH_4^+ -N concentrations in soil solution at 5cm and 15cm depths during the rice season. With rice growing, change of NH_4^+-N concentration in soil solution at 5cm depth in FACE treatment had the same trend with that in ambient treatment (Figure 1a). There was significant difference (P<0.01) between different stages (Table 1). The NH_4^+-N concentration in soil solution at 5cm depth in FACE treatment on 30 June was 105.7% (P>0.05) higher than that of ambient treatment, while 43.8% (P<0.05) lower than that of ambient treatment on 15 August.

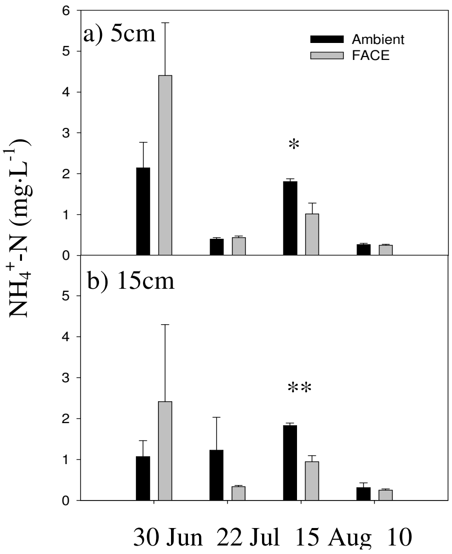

Figure 1. Effect of elevated CO_2 on NH_4^+-N concentration in soil solution at different tillaged-layer soil depths.

Table 1. F-values of a two-way factorial ANOVA on NH_4^+-N concentration in soil solution at different depths.

	5 cm	15 cm
CO_2	0.840(0.376)	0.051(0.824)
Stage	11.297(0.001)	1.298(0.312)
CO_2* Stage	2.469(0.108)	0.948(0.442)

Note: P values are in the parentheses.

The change of NH_4^+-N concentration in soil solution at 15cm depth in FACE treatment had the same trend with that at 5cm depth (Figure 1a, b). The trend of NH_4^+-N concentration in soil solution at 15cm depth in ambient treatment was different. In ambient treatment, the NH_4^+-N concentration in soil solution at 15cm depth on 22 July was slightly higher than that on 30 June, while in FACE treatment, that on 22 July was lower than that on 30 June. Unlike 5cm depth, there was no significant difference at 15cm depth between different stages. The NH_4^+-N concentration in soil solution at 15cm depth in FACE treatment on 30 June was 125.4% (P>0.05) higher than that of ambient treatment, while 48.5% (P<0.01) lower than that of ambient treatment on 15 August (Table 1). Although the effects of elevated [CO_2] on NH_4^+-N concentration in soil solution at 5 cm and 15cm depth were not significant, from the whole growth period, elevated [CO_2] had the trend of increasing NH_4^+-N concentration in soil solution at 5 cm and 15cm depth at early stage (on 30 June), while decreased that at later stage (especially on 15 August).

NO_3^--N concentration in soil solution

NO_3^--N concentration in soil solution at 5cm depth in both FACE and ambient treatment decreased with rice growing, while that at 15cm depth increased (Figure 2 a, b). There was no significant difference between different stages due to large variation between replicates (Table 2). The NO_3^--N concentration in soil solution in FACE treatment was 39.1%, 61.0%, 68.8% and 18.9% (5cm) and 6.4%, 24.0%, 34.9% and 68.3% (15cm) higher than that of ambient treatment on 30 June, 22 July, 15 August and 10 September, respectively. NO_3^--N concentration in soil solution at same stage was decreased with higher depth (Table 2). NO_3^--N concentration in soil solution at different depths during different stages in FACE treatment was higher than that in ambient treatment except at 30cm depth on 30 June and 15 August. NO_3^--N concentrations in soil solution in FACE treatment were almost same with ambient treatment at 60 cm and 90 cm depths on 30 June.

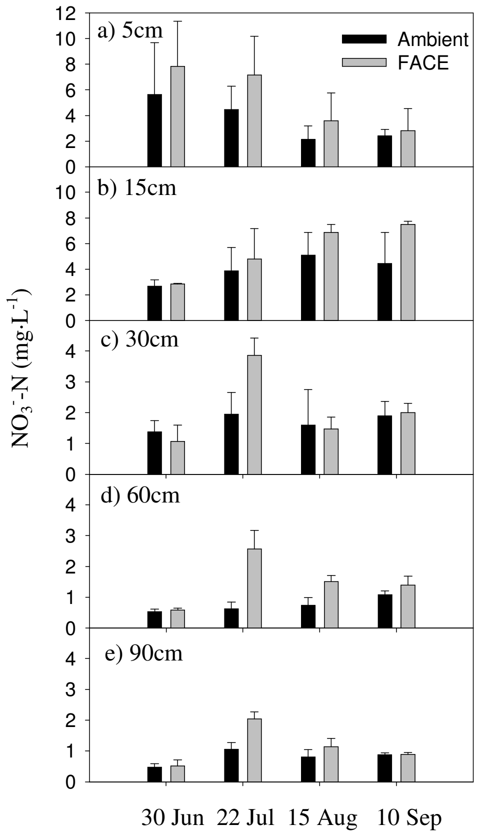

Figure 2. Effect of elevated CO_2 on NH_4^+-N concentration in soil solution at different depths.

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Table 2. F-values of a two-way factorial ANOVA on NO_3^--N concentration in soil solution at different depths.

	5 cm	15 cm	30 cm	60 cm	90 cm
CO_2	0.220(0.646)	0.209(0.654)	0.785(0.391)	16.006(0.001)	6.569(0.021)
Stage	0.788(0.519)	1.870(0.175)	3.356(0.050)	5.056(0.012)	10.870(0.000)
CO_2* Stage	0.253(0.858)	1.057(0.395)	1.560(0.243)	4.798(0.014)	2.894(0.068)

Note: P values are in the parentheses.

NO_3^--N concentrations in soil solution in FACE treatment were 98%, 311.1% (*P*<0.05) and 93.4% (*P*<0.05) higher than ambient treatment at 30 cm, 60 cm and 90 cm depths on 22 July. From the view of the whole rice growth period, NO_3^--N concentrations in soil solution in FACE treatment were 23.3%, 103.7% (*P*<0.01) and 42.7% (*P*<0.05) higher than ambient treatment at 30 cm, 60 cm and 90 cm depths.

Conclusion

Elevated CO_2 had different effects on NH_4^+-N concentration in tillaged-layer soil solution at different stages. FACE condition increased NO_3^--N concentration in soil solution at 5cm, 15cm, 30cm, 60cm and 90cm depth, with 46.5%, 36.8%, 23.3%, 103.7% (*P*<0.01) and 42.7% (*P*<0.05), respectively. The results indicate that N loss via leaching from paddy soil could be larger, and there will need more N inputs to maintain N balance in paddy soil in the future.

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