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Soil-surface CO_2 fluxes in a *Deyeuxia angustifolia* wetland in Sanjiang Plain, China

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Abstract

In many temperate-zone ecosystems, seasonal changes in environmental and biological factors influence the dynamics and magnitude of surface–atmosphere exchange. Research was conducted between July and October 2001 to measure growing season surface-layer fluxes of CO_2 in a *Deyeuxia angustifolia* dominated wetland on the Sanjiang Plain in northeastern China. Seasonal fluctuation and daily change in soil-surface CO_2 fluxes were measured as well as the edaphic factors controlling CO_2 fluxes. Soil-surface CO_2 fluxes were measured with a closed-chamber system. The results revealed that there were both seasonal fluctuations and daily change in CO_2 fluxes. The ranges of measured soil-surface CO_2 flux were 0.208–1.265 g CO_2 m^{-2} h^{-1}. Soil-surface CO_2 fluxes averaged 0.620 g CO_2 m^{-2} h^{-1}. An analysis of several edaphic factors including soil temperature and soil moisture of the *D. angustifolia* wetland showed that there was a significant relationship between flux and temperature ($R^2 = 0.77$).

Introduction

Increasing concentrations of atmospheric CO_2 and the potential for climatic change have made the global carbon balance an important scientific and political topic (Tans and Balkwin 1995). Soil CO_2 efflux is known to play a major role in the global carbon cycle. At the global scale, the annual flux of CO_2 from soil to the atmosphere is estimated to average 68 Pg C y^{-1} (Raich and Schlesinger 1992), roughly 10 times the current annual contribution from fossil fuel combustion (Andres et al. 1996). Soil-surface CO_2 flux measurements have been widely used to construct ecosystem C budgets (Singh et al. 1988; Norman et al. 1992; Hungate et al. 1997). At the microcosmic level, in-depth studies have been made on carbon cycles of forest ecosystems, cropland ecosystems, and grassland ecosystems, but wetland ecosystems have been studied very little. This is the case even more so for China (Lu et al. 1995; Yang and Lu 1999). In this paper, we carried out a field study of soil-surface CO_2 fluxes of a *Deyeuxia angustifolia* dominated wetland.

Measurements of soil-surface CO_2 flux

Several techniques have been used to measure soil-surface CO_2 flux including soil CO_2 profile, micrometeorological (including eddy covariance), and static and dynamic chamber methods. Although the soil CO_2 profile and micrometeorological techniques avoid confounding chamber effects, their application has generally been limited by a combination of cost and methodological requirements (Jong et al. 1979; Baldocchi and Meyers 1991;

Verma et al. 1992). In particular, the soil CO_2 profile technique requires the estimation of soil transport coefficients, while eddy covariance typically requires specific atmospheric conditions and an estimation of aboveground plant respiration.

A majority of soil CO_2 flux studies have relied on the static chamber technique because it is relatively inexpensive and easy to employ (Gupta and Singh 1981; Bowden et al. 1993; Toland and Zak 1994; Marra and Edmonds 1996). In this method, CO_2 diffusing from the soil is absorbed inside a closed chamber using either an alkali solution (e.g., KOH, NaOH) or soda lime (Reinke et al. 1981; Edwards 1982). Although this technique offers some practical advantages, several studies have shown that it tends to overestimate CO_2 flux at low flux rates and severely underestimate CO_2 flux at high flux rates (Rochette et al. 1992; Nay et al. 1994; Jensen et al. 1996).

Dynamic chamber techniques have also been used to measure soil CO_2 efflux in numerous studies (Kucera and Kirkham 1971; Ewel et al. 1987; Hall et al. 1990; Norman et al. 1992; Luo et al. 1996). Dynamic chambers are generally considered more accurate than static methods (Cropper et al. 1985; Rochette et al. 1992; Nay et al. 1994) and can be operated as either closed or open systems. In closed dynamic systems, air is circulated in a closed loop between the chamber head space and an infrared gas analyzer (IRGA). Soil CO_2 efflux is then calculated using the difference in CO_2 concentration between the beginning and end of the measurement period. In open dynamic systems, ambient air is passed continuously through the chamber head space, and soil CO_2 efflux is calculated using the difference in CO_2 concentration between air entering and leaving the chamber. Open systems are typically preferred for continuous measurements over periods of hours to days because the flow of outside air into the system maintains near ambient chamber temperature and CO_2 concentration.

Site description

The study site was located in the Sanjiang Plain, a low alluvial plain formed by three rivers: Songhuajiang River, Heilongjiang River, and Wusulijiang River. The Sanjiang Plain is situated in the northeast part of China, with a total area of 5.13×10^6 ha, and it is the most wide spread area of freshwater wetlands in China with 21% mires (Yang 1989). Freshwater mire wetlands are widespread and quite typical in this area.

Measurements were carried out at the ecological experimental area in the Ecological Experiment Station of Mire-Wetland in the Sanjiang Plain, Chinese Academy of Science, which belongs to one of the fundamental stations of the Chinese Ecosystem Research Network (CERN). The station lies in Honghe Farm, Tongjiang City, Heilongjiang Province, China (47°35′N, 133°31′E) and encompasses 100 ha.

The Ecological Experiment Station of Mire-Wetland is located in the interior of the Sanjiang Plain with a continental monsoon climate of the temperate zone. The mean annual temperature is about 1.9 °C and the mean annual precipitation is about 550 mm, 70% of which occur from June to September. The area has a low, smooth topography developed in a meander bend, and various depressions causing poor drainage of the surface. The natural vegetation is dominated by *D. angustifolia*, but meadow and mire plants such as *Carex lasiocapa*, *C. pseudocuraica*, and *C. meyeriana* along with secondary forest consisting of *Quercus* and *Betula* stands can also be found. The soil, except meadow soil and brown soil, is dominated by various mire soils, including meadow-, humus-, peat-boggy soils, and peat soil. We studied soil-surface CO_2 fluxes of the *D. angustifolia* wetland. At the sampling sites, the soil type is meadow lessive (Yang and Lu 1996). Soil chemical characteristic are given in Table 1.

Methods

Soil-surface CO_2 flux was measured with closed-dynamic chambers and an IRGA. Flux measurements were made during the growing season, 2001. Collars (50 × 50 cm polyvinyl-chloride (PVC) frame) were placed into the ground to a depth of 2–4 cm. For each flux measurement, a transparent rectangular Plexiglas chamber cover (50 × 50 × 50 cm) was placed over the collar, and a QGS-08B IRGA was used to measure CO_2 concentration within the chamber. Air was circulated between the chamber and the IRGA with a small pump, at a rate of 0.5 l min^{-1}. CO_2 concentrations were measured at 1-min intervals.

Table 1. Chemical characteristics of meadow lessive soil type.

Soil depth (cm)	pH	Organic matter content (%)	Entire N (%)	Entire P (%)	Entire K (%)	Mineral composition (%)					
						SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO
0–13	4.94	10.19	0.54	0.12	2.03	62.38	3.97	10.57	0.82	1.86	0.07
13–21	4.74	3.18	0.24	0.05	2.13	67.47	4.11	12.30	0.86	1.69	0.24
21–40	5.29	0.57	0.07	0.05	2.32	70.87	4.19	21.21	1.20	1.60	0.07
40–60	5.59	2.80	0.10	0.04	2.12	59.61	7.15	16.89	0.93	1.74	0.24
60–100	6.48	0.79	0.08	0.04	2.14	57.96	7.26	17.20	0.91	1.77	0.29

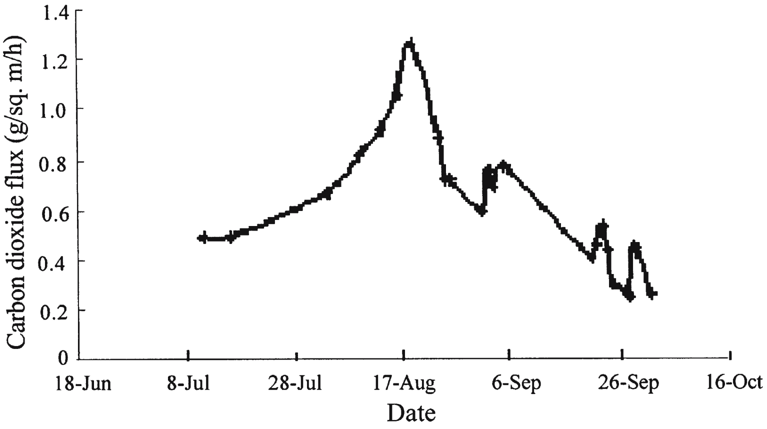

Figure 1. Seasonal pattern of soil CO_2 fluxes of *D. angustifolia* wetland.

Fans mounted inside each chamber ensured well-mixed air during the sampling period. Aboveground vegetation was clipped before the cover was put in place; thus, we did not have to consider the vegetative photosynthesis before we measured the concentration of CO_2 in chamber. Three replicate chambers were measured on each sampling day. We measured soil temperature with ageothermometer, and soil moisture was measured with the roast method.

A linear regression was applied to the linear portion of CO_2 concentration. The function (Yang and Du 1996) for soil-surface CO_2 flux is

$$F = k \cdot a \cdot \frac{\Delta c}{\Delta t} \cdot h, \qquad (1)$$

where F represents the soil-surface CO_2 flux (g CO_2 m^{-2} h^{-1}), k is the appropriate coefficient, Δc is the difference in CO_2 concentration in the chamber during the Δt minute, and h is the height of the chamber. Fluxes were corrected by the coefficient for atmospheric pressure and air temperature:

$$k = \left(\frac{P_c}{P_s}\right)\left[\frac{273.16}{(273.16 + T_c)}\right], \qquad (2)$$

where k represents the coefficient, P_c is the air pressure in the chamber, P_s is the criterion barometric pressure (1013.25 h Pa), and T_c is the temperature (°C) in the chamber.

Results and discussion

Seasonal variations of soil surface CO_2 fluxes

Wetland soil-surface CO_2 fluxes exhibited a distinct seasonal pattern from July to October in 2001 (Figure 1). From the beginning of July, soil-surface CO_2 fluxes increased gradually until the middle of August when it reached the maximum value, and then soil-surface CO_2 fluxes decreased gradually until the beginning of October. The

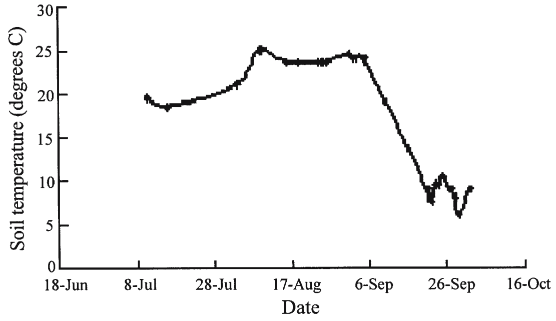

Figure 2. Seasonal pattern of 5 cm soil temperature of *D. angustifolia* wetland.

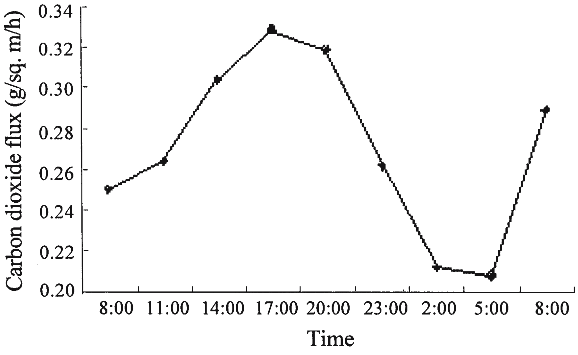

Figure 3. Daily variation of soil-surface CO_2 fluxes of *D. angustifolia* wetland.

range of soil-surface CO_2 fluxes during the growing season was 0.250–1.265 g m^{-2} h^{-1}, with a mean value of 0.619 g m^{-2} h^{-1}. This pattern was similar to the seasonal soil temperature change at 5 cm depth (Figure 2). Soil temperature reached its maximum value in July, and then decreased gradually until the beginning of October. However, soil CO_2 exchange is a complicated biological process and is affected by several environmental factors. Soil temperature is only one of these factors, so the seasonal pattern between soil CO_2 flux and 5 cm soil temperature have several inconsistent points in Figures 1 and 2.

Daily variation of soil-surface CO_2 fluxes

Deyeuxia angustifolia dominated wetland soil-surface CO_2 fluxes exhibited a distinct daily pattern (Figure 3). Soil-surface CO_2 flux increased from 8:00 until 17:00, decreased gradually until 5:00 the next day, and then increased again. The range of soil-surface CO_2 fluxes during the day was 0.208–0.329 g m^{-2} h^{-1}, and the mean value was 0.271 g m^{-2} h^{-1}.

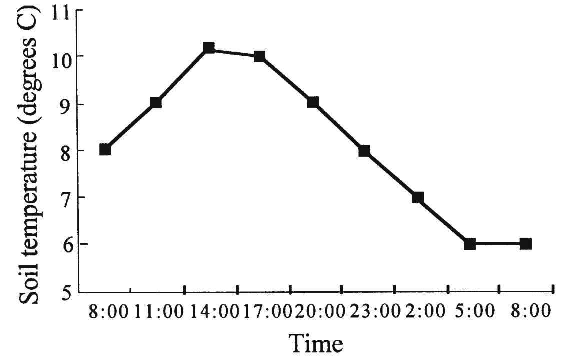

Figure 4. Daily variation of 5 cm soil temperature *D. angustifolia* wetland.

In September, soil-surface CO_2 fluxes decreased steadily. The amount of soil-surface CO_2 exchange is small, but the atmosphere and soil temperature had a measurable daily variation due to the regional climate condition, so that the soil-surface CO_2 flux has a distinct daily pattern. Figure 4 is the daily variation pattern of 5 cm soil temperature on September 28–29. It is clear that the trend seen in Figures 3 and 4 is very similar. This indicates that the soil temperature had a strong effect on soil-surface CO_2 fluxes.

Flux–temperature relationships

Soil-surface CO_2 flux is a measure of soil respiration. Soil respiration is the sum of root respiration and heterotrophic decomposition of soil organic matter. This biological activity is strongly affected by temperature and moisture (Oberbauer et al. 1992; Zak et al. 1999) and respiration rates are positively correlated with soil temperature (Lloyd and Taylor 1994; Raich and Potter 1995; Davidson et al. 1998). However, temperature responses differ depending on temperature range and type of ecosystem (Lloyd and Taylor 1994; Kirschbaum 1995; Winkler et al. 1996). Root respiration and soil microbial respiration may also respond differently to variation in soil temperature (Boone et al. 1998; Fang and Moncrieff 2001). Some of the variability in apparent responses to temperature may be the result of confounding variation in soil water

Table 2. Correlation analysis between soil CO_2 flux and soil temperature of *D. angustifolia* wetland.

	Flux	0 cm	5 cm	10 cm	15 cm	20 cm	40 cm
Flux	1.000	0.605**	0.770**	0.812**	0.844**	0.886**	0.877**
0 cm	0.605	1.000	0.820**	0.782**	0.777**	0.736**	0.684**
5 cm	0.770	0.820	1.000	0.995**	0.968**	0.942**	0.944**
10 cm	0.812	0.782	0.995	1.000	0.975**	0.957**	0.963**
15 cm	0.844	0.777	0.968	0.975	1.000	0.979**	0.969**
20 cm	0.886	0.736	0.942	0.957	0.979	1.000	0.964**
40 cm	0.877	0.684	0.944	0.963	0.969	0.964	1.000

** Correlation is significant at the 0.01 level (two-tailed), $N = 22$.

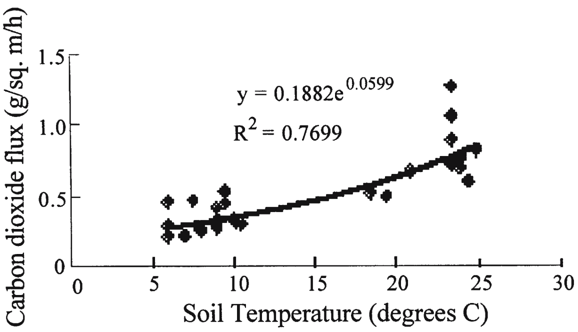

Figure 5. Relationship between soil-surface CO_2 flux and 5 cm soil temperature.

content (Dorr and Munnich 1987; Bowden et al. 1998; Davidson et al. 1998).

We analyzed the relationship between soil CO_2 flux and two important environmental factors, which are soil temperature and soil water content. At the same time we measured wetland soil CO_2 exchange, we investigated soil temperature at different depths (0, 5, 10, 15, 20, 40 cm). Because former studies primarily used the 5 cm soil temperature to identify the effects of soil temperature for soil CO_2 flux, we also selected 5 cm soil temperature for our analyses. The results of correlation analysis indicated that there are obvious positive correlations between soil temperature and soil CO_2 flux (Table 2, Figure 5). CO_2 flux increased exponentially with increasing soil temperature. The simulated equation is:

$$y = 0.1882e^{0.0599x} \quad (R^2 = 0.77), \tag{3}$$

where y represents soil-surface CO_2 flux (g m^{-2} h^{-1}), and x is 5 cm soil temperature. Because the measurements were not continuous during the growing season, there is lack of results where soil temperature equals about 15 °C at the beginning of July and September. But from the relationship, the positive correlation between soil-surface CO_2 flux and soil temperature is obvious. From the temperature versus CO_2 flux equation, we calculated a Q_{10} value (1.82).

In addition, soil moisture ranged from 32 to 40.1% with an average of 34.5%. We also calculated the correlation coefficient between soil-surface CO_2 flux and soil moisture; the resulting coefficient of 0.306 was not significant. This result is similar to other research results (Reiners 1968; Kucera and Kirkham 1971; Edwards and Harris 1977; Mathes and Schriefer 1985). That is to say, where soil water content is sufficient, it is not the limiting factor.

Conclusions

Data were collected between July and October, 2001 on the Sanjiang Plain in northeastern China. The results revealed that there were both seasonal fluctuations and daily changes in soil-surface CO_2 fluxes. The ranges of measured soil-surface CO_2 flux were 0.208–1.265 g CO_2 m^{-2} h^{-1} (a positive value represents efflux to the atmosphere). Soil-surface CO_2 fluxes averaged 0.620 g CO_2 m^{-2} h^{-1}. Study of edaphic factors such as soil temperature and soil moisture of the *D. angustifolia* wetland showed that the flux-temperature relationships were significant ($R^2 = 0.77$).

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