Environ Geol (2007) 52:529–539
DOI 10.1007/s00254-006-0485-9

ORIGINAL ARTICLE

Effects of nitrogen on the ecosystem respiration, CH_4 and N_2O emissions to the atmosphere from the freshwater marshes in northeast China

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Received: 22 August 2006 / Accepted: 22 August 2006 / Published online: 27 September 2006

Abstract Freshwater marshes could be a source of greenhouse gases emission because they contain large amounts of soil carbon and nitrogen. These emissions are strongly influenced by exogenous nitrogen. We investigate the effects of exogenous nitrogen on ecosystem respiration (CO_2), CH_4 and N_2O emissions from freshwater marshes in situ in the Sanjiang Plain Northeast of China during the growing seasons of 2004 and 2005, using a field fertilizer experiment and the static opaque chamber/GC techniques. The results show that there were no significant differences in patterns of seasonal variations of CO_2 and CH_4 among the fertilizer and non-fertilizer treatments, but the seasonal patterns of N_2O emission were significantly influenced by the exogenous nitrogen. Seasonal averages of the CO_2 flux from non-fertilizer and fertilizer were 987.74 and 1,344.35 mg m^{-2} h^{-1}, respectively, in 2004, and 898.59 and 2,154.17 mg m^{-2} h^{-1}, respectively, in 2005. And the CH_4 from the control and fertilizer treatments were 6.05 and 13.56 mg m^{-2} h^{-1} and 0.72 and 1.88 mg m^{-2} h^{-1}, respectively, in 2004 and 2005. The difference of N_2O flux between the fertilizer and non-fertilizer treatments is also significant either in 2004 and 2005. On the time scale of 20-, 100-, and 500-year periods, the integrated global warming potential (GWP) of $CO_2 + CH_4 + N_2O$ released during the two growing seasons for the treatment of fertilizer was 97, 94 and 89%, respectively, higher than that for the control, which suggested that the nitrogen fertilizer can enhance the GWP of the CH_4 and N_2O either in long time or short time scale.

Keywords Exogenous nitrogen · Freshwater marshes · Ecosystem respiration · CH_4 · N_2O emissions · GWP

Introduction

Greenhouse gases in the atmosphere (CO_2, CH_4, and N_2O) are believed to play an important role in regulating the global climate (Wang et al. 2000). Concentrations of atmospheric CO_2, CH_4, and N_2O have been continually rising as a result of anthropogenic activities (Hollinger et al. 2005) since the industrial revolution, and the rising levels of the greenhouse gases have caused an increase in radiative forcing of the earth's atmosphere. These gases are produced by aerobic respiration, methanogenesis and denitrification, the microbiological processes are sensitive to the availability of their substrates, carbon and nitrogen (Liikanen et al. 2003). Numerous studies have established peatlands as the major sink of atmospheric CO_2 (Waddington and Roulet 2000) and the significant source of atmospheric CH_4 (Bartlett et al. 1992; Moore and Roulet 1995; Moosavi and Patrick 1996; Song et al. 2003) to the biosphere. Though the CH_4 concentration is much lower than the CO_2 in the atmosphere, the contribution to climate forcing has been about 35% of

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the climate forcing by CO_2 and about 22% of the forcing by all long-lived greenhouse gases in the past 150 years (Lelieveld et al. 1998). Northern peatlands play an important role in the global carbon sinks; they have accumulation rates of between 10 and 30 g C m^{-2} $year^{-1}$, and contain between 5 and 250 kg C m^{-2} with a global carbon mass of between 250 and 450 Pg (Gorham 1991; Turunen et al. 2001). The productivity of peatland is often limited by available nitrogen (Berendse et al. 2001); nitrogen saturation of terrestrial ecosystems may drastically alter fluxes to the atmosphere of a number of radiatively active gases (CO_2, CH_4, and N_2O) (Fenn and Poth 1998), but the accumulation and retention of nitrogen in peatlands are less established. Much attention (Crill et al. 1991; Magnusson 1993) has been focused on the quantification of the greenhouse gases production in different types of mires; elevated nitrogen loading has been identified as a critical environmental concern of global proportions (Vitousek et al. 1997) in affecting the greenhouse gases flux. However, there is no quantitative data on the emission of these gases from the freshwater marshes in China, except the preliminary reports (Song et al. 2003, 2004, 2005) CO_2 and CH_4 from the same area. And there has been no consideration of the effects of nitrogen on the ecosystem respiration, CH_4 and N_2O emissions from the freshwater marshes in China.

The area of mires in China is at present about 9.40×10^{10} m^2, accounting for 1% of total national area (Zhao 1999). The Sanjiang Plain is the biggest wetland distribution in China, 9.56% of which belonged to marshes in 1994, reduced greatly compared to > 90% in 1893 (Liu and Ma 2000). Recently, more and more marshes have been drained for conversion to agricultural production. The still undrained marshes often receive some leaching nitrogen during the agricultural activity, which may influence the rates of plant production and decomposition and carbon cycling, and enrichment by nitrogen from agricultural runoff in Sanjiang Plain marshes is thought to contribute to the effects of greenhouse gas emissions. Most of the understanding of nitrogen influences on wetland ecosystem mainly focuses on the decontaminate function of hygrophytes to the nitrogen pollution (Romero et al. 1999), although the effects of elevated nitrogen to the ecosystem respiration, CH_4 and N_2O emissions have not been well understood in most natural ecosystems, in part because of the confounding effects of several variables, which interact in field situations. Adams (2003) had been asked to cover the ecological issues relating to nitrogen deposition to natural ecosystems and proposed the question whether ambient rates of nitrogen deposition are sufficient to similarly alter productivity in natural ecosystems and significantly affect carbon cycling. Based on this question and considering there is a lot of extraneous nitrogen coming into the wetland along with the agricultural activities and atmospheric deposition in Sanjiang Plain, we examine the influence of exogenous nitrogen (atmospheric deposition, surface runoff, and agricultural leaching) on ecosystem respiration, CH_4 and N_2O emissions from the *Doyeuxia angustifolia* wetland, using a field fertilizer experiment in situ, during the whole growing season of 2004 and 2005 in Sanjing Plain northeast of China.

Materials and methods

Study site and field work

The field experiment was carried out at the Sanjiang Mire Wetland Experimental Station, Chinese Academy of Sciences, in Heilongjiang province, China, at approximately 47°35′N, 133°31′E in 2004 and 2005, where there are many types of herbage swamp and dismal meadow. The mean annual precipitation was 550–600 mm and the mean annual temperature was 1.9 °C. The types of vegetation vary from *Deyeucia angustifolia* to *Carex lasiocarpa* as the standing water depth increases. The main soil includes meadow mire soil and peat land soil, with the high soil organic matter content (Table 1). One of main typical types of *D. angustifolia* was selected for the study.

Six randomly selected plots (50 cm × 50 cm) were permanently marked two groups: three were enriched with nitrogen biweekly (group A), while three remained as controls (group B). The distance between groups A and B was about 10 m. In each group, the distance between the two sites is 1 m. A drip irrigation instrument was run to apply fertilizer with water solution in the nitrogen fertilizer treatment plots during growing sea-

Table 1 The characteristics of the soil in field experiment

Wetland	Soil	Depth (cm)	Organic carbon (%)	Total nitrogen (%)	Bulk capacity (g m^{-3})
Carex lasiocarpa	Peatland soil	0–5	32.18 ± 1.91	1.47 ± 0.23	0.35 ± 0.08
		5–15	26.64 ± 3.84	1.25 ± 0.17	0.54 ± 0.13
Deyeuxia platyphylla	Meadow soil	0–5	14.81 ± 5.10	0.95 ± 0.25	0.56 ± 0.21
		5–15	7.63 ± 0.72	0.82 ± 0.25	0.79 ± 0.17

sons for two years from 2004 to 2005 and the same quantity of non-fertilizer water was added to the control treatment. Fertilizer treatment was 240 kg N ha^{-1} $year^{-1}$ in order to discuss whether the greenhouse gases emissions were significantly affected by the nitrogen fertilizer. The experiment started in June 2004 and ended in September 2005. Every two weeks, nitrogen was applied as a concentrated solution of NH_4NO_3 divided into seven equal doses (June–September) in 2004 and nine equal doses (May–September) in 2005, totaling 240 kg N ha^{-1} $year^{-1}$. At the same time, the plant height was measured every 10 days and the final biomass was harvested in order to get the relationship function of plant height and aboveground biomass.

Sample collection and analysis

Seasonal field measurements were conducted at the fertilizer and non-fertilizer treatments (N240 and N0) sites during the growing season of 2004 and 2005 almost two or three times weekly in order to find temporal pattern of the emission of greenhouse gases from freshwater mashes. Measurements for this study began during the first week of June 2004 and the third week of May 2005 while the plants started to become green. Sampling was conducted on a weekly twice basis until September in 2004 and 2005. CO_2, CH_4, and N_2O flux measurements were collected at six sample stations (each treatment three replicates) using static chamber/GC methods described by Wang and Wang (2003). Three replicate plots were simultaneously observed for each field treatment. The static flux chamber method involves placing an open bottom chamber on a scalable stainless collar according to the plant height. Trace gas concentrations inside the chamber were measured and recorded as a function of time to determine flux rates for each sampling interval (Crill et al. 1988). Boardwalks and stainless collar were installed during 2003 so that measurements could be made on a regular basis with minimal disturbance. Simultaneously, the temperature was recorded in chamber. The air samples were analyzed with the GC (Agilent 4890) within the 24 h. The GC configurations for analyzing CO_2, CH_4, and N_2O in the samples and the methods for calculating the three greenhouse gas flux were completely the same as those described by Wang and Wang (2003). The flux was calculated according to the equation as described by Song et al. (2003).

Statistical analysis

The SPSS 11.0 and origin 7.0 statistical packages were used in the statistical analysis. The difference in gas fluxes between fertilizer and non-fertilizer treatments was tested by ANOVA, repeated measures, by using two or three times weekly average flux per plot as a variable. In all analysis where $P < 0.05$, the factor tested and the relationship were considered statistically significant.

Results

Deyeucia angustifolia aboveground biomass

Table 2 shows that there was a significant effect of the nitrogen fertilizer on *D. angustifolia* aboveground biomass ($P < 0.001$). The aboveground biomass of the three replicates under nitrogen fertilizer was higher than under ambient conditions and the fertilizer treatment increased 375% compared with the control treatment. The difference of the *D. angustifolia* biomass in fertilizer and non-fertilizer treatments is significant. The standard deviation was large among replicates, which indicated that soil was not particularly homogenous because the microclimate and microtopography of the freshwater marshes were reasonably homogeneous. These results indicated that nitrogen fertilizer may stimulate *D. angustifolia* growth and that the stimulation may be further intensified by increasing the other factors, such as temperature and precipitation.

Seasonal variation and effects of exogenous nitrogen on ecosystem respiration (CO_2 release)

CO_2 flux measurements using dark static chambers include respiration from living aboveground and belowground plant parts as well as aerobic and anaerobic microbial activities within the peat column (Merritt et al. 2002). This flux is termed the ecosystem respiration or community CO_2 release (Nykanen et al. 1998). Figure 1 shows the dynamic seasonal pattern of CO_2 fluxes from the two treatments during the plant growing season of 2004 and 2005. In this study, a clear seasonal variation of CO_2 release from *D. angustifolia* freshwater marsh was observed. There were no signif-

Table 2 Effects of nitrogen fertilization on *D. angustifolia* biomass

Application of nitrogen (kg N ha^{-i})	Biomass (g m^{-2})
N0	200.76 (48.50)
N240	953.87 (114.60)

The *number* in the parenthesis is the standard deviation

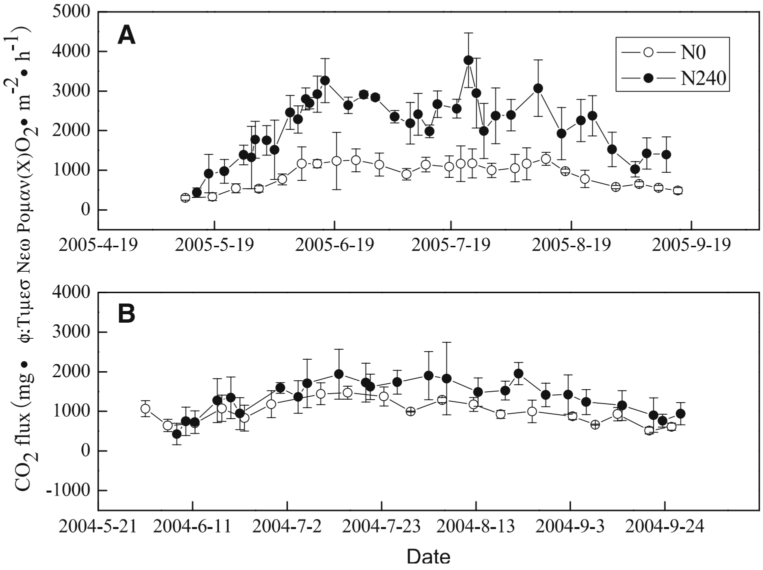

Fig. 1 Seasonal variations in CO_2 fluxes from the two treatments during the two growing seasons of 2004 and 2005

icant differences in the patterns of seasonal variations of CO_2 fluxes from the fertilizer treatment among the 2 years while the seasonal variations of the control treatment is not similar (Fig. 1). In 2004, CO_2 fluxes gradually increased following germination emergence and reached maximum values, 1,472.02 mg m^{-2} h^{-1} in the middle of July, and then decreased gradually after anthesis (about 16th July) from the control treatment. In 2005, there are three obvious peaks of CO_2 fluxes: one appears at the panicle stage (about 25th June) and another at the fruitage (about 25th July) and ripening (about 13th August) stages. Similar seasonal dynamic patterns were observed for the fertilizer treatment of 2004 and 2005 (Fig. 1). Fertilizer treatment CO_2 flux emergence pulse-like along with every nitrogen input scenario, and there is a distinct correlation between the peak value beginning time and the nitrogen input time. But the beginning time of the peak value is different in the two years. In 2004, the peak value mostly appears in the next time observation before the nitrogen application except the last nitrogen application in August, which occurs after the nitrogen input observation. But in 2005, the time of the peak value does not appear regularity, after fertilizer application and before each time, as well as between the two fertilizer application time, which the peak value has been observed. The CO_2 emission flux from the non-fertilizer treatment has not been changed obviously during the two growing seasons (Fig. 1), CO_2 flux was in the range from 514.44 to 1,472.02 mg m^{-2} h^{-1} in 2004 and from 271.99 to 1,308.49 mg m^{-2} h^{-1} in 2005. However, the CO_2 flux from the fertilizer treatment is significantly higher in 2005 compared with that of 2004 (Fig. 1): the flux range was 428.42–1,951.82 mg m^{-2} h^{-1} in 2004 while it enhanced to 438.82–3,778.30 mg m^{-2} h^{-1} in 2005.

The data of this study clearly demonstrates that elevated nitrogen has a significantly positive effect on CO_2 emissions from freshwater wetlands (Figs. 1, 2). There were no significant differences in the mean CO_2 flux between the fertilizer and non-fertilizer treatments in June while in July, August, and September, the mean CO_2 flux of the fertilizer treatment was significantly higher than that of the non-fertilizer in 2004 (Figs. 1B, 2). However, the positive effect of fertilizer on CO_2 emission was most obvious during the whole growing season from the beginning of the plant season which fertilizer scenario beginning in 2005 (Fig. 1A). In general, continuously two growing season nitrogen applications exerted a remarkably stimulating effect on CO_2 emission from *D. angustifolia* wetlands (using one-sample statistics of SPSS, $P < 0.001$). The fertilizer and non-fertilizer treatments of CO_2 flux is different (Fig. 2). And the seasonal averages of the CO_2 flux from non-fertilizer and fertilizer were 987.74 and 1,344.35 mg m^{-2} h^{-1}, respectively, in 2004, and 898.59 and 2,154.17 mg m^{-2} h^{-1}, respectively, in 2005 (Fig. 2), which shows the CO_2 emission flux of nitrogen fertilizer is far higher than that of the non-fertilizer ($P < 0.001$).

Seasonal variation of CH_4 emission and response to the exogenous nitrogen

CH_4 fluxes between peatlands and atmosphere may range from slight uptake to emissions of more than 1,000 mg m^{-2} day^{-1} (Klinger et al. 1994). Fluxes are temporally and spatially highly variable (Bubier et al.

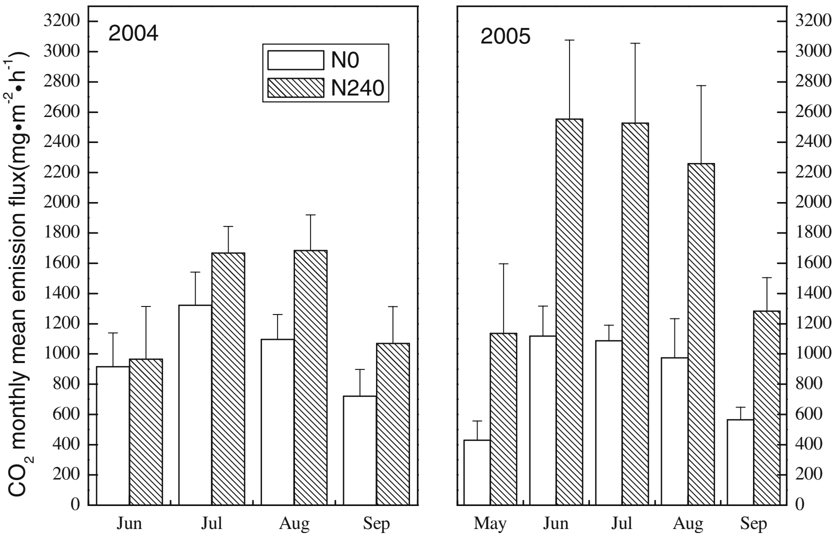

Fig. 2 Variation of monthly CO_2 emission flux for control and fertilization treatments during 2 years

1993; Roulet et al. 1997; Moore et al. 1998). Average emissions of 5–80 mg m^{-2} day^{-1} are most common in northern peatlands. Figure 3 shows the CH_4 flux of the two treatments from the *D. angustifolia* wetland during the two growing seasons of 2004 and 2005. There was a noticeable seasonal variation in CH_4 emission velocity in 2004 and 2005. CH_4 emissions from the freshwater marshes were greatly different at different days of the growing season and exhibited a unique peak approximately in June during the two growing seasons. The fluxes given in Fig. 3 are the averages of the triplicates. There were no significant differences in the patterns of seasonal variations of the CH_4 fluxes between the two treatments during the two growing season of 2004 and 2005. After the *D. angustifolia* germinating and growing, CH_4 fluxes generally increased and reached peaks approximately on June 20th in 2004 and on June 7th in 2005, respectively, and then dropped off in both two growing seasons. CH_4 fluxes further decreased from about July 10th in 2004 and about June 25th in 2005 and remained at low levels afterwards (Fig. 3). But the fertilizer peak value appears lagging several days compared with the non-fertilizer treatment during 2005, while in 2004, the peak value time of the two processing is consistent. In two years, the *D. angustifolia* plant showed higher fertilizer than non-fertilizer treatment emissions. However, the treatment difference in CH_4 emission was much smaller in 2005 than in 2004 (Figs. 3, 4). As Fig. 3 shows, CH_4 emission flux from the prophase of the growth season that the plant developed rapidly is higher remarkably compared to that of the anaphase during the growing seasons of

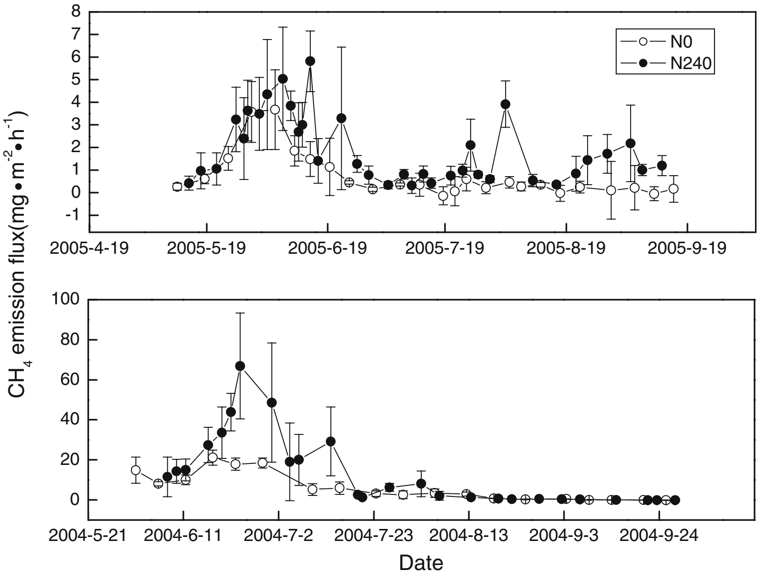

Fig. 3 Seasonal variations in CH_4 fluxes from the two treatments during the two growing seasons of 2004 and 2005

2004 and 2005, which demonstrate that plants rather than soil organic matter provide the substrates for methanogens to result in the difference in CH_4 emission.

Figure 4 shows the two treatments monthly means of CH_4 fluxes from freshwater wetland throughout the period of *D. angustifolia* growth in 2004 and 2005. The average of the mean CH_4 flux tended to significantly increase with the nitrogen fertilizer, especially in June and July of 2004, while in 2005, the CH_4 emission of fertilizer treatment is always higher than the non-fertilizer from the plant germination to senescence. In 2004, the non-fertilizer and fertilizer CH_4 flux in June and July averages were 30.36 and 15.09 mg m^{-2} h^{-1} and 18.12 and 4.22 mg m^{-2} h^{-1}, respectively, while the August averages and September averages were 2.15 and 1.82 mg m^{-2} h^{-1} and 0.05 and 0.06 mg m^{-2} h^{-1}, respectively; however, the September average flux of fertilizer is lower than that of the non-fertilizer. In 2005, the fertilizer and non-fertilizer CH_4 flux is as follows, and the May averages were 1.95 and 1.49 mg m^{-2} h^{-1}, the June averages were 3.18 and 1.72 mg m^{-2} h^{-1}, the July averages were 0.79 and 0.23 mg m^{-2} h^{-1}, the August averages were 1.47 and 0.24 mg m^{-2} h^{-1}, the September averages were 1.46 and 0.11 mg m^{-2} h^{-1}, respectively. The data of this study clearly demonstrate that nitrogen fertilizer has a significantly positive effect on CH_4 emissions from the freshwater wetland (Figs. 3, 4), which maybe was caused by the increase in *D. angustifolia* biomass and root exudates that may provide a primary source of organic carbon for rapid utilization by methanogenic microbes, which may also stimulate methane emission from the submerged soils to the atmosphere.

N_2O emission

The patterns of seasonal variations in N_2O fluxes from *D. angustifolia* freshwater marsh plots were quite different from those of CH_4 and CO_2 fluxes (Fig. 5). The seasonal variation of N_2O emission was not clear and looks sporadic and pulse-like, especially in the nitrogen fertilizer treatment. The amounts of N_2O emitted from the freshwater marsh were very small and a large proportion of N_2O was emitted after every nitrogen addition scenario in the fertilizer treatment, while in the non-fertilizer, the phenomenon is not obvious. And the flux peaks were usually observed immediately after the following of the nitrogen applied. N_2O flux of the non-fertilizer treatment was very low or nil compared with CO_2 and CH_4 during the period of the *D. angustifolia* plant growing of 2004 and 2005 (Fig. 5), while the N_2O emission increased significantly with the nitrogen application (Figs. 5, 6). The N_2O emission from the fertilizer and non-fertilizer treatments reached a maximum value 0.89 and 0.31 mg m^{-2} h^{-1} in July and June 2004, 2.25 and 0.27 mg m^{-2} h^{-1} in July 2005, respectively, while the minimum value of N_2O flux of the fertilizer and non-fertilizer treatments is -0.178 and 0.008 mg m^{-2} h^{-1} in 2004, 0.064 and 0.02 mg m^{-2} h^{-1} in 2005, respectively, which occurs in winter. And in the two growing seasons, the fertilizer treatment N_2O flux varied widely compared to the non-fertilizer treatment. In 2004, the non-fertilizer treatment was in the range from 0.008 to 0.307 mg m^{-2} h^{-1} while the fertilizer was in the range from -0.178 to 0.891 mg m^{-2} h^{-1}. In 2005, the non-fertilizer treatment was in the range from 0.020 to 0.270 mg m^{-2} h^{-1}, while the fertilizer was in the range from 0.064 to 2.250 mg m^{-2} h^{-1}, which shows the N_2O

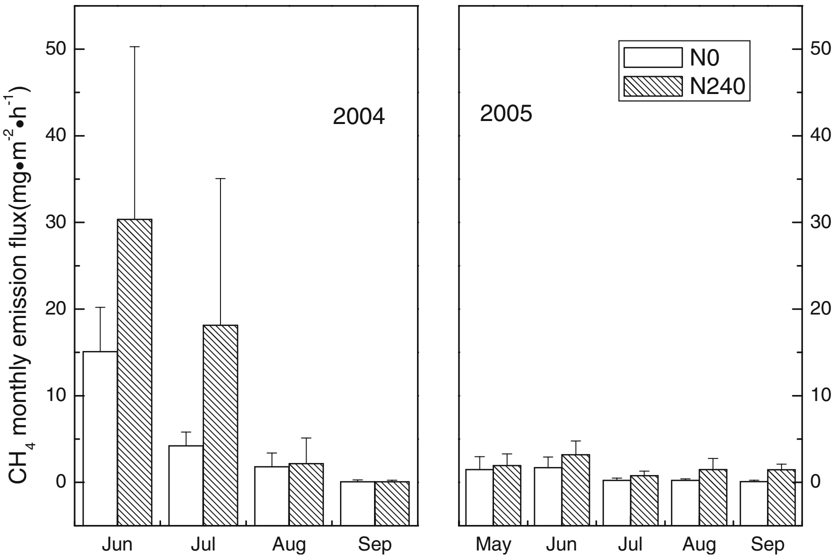

Fig. 4 Variation of monthly CH_4 emission flux for control and fertilization treatments during 2 years

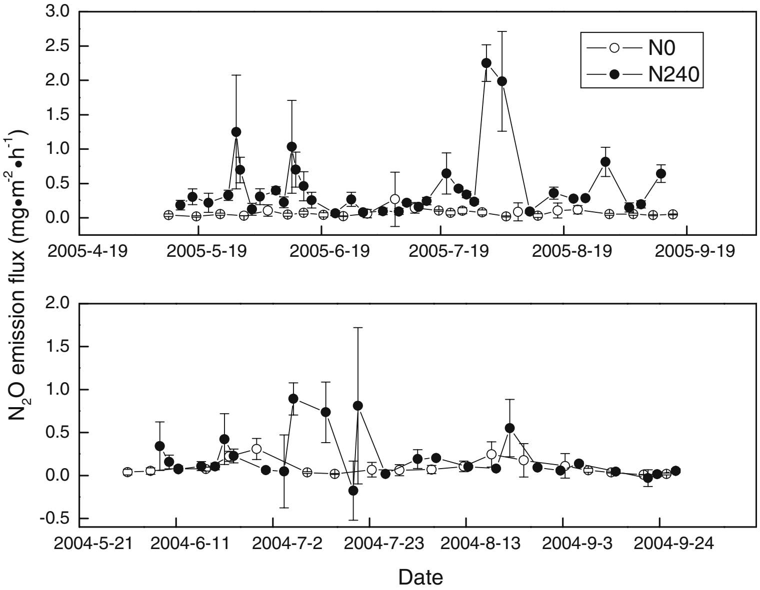

Fig. 5 Seasonal variations in N_2O fluxes from the two treatments during the two growing seasons of 2004 and 2005

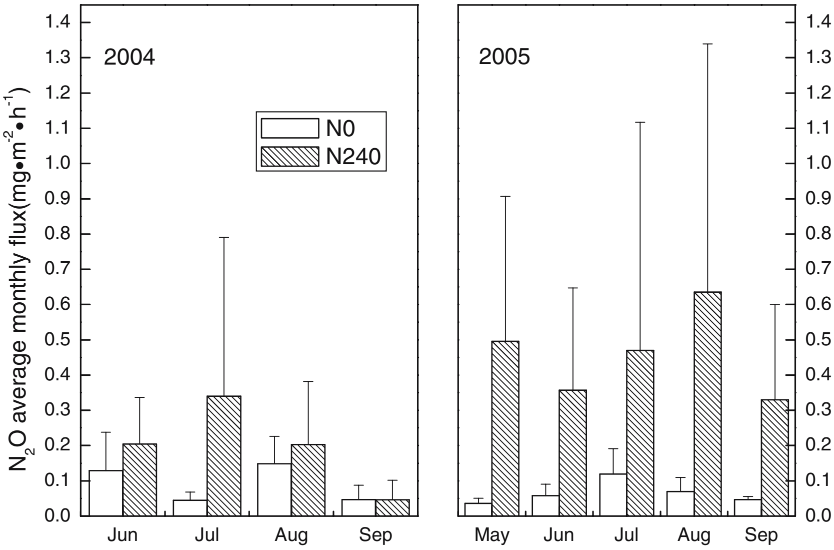

Fig. 6 Variation of monthly N_2O emission flux for control and fertilization treatment during 2 years

emission from the freshwater marsh was significantly affected by the nitrogen fertilizer ($P < 0.001$).

Figure 6 shows the monthly means of the N_2O emission flux of the two treatments. The mean N_2O flux of the treatment with nitrogen fertilizer was significantly higher than that of the non-fertilizer, especially in 2005. For investigating the effect of application nitrogen on N_2O emission, the mean fluxes of N_2O in each treatment were important indicators. Therefore, it was assumed that each measured N_2O flux represented the average of the interval of two measurements, and then the mean N_2O fluxes were calculated from averaging N_2O fluxes throughout the period of the two growing seasons. The monthly average N_2O emission is given in Fig. 6. In 2004, the N_2O emission of fertilizer increased by 59, 661, 37 and –1.4% in June, July, August and September, respectively, compared to the non-fertilizer, while in 2005, the increased value in May, June, July, August and September is 1274, 518, 295, 819 and 607%, respectively. We can calculate the N_2O mean emission of the whole growing season based on every measurement flux during the whole growing season. Investigating whether the N_2O emission was significantly affected by the nitrogen fertilizer, we analyzed the two treatments data to *t*-test by using SPSS/PC for Windows and show the effect of nitrogen fertilizer on N_2O fluxes was statistically significant in both years (2004: $P < 0.005$; 2005: $P < 0.0001$).

Discussion

Effect of exogenous nitrogen on greenhouse gases

Our findings confirm the argument that nitrogen fertilizer results in enhancement of greenhouse gas flux to the atmosphere. Based on the seasonal changes of CO_2, CH_4, and N_2O emissions from the marshes, growing season emission rate was calculated (Table 3). As Figs. 1, 2, 3, 4, 5, and 6 show, fertilizer exerted a stimulating effect on greenhouse gas emissions from freshwater marshes. In both years, the positive effect of nitrogen fertilizer on the greenhouse gas emissions was most obvious in the period from the beginning of the growing season to the fruiting.

The effects of nitrogen fertilizer on annual ecosystem respiration are shown on a monthly basis in Fig. 2 and on a seasonally basis in Table 3. The enhancement due to fertilizer for respiration in 2004 and 2005 growing seasons is 36 and 140%, respectively. Nitrogen enhanced the respiration significantly in this study, which is consistent with the previous studies in pine plantations (Castro et al. 1994; Maier and Kress 2000; Lai et al. 2002). Nitrogen fertilizer is one of the most important controlling factors for biological reactions in soil, including heterotrophic microorganisms and plant roots, which produce CO_2 to the atmosphere. Therefore, nitrogen generally enhances CO_2 emission by stimulating the root growing and microbial activity. More importantly, respiration in the fertilizer stand is greater than in the non-fertilizer stand because fertilizer increased the aboveground respiration biomass (Table 1), which is consistent with the previous studies that the enhancement due to fertilizer for biomass is 250% (Lai et al. 2002), 20 and 40% (Mäkipää et al. 1998), respectively. The enhancement function is obvious in summer, the reason is maybe that increased temperature will stimulate decomposition of the large C stocks in northern soils (Post 1990) and that this decomposition will be associated with increased mineralization of organic nutrients (Shaver et al. 1992), which can be more easily uptaken by plants so induced to the plant growing. Therefore, more CO_2 can be produced. In this study, temperature, precipitation, and nitrogen have a corporate stimulation influence on the CO_2 emissions from the freshwater marshes.

The controversial effects of nitrogen fertilizer on CH_4 emissions from wetlands have been widely discussed in previous studies (Saarnio and Silvola 1999; Nykanen et al. 2002). There was a positive effect in our study which is different from the Cai's study that the mean CH_4 fluxes tended to decrease with the increase of nitrogen application rate (Cai et al. 1997) and the Flessa's study that there was no effect of fertilizer on the annual CH_4 uptake (Flessa et al. 2002) while consistent with Saarnio and Silvola's study when the sedge cover was low (Saarnio and Silvola 1999) and Paul's (Paul Bodelier and Laanbroek 2004) study. On the average, the mean CH_4 flux increased 124 and 163% in 2004 and 2005, respectively, compared to non-fertilizer (Table 3). However, the results from numerous studies on the application of nitrogen fertilizer relation to CH_4 emission have so far been inconsistent, ranging from stimulation (Banik et al. 1996) to inhibition (Xu et al. 2004) on CH_4 emission. The effects of nitrogen fertilizer on methanogenesis are not clearly understood, nitrogen fertilizers applied to the soil of submerged wetland may lead to three effects: (1) stimulating plant growth and therefore intensifying CH_4 emission by providing more methanogenic substrates or improving aerenchyma conditions, (2) intensifying CH_4 oxidation by providing O_2 to the rhizosphere due to improvement of aerenchyma conduits and accordingly decreasing CH_4 emission, and (3) intensifying CH_4 consumption by stimulating the activities of methanotrophic bacteria (Kruger and Frenzel 2003) or mitigating CH_4 consumption by inhibiting the activities of methanotrophic bacteria (Hutsch et al. 1994) and consequently reducing or increasing CH_4 emission. Therefore, the net effect of nitrogen fertilizer on CH_4 emission should depend upon the counterbalance between the stimulation of CH_4 production and oxidation by nitrogen fertilizer. In our study, the increase in plant biomass induced by nitrogen may also stimulate CH_4 emission from freshwater marsh by enlarging the capacity for vascular transportation of CH_4 from the

Table 3 CO_2, CH_4, and N_2O mean emissions of the two growing seasons

Treatment	2004			2005		
	CO_2 (mg m^{-2} h^{-1})	CH_4 (mg m^{-2} h^{-1})	N_2O (mg m^{-2} h^{-1})	CO_2 (mg m^{-2} h^{-1})	CH_4 (mg m^{-2} h^{-1})	N_2O (mg m^{-2} h^{-1})
N0	987.74 (287.13)	6.05 (7.07)	0.09 (0.08)	898.59 (313.69)	0.72 (1.01)	0.07 (0.05)
N240	1344.35 (418.46)	13.56 (18.05)	0.20 (0.27)	2154.17 (745.57)	1.88 (1.49)	0.46 (0.49)

Numerical values in the parenthesis are the standard deviation of the all measurement values submerged soils, where CH_4 is produced, to the atmosphere. This can be supported by some studies (Aulakh et al. 2001; Inubushi et al. 2003) that have suggested an enhancement of CH_4 production potential associated with an increase in plant biomass or root exudates.

In the case of N_2O, there are two microbial processes of nitrification and denitrification to produce N_2O (Huang et al. 2004). Nitrifiers produce N_2O in two ways, by nitrification and nitrifier denitrification. Denitrifiers produce N_2O as an intermediate possible end product of the reduction of NO_3^- to N_2. In our study, High N_2O emissions have been found after fertilizer, which enhanced N_2O fluxes by factors up to 118 and 525% during 2004 and 2005, respectively, compared to control (Table 3). The mechanical transportation of gases through aerenchyma tissue is well known with wetland plants (Thomas et al. 1996; Yan et al. 2000). Therefore, plants may also have some importance in the transportation of N_2O from soil to atmosphere. Nitorgen oversupply in plant induced by fertilizer may directly induce the enhancement of N_2O emission through the plant (Chen et al. 2000). Fertilizer increased the microbial processes both nitrification and denitrification in soils, which made some nitrogen emission with the N_2O form. More importantly, nitrogen enhanced N_2O emission because nitrogen application stimulate the plant growth, plant and root biomass accumulation increased, which conduce to obtain the more C source in the edaphon from the rhizosphere to take the energy that denitrification needs, which promotes the N_2O emission. This experiment shows nitrogen input promoted the *D. angustifolia* plant's growth and the biomass accumulation, which influences the N_2O emission; therefore the emission of N_2O of fertilizer is higher than that of non-fertilizer. On the other hand, an enhancement of N_2O production maybe associated with the increase of plant biomass and root exudates accumulation. But so far, controlling factors for N_2O emission are still not clear even in the seasonal pattern that showed some trends. Both nitrification and denitrification can produce N_2O; so ^{15}N isotopic labeling method (Christoph et al. 2004) during the nitrogen cycle, particularly that of the gaseous products of microbial metabolism, should further improve our understanding of the relative contribution of the nitrification and denitrification process to N_2O flux.

Table 4 Two growth season total emission of CO_2, CH_4, and N_2O of the two treatments from freshwater marsh

Treatment	Two growth season total emissions (kg ha^{-1})		
	CO_2	CH_4	N_2O
N0	69265.91	248.61	6.11
N240	128465.69	567.05	24.22

Exogenous nitrogen on the (global warming potential) GWP of the CO_2, CH_4 and N_2O

Global warming potential (GWP) is intended as a quantified of the globally averaged relative forcing impacts of a particular greenhouse gas (IPCC 1996). CO_2 was chosen as the reference gas. All emissions were converted to CO_2 equivalents using the GWP, which determines the relative contribution of a gas to the greenhouse effect. The GWP index is defined as the cumulative forcing between the present and a selected time in the future, caused by a unit mass of gas emitted now (IPCC 1996). The GWP of CO_2, CH_4 and N_2O is 1, 21 and 310, respectively, with a time span of 100 years, while with a span of 20 years is 1, 56 and 280, respectively, and the span of 500 years is 1, 6.5 and 170, respectively (IPCC 1996). Based on the observed seasonal mean emission, we can calculate the two treatments of the greenhouse gas total emissions from the two growing seasons (from May to September) (Table 4). Taking the GWP of CO_2 1 kg ha^{-1} as 1, then we can calculate the integrated GWP of greenhouse gases (CO_2, CH_4 and N_2O) emissions of the two treatments in 100 years span, 20 and 500 years span, respectively (Table 5). As Table 5 shows, the integrated GWP of fertilizer treatment increased 97, 94 and 89% in 20, 100 and 500 years span, respectively, compared with the non-fertilizer treatment. The nitrogen application to the freshwater marsh strengthens the greenhouse gas effect either in short time scale or long time scale, whose future global warming forcing effect is not neglected.

Conclusion

This study has demonstrated that exogenous nitrogen may significantly stimulate greenhouse gas (CO_2, CH_4, and N_2O) emission from freshwater marshes. This

Table 5 Effect of N fertilization on the integrated GWP of CO_2, CH_4, and N_2O

Treatment	Integrated GWP		
	20 years	100 years	500 years
N0	84898.07	76379.82	71920.01
N240	167001.34	147881.07	136268.44

stimulative effect is primarily due to the stimulation of *D. angustifolia* plant growth by nitrogen fertilizer, which is firmly supported by the significantly positive correlation between the interactions among plant and soil processes with climatic factors such as precipitation and temperature in predicting responses of greenhouse gas emission to nitrogen fertilizer. The greenhouse gas emission was correlated with temperature, precipitation, plant biomass, and nitrogen fertilizer suggesting a close linking of these processes. Nitrogen fertilizer also played an important role in enhancing the greenhouse effect of CO_2, CH_4, and N_2O. In 20, 100 and 500 years span, the integrated GWP increased 97, 94 and 89%, respectively. Such information would provide a better key for proving C and N management decision-making at wetland ecosystem.

Acknowledgments This project was supported by Knowledge Innovation Program of Chinese Academy of Sciences, KZCX1-SW-01 and KZCX3-SW-332 and National Natural Science Foundation of China (40471124).

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