Environmental Pollution 180 (2013) 55–62

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Responses of ecosystem carbon dioxide exchange to nitrogen addition in a freshwater marshland in Sanjiang Plain, Northeast China

Lihua Zhang[a], Changchun Song[b,*], Philip N. Nkrumah[c]

[a] State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China
[b] Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Weishan, Changchun 130012, China
[c] Ministry of Education Key Laboratory of Integrated Regulation and Resource Development on Shallow Lakes, Hohai University, No. 1 Xikang Road, Nanjing 210098, China

ARTICLE INFO

Article history:
Received 4 December 2012
Received in revised form
22 March 2013
Accepted 23 March 2013

Keywords:
Net ecosystem carbon exchange
Nitrogen addition
Global warming potential
Freshwater marshland

ABSTRACT

It has widely been documented that nitrogen (N) stimulates plant growth and net primary production. But how N affects net ecosystem CO_2 exchange (NEE) is still dispute. We conduct an experimental study to assess the response of NEE to N addition in a freshwater marsh. Experimental treatments involved elevated N and control treatments on triplicate 1 m^2 plots. Gas exchange, air temperature, plant biomass and leaf area as well as N% of leaf were measured from 2004 to 2005. The results indicated that N addition initially decreased the CO_2 sequestration but the trend changed in the second year. It was concluded that N addition enhanced the greenhouse effect in marshland as far as global warming potential (GWP) is concerned. This increase was attributed to a substantial increase in CH_4 and N_2O emissions after N addition. We recommended long-term studies to further clarify the effect of N addition on NEE.

1. Introduction

Freshwater marsh is characterized by frequent waterlogging and low nutrient availability (Bobbink et al., 1998), played an important role in the global carbon (C) cycle. It is one of the most important global terrestrial ecosystems, covering about 1% of total national area and 14.92% of the Chinese wetlands (Zhao, 1999). Marshlands contain about 12% of the global C pool (IPCC, 1996), therefore significantly affect both C flux and the volume of C stored. The increase in the atmospheric nitrogen (N) deposition is one of major concerns in marshland ecosystems. Global changes and human activities have caused increased N inputs into these ecosystems through atmospheric deposition, fertilizer application and the wide spread of N-fixing plants (Vitousek et al., 1997; Balmford et al., 2002; Galloway and Cowling, 2002). The C sequestration potential in these ecosystems is one of the largest uncertainty in projection of climate-C feedbacks. This observation is largely caused by the negligence of N limitation to terrestrial C sequestration in model simulation (Heimann and Reichstein, 2008). Better understanding of the interaction between N input and ecosystem C dynamics is crucial to reduce this uncertainty (Reay et al., 2008).

In the temperate marshlands in China, the occurrence of extensive landscape transformations from natural marshlands to a multitude of cropland types is accompanied by massive effects of anthropogenic activities. Conversion of marshland to cropland introduces N into the neighboring marshes (Zhang et al., 2007a), affecting the marsh ecosystems. Experiments examining the response of ecosystem CO_2 exchange (NEE) to exogenous N input can provide critical information on how marshland C stocks are affected. This would allow an assessment of feedbacks between ecosystem and atmospheric C pools and further global warming. Understanding the NEE response to N addition is critical for predicting the productivity and C sequestration potential of marshland ecosystems in the 21st century. Several aspects of human-caused environmental changes can be expected to affect the physiological adaptations of marsh plants to marshland habitats. This can ultimately alter rates of C accumulation in marshlands (Heinsch et al., 2004), but how the C sequestration will respond to anthropogenic N addition is uncertain in the marshland ecosystems.

Elevated input of N effect on ecosystems has been examined in forest (Li et al., 2006; Sievering et al., 2007; Allison et al., 2008; Callahan et al., 2008), grassland (Aeschlimann et al., 2005; Siemann et al., 2007; Niu et al., 2010), heathland (Power et al., 2006), bog and

---

* Corresponding author.
E-mail addresses: songchanghun@neigae.ac.cn, lanse788403@hotmail.com (C. Song).

0269-7491/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.envpol.2013.03.055

boreal mire (Gerdol et al., 2008; Bubier et al., 2007; Saarnio et al., 2003) and tropical agroecosystems (Ngoze et al., 2008). Most studies primarily focused on plant biomass (Reich et al., 2006; Callahan et al., 2008), total N concentration, N retention ability (Bragazza et al., 2005), potential decay rates (Bragazza et al., 2005; Gerdol et al., 2007), fine root dynamics (Rasse, 2002), soil C sequestration (Li et al., 2006) and microbial processes (Allison et al., 2008; Ngoze et al., 2008) as well as fertility (Tripathi et al., 2008). However, few studies have addressed the response of NEE to N increase which induced by human activity in marshlands and even if the few studies in a mire (Saarnio et al., 2003) and a bog (Bubier et al., 2007), which getting the conflicting results. Some of studies indicate that plant growth (Zhang et al., 2007a; Gerdol et al., 2008) and C sequestration (Turunen et al., 2004) are frequently limited by supplies of N in marshy environment. High levels of N may cause changes in plant composition (Langley and Megonigal, 2010) and productivity (Berendse et al., 2001) and also decrease the ability of marshlands to sequester CO_2 from the atmosphere (Throop et al., 2004). Simulated N deposition studies at non-marshland ecosystems have revealed NEE variation in forest after N addition depended on canopy N uptake (Sievering et al., 2007), the difference of ecosystem respiration (ER) and photosynthesis response to N (Lai et al., 2002; Gerdol et al., 2008). These differences in ecosystem response are not surprising given the large suite of factors that can influence how N impacts C stocks.

Currently, information on how sequestration of C will respond to the global increases in N deposition from anthropogenic sources in freshwater marsh remains scarce. Hence, it is important to understand the contribution of N deposition to NEE and C cycling for quantifying the marshland ecosystem feedbacks to global climate change. In order to predict the effects of N deposition on NEE in marshlands, we performed an experiment in which we created high N conditions. And we added NH_4NO_3 (7.6 g m^{-2}) simulating N deposition every two weeks to examine: (1) whether and how the exogenous N affected the C fluxes of marshland and (2) whether the cooling effect due CO_2 uptake in marshland would be offset by other greenhouse gas emissions if considering GWP.

2. Materials and methods

2.1. Study site

The experiment was performed at the Sanjiang Mire Wetland Experimental Station in Sanjiang Plain marsh (47°35′ N, 133°31′). This marsh is primarily a large freshwater marsh located in Heilongjiang province, Northeast China. The mean annual precipitation is 600 mm with the majority of rainfall occurring between May and August. The range of the annual mean temperatures is 1.4–4.3 °C. The ambient N deposition is about 6.6 g N m^{-2} y^{-1} (Zhang et al., 2007a). Because of increasing population coupled with encroachment of the marshland by farmers, conversion of primary marsh to permanent agriculture is the dominant form of land-use change occurring over the past century. And the marshland was surrounded by cropland in the experiment site. The depth of organic deposits was about 1 m. Soil pH averaged 5–6 and the slope grade is about 1:5000–1:10,000. There are four types of vegetation, which vary from *Calamagrostis angustifolia* to *Carex lasiocarpa* as the standing water depth increases. The experimental site was selected to represent the typical, seasonal waterlogged marsh plant communities, *Calamagrostis angustifolia*.

2.2. Experimental design

On 10 October 2003, we established six 1 m^2 plots (the choice of the experimental plots was subjective). All plots within each habitat were homogeneous with regard to microtopography and vegetation structure. The N was added as sprayed solution by simulating small rainy events. The control plots received the same amount of surface marsh water. Board walks, which provided access to the whole experimental area, were installed during the following spring to minimize further disturbance to the soil. The N was amended nine times during the whole growing season of 2004–2005, from early May to mid-September. N treatment (aqueous NH_4NO_3 in surface marsh water) was added biweekly, at rates of 0 g N m^{-2} y^{-1} (N0) and 24 g N m^{-2} y^{-1} (N24). Both N0 and N24 treatments were done in triplicate. Treatment plots were separated by at least a 4 m buffer zone. In this way, the effects of increased N on marshlands could be assessed under chronic N input. This approach prevents possible toxic effects associated with abrupt N supply as this happens in short-term fertilization experiments. Specifically, we applied N with 24 g N m^{-2} y^{-1} to explore NEE responses to exogenous N during the 2004 and 2005 growing seasons. The high N level of 24 g N m^{-2} y^{-1} was used to study NEE under highly N saturated conditions that may occur in the future within the Sanjiang plain. We measured gas exchange in a 0.5 × 0.5 collar and plant biomass, leaf area and nitrogen content (N%) of leaf outside of the collar located in the 1 m × 1 m plots. Long-term ambient 1.5 m air temperature, precipitation and photosynthetically active radiation (PAR) data, from 1990 to 2006, were provided by a climate station located in the Sanjiang Experimental Station of Wetland Ecology, Chinese Academy of Sciences. And only two years (2004 and 2005) of the air temperature, precipitation and PAR data was used in our work.

2.3. Ecosystem CO_2 fluxes measurement and plant quality analysis

In October 2003, six stainless steel collars (0.5 × 0.5 m) were inserted into the soil to a depth of approx. 20 cm. We measured ecosystem C exchange with an infrared gas analyzer (IRGA; LI-6400, LiCor Inc., Lincoln, NE, USA). The analyzer was attached to a transparent chamber (0.5 m × 0.5 m × 0.5 m and 0.5 m × 0.5 m × 1 m for the plant with higher height), which covered all the vegetation within the stainless steel collars. During the measurement, the chamber was sealed. Two small electric fans were running continuously to promote air mixing within the chamber during the measurement. Ten consecutive recordings of CO_2 concentrations were taken on each frame at 10-s intervals during a 90-s period. The recordings were made after steady-state conditions were achieved within the chamber. CO_2 concentrations were allowed to build up or draw down over time, from which flux rates were determined to calculate the NEE. At the same time, the PAR, temperature and pressure in the chamber were recorded by the Li-6400. The details on these static-chamber flux calculations can be found in the soil-flux calculation procedure on the LI-6400 manual (LiCor Inc., 2004). The method was similar to that reported by Waddington and Roulet (2000) in a boreal patterned peatland, and was validated in some previous studies (Suyker and Verma, 2001; Wilsey et al., 2002; Aeschlimann et al., 2005). Ecosystem diurnal patterns of C fluxes were measured twice a month on clear days from May to September in 2004 and 2005. The measured NEE once a day in this study was 100.4% of the observed daytime average based the diurnal pattern in the control plots (data not published). Ecosystem gas exchange (ER and NEE) was measured at 2-day intervals (8:00–11:00 am) from May to October during 2004 and 2005 growing seasons. And the ER was measured before the NEE measurement at the same day between 08:00 and 11:00 am using the dark chamber and gas chromatograph technique. More details were described by Wang and Wang (2003), either the methane (CH_4) and nitrous oxide (N_2O) (Table 1; Zhang et al., 2007b). And the ER, CH_4 and N_2O samples were taken every 10 min during a 30 min sampling period (Zhang et al., 2007b). Gross ecosystem productivity (GEP) was calculated as the difference between NEE and ER in the same day. Seasonal cumulative GEP, ER and NEE was calculated using a simple linear interpolation, by which the arithmetical mean of the two temporally closest observations was extrapolated to represent the flux of each duration.

We measured leaf area with a CI-203 Portable Leaser Area Meter (made in USA) in each plot at biweekly intervals. At the end of the growing season, when we finished the gas measurement, we harvest the plant outside the collar in the gas

Table 1
The variation of seasonal cumulative ecosystem respiration (ER), gross ecosystem productivity (GEP), methane (CH_4) and oxide nitrous (N_2O) after N addition, letter a and b refer to significant difference between control and treatment in one year.

		GEP	NEE	ER[a]	CH_4[a]	N_2O[a]
2004	N0	1167.2 (72.8)a	−365.7 (20.1)b	801.5 (28.4)a	16.7 (1.0)b	0.2 (0.01)b
	N24	1282.6 (91.0)a	−166.1 (17.7)a	1137.3 (119.5)a	37.3 (2.0)a	0.5 (0.02)a
2005	N0	1168.7 (70.9)b	−333.9 (9.7)a	834.8 (51.9)b	2.0 (0.1)b	0.2 (0.01)b
	N24	2353.1 (91.3)a	−304.8 (9.4)a	2048.3 (112.3)a	5.2 (0.1)a	1.1 (0.03)a

The units for NEE, ER, GEP and CH_4 are g C m^{-2} yr^{-1}, the unit for N_2O is g N m^{-2} y^{-1}. Different letters (a, b, c) indicate statistical differences at $p < 0.05$ among the two treatments in each year. Numerical values in the parenthesis are the standard error of the repeat ($n = 3$) values.

[a] Zhang et al. (2007b).