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EFFECTS OF WATER TABLE AND NITROGEN ADDITION ON CO_2 EMISSION FROM WETLAND SOIL

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ABSTRACT: Soil respiration is a main dynamic process of carbon cycle in wetland. It is important to contribute to global climate changes. Water table and nutritious availability are significant impact factors to influence responses of CO_2 emission from wetland soil to climate changes. Twenty-four wetland soil monoliths at 4 water-table positions and in 3 nitrogen status have been incubated to measure rates of CO_2 emission from wetland soils in this study. Three static water-table controls and a fluctuant water-table control, with 3 nitrogen additions in every water-table control, were carried out. In no nitrogen addition treatment, high CO_2 emissions were found at a static low water table (¢æ) and a fluctuant water table (¢ô), averaging 306.7 mg/(m²·h) and 307.89 mg/(m²·h), respectively, which were 51%–57% higher than that at static high water table (¢ò and ¢ó). After nitrogen addition, however, highest CO_2 emission was found at ¢ò and lowest emission at ¢ó. The results suggested that nutritious availability of wetland soil might be important to influence the effect of water table on the CO_2 emission from the wetland soil. Nitrogen addition led to enhancing CO_2 emissions from wetland soil, while the highest emission was found in 1N treatments other than in 2N treatments. In 3 nutritious treatments, low CO_2 emissions at high water tables and high CO_2 emissions at low water tables were also observed when water table fluctuated. Our results suggested that both water table changes and nutritious imports would effect the CO_2 emission from wetland.

KEY WORDS: CO_2 emission; water table; nitrogen addition; wetland soil

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1 INTRODUCTION

CO_2 emission from soil to atmosphere, which is important to contribute to the carbon balance of ecosystem, is one of the largest fluxes in the global carbon cycle (SCHLESINGER and ANDREWS, 2000). Furthermore, the change of CO_2 emission from soil, as a result of soil organic matter decomposition, is a main process of soil carbon cycle responding to climate changes (WANG and LIU, 2002). Therefore, because of climate warming, the potential of CO_2 emissions from various ecosystems have been concerned increasingly (HOUGHTON *et al*., 1992). This also drove the research of the relationships between CO_2 emissions and impact factors of ecosystem (MOORE, 1994).

Wetlands act as carbon sinks because mean annual primary production exceeds annual organic matter decomposition, but only a small fraction of carbon fixed by plants each year accumulates in the soil. More than 90% fixed carbon is re-released to the atmosphere, with up to 95% of output being CO_2 (CLYMO, 1983; WADDINGTON and ROULET, 2000). This small net carbon storage can be offset by increasing in CO_2 emissions, converting wetlands from sinks to sources of carbon to the atmosphere (FRANCEZ and VASANDER, 1995).

Temperature, water table and nutritious availability are main controls of CO_2 emissions from wetland soils (BRIDGHAM *et al*., 1995). As a result of climate changes, however, temperature may increase, water table may draw down in the drought summers, and input of nutritious matter to wetland ecosystems may increase (AERTS and LUDWIG, 1997; BLODAU, MOORE, 2003a; KELLER *et al*., 2005). Warming air and soil temperatures can stimulate the microbial activity and the organic matter decomposition, resulting in higher CO_2 emissions from boreal peatlands (CHRISTENSEN *et al*., 1999). Water table draw down can enhance the soil temperature and the aerobic decomposition of or-

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ganic matter (LIEFFERS, 1988; AERTS and LUDWIG, 1997), which stimulates the roots respiration and microbial respiration in soil (SILVOLA *et al*., 1992; BLODAU *et al*., 2004), and consequently CO_2 emission from soil increases (KIM and VERMA, 1992). Increase of nutritious availability in soil can play a positive role to enhance the microbial activity and CO_2 emission (BRIDGHAM and RICHARDSON, 1992; AERTS and LUDING, 1997). Therefore, the study on effects of temperature, water table and nutritious availability on CO_2 emission from wetland soils is crucial to understand mechanisms of greenhouse gases from wetlands responding to climate changes.

The Sanjiang Plain is an area where the biggest wetland in China is located and the wetland total area is 835×10^3ha (LI *et al*., 2002). Many studies have been carried out on CO_2 emission in the Sanjiang Plain, but the majority of them focus on investigating characteristics of CO_2 fluxes and exploring relationships between fluxes and environmental factors (SONG *et al*., 2003a; 2003b; 2004). It is still not clear on CO_2 emission from wetland soil responding to water table and nutritious availability. In this incubation study, 4 water table controls and 3 nitrogen addition treatments in ambient environment were carried out to measure the rates of CO_2 emission from wetland soils. Specific aims of this study were: 1) to study effects of water table and nutritious availability on CO_2 emissions from intact wetland soil monoliths; and 2) to investigate whether an observed effect depended another.

2 STUDY SITE AND METHODS

2.1 Study Site

Soil monoliths used in this study were collected in a wetland, with the area of 15ha, 10km away from Sanjiang Mire Wetland Ecosystem Experimental Station, Chinese Academy of Sciences, located at Honghe Farm in the eastern part of Heilongjiang Province, China at approximately 47°35′N, 133°37′E. The centre of wetland is perennially flooded and the climate characteristics are similar to Sanjiang Mire Wetland Ecosystem Experimental Station, CAS. The station's climate, vegetation and soil types may refer to the paper by SONG Chang-chun *et al*. (2003). The soil monoliths collected in the study is selected in *Deyeuxia angustifolia* community located in the margin of the wetland, where the water table position is seasonal fluctuant with the local rainfall. In a year, the soil surface is flooded by water of 0–5cm depth for about 2 months, and is exposed to the air in the other months.

2.2 Methods

Twenty-four inelasticity plastic barrels (Fig. 1d), 45cm in top diameter and 35cm in bottom diameter and 50cm high, were used to incubate the soil monoliths, which were collected with stainless steel shovel on June 7. First, a sample plot of 15m×15m was selected randomly for monoliths collecting. The intact roots layer, 45cm in diameter and about 17cm thick, with living plants aboveground together, was dug up carefully and placed aside for use. Then, nether soil below the roots layer, about 15cm thick, was extracted and installed in the barrel. Finally, the roots layer for use was tightly placed on the top of nether soil in the barrel. Twenty-four monoliths were collected with the same means and carried back the station to incubate.

Before incubated, water was aptly added to the monoliths and pre-incubated for a week to renew the disturbed roots. Water table controls and nitrogen addition treatments were carried out on June 14. In the study, 4 water table controls were set: (¢æ) 10cm below the soil surface, (¢ò) at the soil surface, (¢ó) 5cm above the soil surface, and (¢ô) fluctuating between 5cm below and 5cm above the soil surface in weekly intervals. Control ¢æ was achieved through the equipments installed on the barrel (Fig. 1). Water was added through a thin plastic pipe (Fig. 1a), 5mm in diameter and 20cm long, inserted 10cm in the soil monolith. Another water receiver(c) joined to the barrel, with a vessel at 10cm below the soil surface, was used to collect the redundant water, which was used to next water adding to avoid the nutrition losing. Control ¢ò, ¢ó and ¢ô were directly carried out by water adding from the soil monoliths surface. And 3 nitrogen addition treatments with 2 replications were also set in every water-table control: no nitrogen addition (0N), 3.133g NH_4Cl (1N), and 6.266g NH_4Cl (2N).

Small PVC tubes (Fig. 1b), 7.5cm in diameter and 25cm long, were used to sample the CO_2 released from the incubated soils. Before gas sampling, a small cluster of plants aboveground were resected at the ground surface and tube was inserted 5cm into the soil. When sampling began, the top of tube was sealed and a 50ml glass injector was used to collect 40ml gas at 0min, 10min and 20min, respectively, after tube sealed. Gas samples were saved in 0.5L gasbags. CO_2 concentration was measured on a Shimadzu GC-12A in Sanjiang Mire Wetland Ecosystem Experimental Station within a week. Methods of CO_2 concentration analyzing and CO_2 flux calculating were taken from the paper written by SONG Chang-chun *et al*. (2003b).

Plant was harvested and aboveground biomass, de-

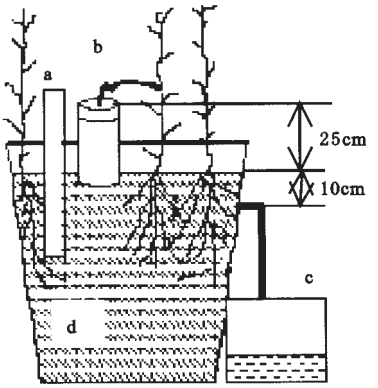

Fig.1 Equipments used to marsh soil column incubating (d), water table at 10cm below surface controlling (a, c) and gas sampling (b)

noted by the weight of dry mass in every monolith, was measured at the end of the experiment.

The data of aboveground biomass and of CO_2 emission rates in this paper were from samples with two replications and no replications, respectively. SPSS 13.0 and OriginPro 7.5 were used to do statistical analysis of the data.

3 RESULTS AND DISCUSSION

3.1 Effect of Water Table on CO_2 Emission from Wetland Soil

CO_2 emission from soils at different water table positions with no nitrogen addition showed a pattern of an increase followed by a decrease with the time going on (Fig. 2). The higher CO_2 emissions were observed in August and lower CO_2 emissions were in July and September in all water table controls. ANOVA analysis showed that the rates of CO_2 emission from soils at different water table positions presented some variance but not significant at the level of 95% ($0.1<p<0.5$). According to the mean values, the rates of CO_2 emission could be classified into tow groups: ¢æ and ¢ô, in which the rates of CO_2 emission were similar ($p>0.9$), averaging 306.7mg/(m^2·h) and 307.89mg/(m^2·h), respectively; ¢ò and ¢ó similar too ($p>0.9$), averaging 202.66mg/(m^2·h) and 196.68mg/(m^2·h), respectively (Table 1). That is to say, when the water table was 10cm below the soil surface and fluctuated between 5cm below and 5cm above the soil surface, CO_2 emissions from soil were 51% – 57% higher than the water table of 0cm and 5cm above the soil surface in the study.

Consistent with many results of other studies, CO_2 emissions at static low water tables were higher than that at static high water tables (CHIMNER and COOPER, 2003; MOORE and DALVA, 1993a; FUNK *et al*., 1994). In the study it was found in 0N treatment CO_2 emission at 10cm water table below the soil surface was 51% and 55% higher than at 0cm and 5cm water table above the soil surface (Fig. 3). Soil respiration is mainly

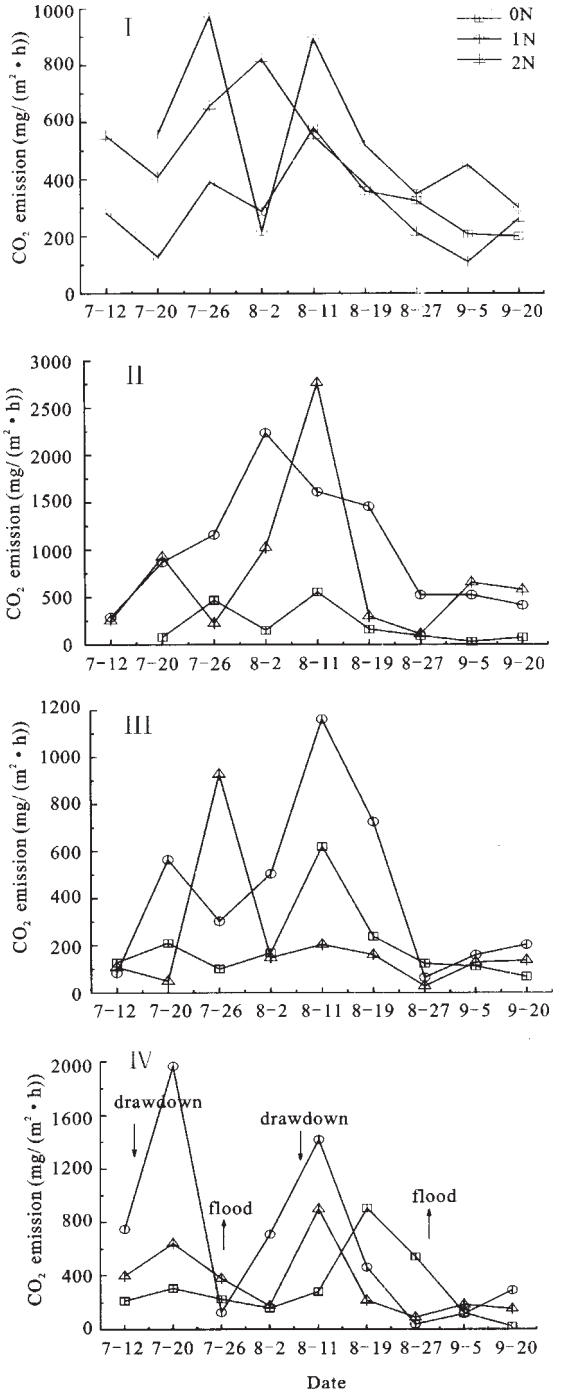

Fig.2 CO_2 emissions from incubation soils in different nitrogen addition treatments at different water table controls

Table 1 Means of CO_2 emission rates in all treatments and changes from no nitrogen addition (0N) treatment

Treatment		Sample	Range of values (mg/(m²·h))	Mean ± SD (mg/(m²·h))	Relative changes from 0N treatment(%)
Water table	Nitrogen addition				
I	0N	9	127.36–580.46	306.70±131.99	0
	1N	8	217.69–971.69	532.59±271.83	+73.65
	2N	9	110.56–821.45	439.86±227.40	+43.42
II	0N	8	30.39–554.53	202.66±197.05	0
	1N	9	290.00–2235.06	1009.97±656.87	+398.36
	2N	9	110.45–2764.33	759.06±816.59	+274.55
III	0N	9	68.19–620.83	196.68±167.91	0
	1N	9	64.13–1161.36	418.92±360.29	+112.99
	2N	9	27.58–927.61	210.12±274.48	+6.83
IV	0N	9	22.22–902.86	307.89±265.27	0
	1N	9	38.47–1966.98	652.93±655.16	+112.07
	2N	9	88.86–899.24	348.27±267.71	+13.12

Note: '+' means the rate of CO_2 emission relatively increases compared to 0N treatment

composed by plant roots autotrophy respiration and microbial heterotrophic respiration. Autotrophy respiration is mainly used to maintain the energy consumed by plant for growth. So, soil respiration is related to the plant production to a certain extent. However, the data from our study showed that the plant aboveground biomass was not significantly different among different water table controls (Fig. 4), which seemed to indicate microorganism played a main role on CO_2 from incubated soil responding to water table changes. That is, CO_2 production in aerobic condition was higher than in anaerobic condition. This was confirmed by data from former researches both in incubation and in the field. BLODAU C (2002) summarized data from incubations and presented that the ratios of carbon mineralization in aerobic condition and in anaerobic condition were 1.2–6.0. MOORE and DALVA (1997) found that aerobic production of CO_2 of incubated peat was 1.5 times as high as anaerobic production. CHIMNER and COOPER (2003) found in field microcosms that mean CO_2 emissions were lowest at the highest water tables (+6 to +10cm above the soil surface), averaging 133.8 mgCO_2-C/(m²·h), increased to 231.3 mgCO_2-C/(m²·h) when the water table was +1 to +5cm above the soil surface and doubled to 453.7 mgCO_2-C/(m²·h), when the water table was 0–5cm below the soil surface. An explanation for this was that high water table and saturated soil limited the diffusion of atmospheric oxygen into the wetland soil, consequently, limited the microbial activity and organic matter decomposition. Conversely, a water table decline increased oxygen diffusion into soils allowing aerobic decomposition (CLYMO, 1983) and also CO_2 transportation from soils to atmosphere was more

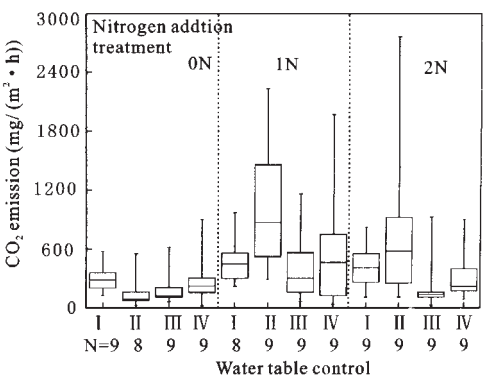

Fig. 3 Box plots of CO_2 emission rates at different water table positions and in nitrogen addition treatments

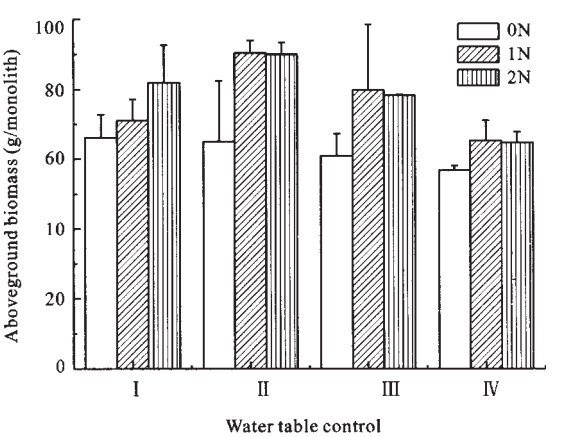

Fig. 4 Aboveground biomass in different nitrogen addition treatments at different water table controls

effective (MOORE and DALVA, 1993b).

However, some studies found that CO_2 emission at low water table did not exceed the emission at high water table (CHIMNER, 2004; AERTS and LUDWIG, 1997; HOGG, 1993). For example, AERTS *R* and LUDWIG (1997) found that the CO_2 production was similar in aerobic and anaerobic conditions, and even CO_2 emission from mesotrophic peat with 10cm water table below the soil surface was lower than from mesotrophic peat with water table at the soil surface. A possible explanation reported by AERTS and LUDWIG (1997) was that lowering the water table might expose peat layers that were not very readily decomposed and would, thus, contribute little to CO_2 emission.

When the water table fluctuated between 5cm below and 5cm above the soil surface at weekly intervals, it was also found low CO_2 emission at high water tables and high CO_2 emission at low water tables (Fig.2Ⅳ) as observed in other studies (FUNK *et al*., 1994; AERTS and LUDWIG, 1997). Furthermore, the CO_2 emission of¢ô, similar to the emission of¢æ, was 52% higher than that of¢ò and 57% higher than that of¢ó, respectively (Fig.3). The results suggested that fluctuation of water table contributed to the increased CO_2 emission from wetland soil. It is confirmed by data from BLODAU C and MOORE T R (2003a; 2003b), who found that after water table changed net CO_2 production increased to 140nmol/(cm^2·d) in the incubation condition and CO_2 emission from peat immediately reached to the biggest values (100–300nmol/(cm^3·d) in the field. AERTS and LUDWIG (1997) also found that the accumulative mineralization of carbon increased 1.5–3 times because of the change of water table. CLEIN and SCHIMEL (1994) explained that the increased CO_2 emission was due to not only the increase of aerobic production of CO_2, but also the pulsed increase of carbon mineralization caused by the water disturbance.

3.2 Effect of Nitrogen Addition on the CO_2 Emission from Wetland Soil

After nitrogen addition the pattern of CO_2 emissions in control Ⅱ was similar to no nitrogen addition, with higher emission in August and lower emission in July and September (Fig.2¢ò). However, it changed in controlsⅠ, ¢ó and ¢ô with a sudden higher emission in the medial and late July (Fig.2 ¢æ, ¢ó, ¢ô). On responses of soil respiration to nitrogen addition, what many studies trended to was the limited or little effects of nitrogen addition on soil respiration (SAMUELSON *et al*., 2004; KELLER *et al*., 2005). However, in the study it was found that nitrogen addition stimulated the CO_2 emission from the incubated soils (Fig.2, Fig.3). After nitrogen addition, CO_2 emissions increased 74% –398% and 7% –275% in 1N and 2N treatments, respectively (Table1).

Positive evidences have been given by some researchers that the rate of soil respiration was correlated to plant biomass (PANGLE and SEILER, 2002; BOWDEN *et al*., 2004). In the study it was found that plant aboveground biomass increased significantly after 1N or 2N addition ($p<0.05$) (Fig.4). Furthermore, a significant positive linear correlation ($p<0.05$) was also found between the rate of soil respiration and plant biomass (Fig.5). Therefore, the stimulation of nitrogen addition on soil respiration might be derived from botanic and microbial responses to nutritious amelioration. First, increase of root respiration as a result of biomass enhancing contributed the amount of CO_2 from the soil. Second, a short-term nitrogen addition might stimulate the activity of microorganism, which lead to the quick decomposition of root exudates and readily decomposed organic layer in the top of soil monoliths.

Compared with 1N treatment, 2N treatment led to the decreased CO_2 emission of 17% –50%. Our results also showed that plant aboveground biomass was not significantly different between in 1N and 2N treatments ($p<0.05$) (Fig.5). This indicated that carbon allocation to roots were not different in two treatments, which suggested that roots respiration in 2N treatments did not contribute more than that in 1N treatments. The decline after larger nitrogen addition might be due to the autotrophic respiration of plant roots and the nitrogen assimilation in soil, because it is confirmed that a large fraction of root respiration was allocated to nitrogen assimilation (BLOOM *et al*., 1992), but with larger doses of nitrogen readily available for uptake, energetic costs of nitrogen assimilation might be reduced (BOWDEN *et al*., 2004). On the other hand, FREY *et al*. (2004) found in the laboratory incubation of root-free soil that heterotrophic respiration from the microbial community in fertilized plots was reduced. They observed that active fungal biomass was lower in fertilized plots than in control and also detected a significant reduction in the activity of the enzyme phenoloxidase. Although botanic and microbial factors caused to the reduction of CO_2 emission from soil, it is still not clear that which factor was greater for wetland soil responding to a larger nitrogen addition.

Dissimilar to what was found in no nitrogen treatment, in nitrogen addition treatments the pattern of the response of CO_2 emissions to the water table positions changed, especially the CO_2 emissions from Ⅱ control,

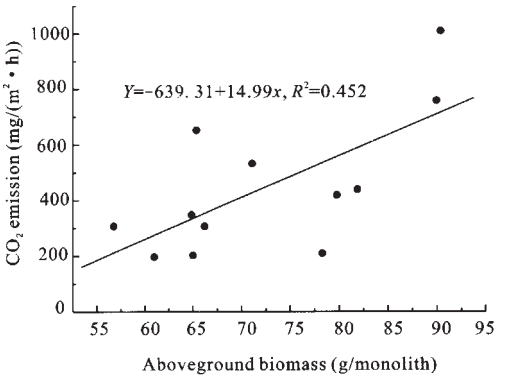

Fig.5 Correlationship between CO_2 emission and aboveground biomass in incubation monoliths

which increased to the highest emissions of all controls ($p<0.05$) (Fig.2 ¢ò; Fig.3) averaging 1009.97 mg/(m²¡h) and 759.06mg/(m²¡h) in 1N and 2N treatments, respectively (Fig.2). This showed that the stimulation of nitrogen addition to the CO_2 emission was greatest when the water table was at the soil surface. The least stimulation were found in control ¢ó with the rates of CO_2 emission averaging 418.92mg/(m²¡h) and 210.12 mg/(m²¡h), respectively. Additionally, the increase of CO_2 emissions at high and fluctuant water tables exceeded the increase at low water tables (Fig. 2 ¢ô). The result suggested that nutritious status in soil might be an important regulator for the effects of water table on the CO_2 emission from wetland soil.

4 CONCLUSIONS

The effects of water table and nitrogen addition on the CO_2 emission have been studied in the incubation. Our experiment found that the CO_2 emissions from the wetland soils have varied because of water table and nitrogen addition changed. CO_2 emissions were high at low water tables and low at high water tables, and rates after nitrogen addition were markedly increased at the water table at the soil surface. When the water table was changed in all controls, low CO_2 emissions were at high water tables and high CO_2 emissions at low water tables. Nitrogen addition stimulated the CO_2 emission from the wetland soil, but the double nitrogen treatment contributed a decline to the CO_2 emission compared with the single nitrogen treatment. As climate changes are concerned increasingly, it is crucial to quantify and predict future patterns of responses of carbon cycle in wetland to climate changes which influence carbon cycle significantly.

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