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Soil warming effect on net ecosystem exchange of carbon dioxide during the transition from winter carbon source to spring carbon sink in a temperate urban lawn

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Abstract

The significant warming in urban environment caused by the combined effects of global warming and heat island has stimulated widely development of urban vegetations. However, it is less known of the climate feedback of urban lawn in warmed environment. Soil warming effect on net ecosystem exchange (NEE) of carbon dioxide during the transition period from winter to spring was investigated in a temperate urban lawn in Beijing, China. The NEE (negative for uptake) under soil warming treatment (temperature was about 5°C higher than the ambient treatment as a control) was –0.71 μmol/(m^2·sec), the ecosytem was a CO_2 sink under soil warming treatment, the lawn ecosystem under the control was a CO_2 source (0.13 μmol/(m^2·sec)), indicating that the lawn ecosystem would provide a negative feedback to global warming. There was no significant effect of soil warming on nocturnal NEE (i.e., ecosystem respiration), although the soil temperature sensitivity (Q_{10}) of ecosystem respiration under soil warming treatment was 3.86, much lower than that in the control (7.03). The CO_2 uptake was significantly increased by soil warming treatment that was attributed to about 100% increase of α (apparent quantum yield) and A_{max} (maximum rate of photosynthesis). Our results indicated that the response of photosynthesis in urban lawn is much more sensitive to global warming than respiration in the transition period.

Key words: soil warming; urban lawn; CO_2 uptake; ecosystem respiration

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Introduction

With increasing atmospheric CO_2 concentration, the global temperature would be predicted to rise at very high confidence level (IPCC, 2007). Terrestrial ecosystems, as one of the global largest carbon storages (IPCC, 2000), could significantly regulate the atmospheric CO_2 content through net ecosystem exchange (NEE) of CO_2. Not only would the future climate change depend on anthropogenic carbon emissions, but also on carbon emission in terrestrial ecosystems. Since the photosynthesis and respiration respond differently to change in temperature, there would be strong feedback between global warming and carbon cycle of terrestrial ecosystem (Delpierre et al., 2009; Huxman et al., 2003; Lafleur and Humphreys, 2008).

The feedback of vegetation to climate in the changing global climate is one of the important contents of the global change studies (Yu et al., 2010). Previous studies have reported that autotrophic respiration is more sensitive than photosynthesis to increases in temperature (Ryan, 1991; Amthor, 1994). Yin et al. (2008) reported that the photosynthetic capacity of *Picea asperata* and *Abies faxoniana* seedlings was increased by warming, and the warming was beneficial to the seedling growth and development during the early growing season. Many models also predict autotrophic respiration will increase at a greater rate than photosynthesis, which implies a substantial increase in temperature could stimulate carbon emission from terrestrial ecosystems or turn terrestrial ecosystems from a carbon sink to a carbon source (Vemap et al., 1995; Ryan et al., 1995, 1996; Goulden et al., 1998). However, a recent study reported that there was not significant changes in the rates of light-saturated net photosynthesis, foliage respiration and stem respiration in boreal black spruce ecosystem under heating treatments in a 3-years experiment, which does not support the early investigation and modeling results (Bronson and Gower, 2010). With climate warming, ecosystem photosynthesis will start early that would increase carbon uptake. Baldocchi and Wilson (2001) have reported that, across a range of temperate deciduous sites, a one-day increase in growing season length (as defined by the number of days between source-sink transition in the spring and sink-source transition in the autumn) increased annual net ecosystem productivity

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(NEP) by 5.7 g C/m^2. Therefore, more field experiments are necessary to investigate the temporal variations in photosynthesis and respiration of terrestrial ecosystem under climate change, especially in period of ecosystem recovery from the dormant period.

The measurements of NEE have mostly focused on the growing season because of higher flux rates. Only a few studies have been done during dormant or low temperature periods. In last decade, some field measurements have showed that small but continuous rates of ecosystem respiration during the winter can significantly influence the annual carbon balance in seasonal forests (Hubbard et al., 2005). The NEE in the transition period from winter to spring has also been paid to more attention in recent years (Lafleur and Humphreys, 2008; Welker et al., 2004; Keeling, 1996). Climate change in early spring could determine the timing of carbon switch from source to sink. For instance, soil thaw-freeze cycles in transition from winter to spring influence ecosystem NEE due to rapid changes in soil moisture condition. The climate change in this transition period would exert an important control over the seasonal variation of NEE (Law et al., 2000; Lloyd et al., 2002; Monson et al., 2002; Huxman et al., 2003; Tanja et al., 2003; Ensminger et al., 2004). Monson et al. (2005) reported that interannual variation in the annual cumulative NEE was mostly explained by variation in NEE during the snow-melt period in subalpine forest. Therefor, it is important to investigate the carbon cycle in the transition period in response to climate change, including global warming.

With the rapid urbanization, half of the world's population has lived on urban areas (World Resources Institute, 1996). Large area of forest, grassland and arable land is annually being lost to the expansion of urban area. Meanwhile, with urban development, urban lawn, a kind of greenlands, is increasing in parks, communities, commercial landscapes, recreational facilities, golf courses, and other greenlands. For example, in Beijing and Shanghai of China, about 115 km^2 land is annually being changed to lawn (Lao, 2002). Some studies had carried out to investigate the CO$_2$ exchange in urban greenland area (Allaire et al., 2008).

Since vegetations are capable of providing multiple ecological services for urban society, e.g., direct shading and indirect evapotranspiration for alleviating heat island effect, conservation of stormwater for reducing flooding, biodiversity conservation, and aesthetic value, the effects of climate change on urban vegetations need to be investigated (Teodorescu, 2010). For example, Mimet et al. (2009) studied the response of flowering time of *Platanus acerifolia* and *Prunus cerasus* to the temperature change induced by the urbanization. Carbon sequestration, one of important ecological service of urban vegetation, has been receiving more attention with global concerning climate change and carbon cycle. Qian and Follet (2002) estimated the carbon sequestration rate in urban lawn was about 1 Mg/(ha·year). Ranajit (2008) suggested that well managed lawns sequester, or store, significant amounts of carbon, and the healthy turf grass can capture up to 1.49 Mg C/(ha·year). In the future, urban land would be stressed by global warming induced by the rise of atmospheric greenhouse gases and intensified urban heat island. It is still not clear how the carbon cycle of urban lawn would respond to climate change.

In this study, NEE of urban lawn were measured by automated chamber system in a paired comparison experiment with heating and no heating treatments. The aims are to investigate: (1) the changes in NEE of urban lawn during the transition period from winter to spring, (2) the feedback between NEE of urban lawn and soil warming, (3) the different responses of ecosystem respiration and photosynthesis to soil warming.

1 Materials and methods

1.1 Experimental site

The experiment was conducted in the Educational Arboretum of Beijing, located in downtown area of Beijing (116°25′37″E, 39°52′28″N). The climate belongs to the temperate monsoon climate. The annual mean temperature is 11°C with range of –20°C and 40°C, and the annual precipitation is about 500 mm. Approximately 80% of the precipitation occurred in summer and autumn.

The lawn of turf grass (*Zoysia japonica* Steud.) was located in the center of the Educational Arboretum, managed as normal practices without drought stress and fertilized two times a year, one in middle of March (45 kg/ha mineral N, 6 kg/ha phosphorus and 3 kg/ha potassium) and another in November before the soil was frozen (40 kg/ha mineral N, 6 kg/ha phosphorus and 2 kg/ha potassium). The grass was mowed at interval of 2–3 weeks in summer and early fall. The soils were sampled on 15-Dec-2009 to measure the soil property. The soil organic carbon, nitrite and ammonium nitrogen were 18.3 mg/g, 6.30 μg/g, 1.59 μg/g respectively, and pH was 7.2.

1.2 Experimental design

The soil warming was achieved by burying heating pipes at 50 cm depth of the lawn (soil warming). The neighboring plot without soil warming was set as the control. The pipes connected the heating system which supports office heating during 15-Jan-2010 to 30-Mar-2010. Four automated chambers were installed in each plot as the replications. The chambers were inserted 6 cm deep into soil to ensure gas tightness.

1.3 CO$_2$ flux measurement

The NEE was measured with an automated multi-channel chamber system. The chambers were installed on 15-Dec-2009. The automated chambers (50 cm × 50 cm × 50 cm, length × width × height) had walls made from transparent PVC glued and fixed to the aluminum alloy and had lids hinged at the sidewalls. The high-density rubber gaskets were glued to the upper edge of the chambers for tight closing. A small fan within each chamber was used for mixing the air when the lid was closed. A tube with inner diameter of 4 mm and length of 1.5 m was inserted through the lid of each chamber to maintain the pressure inside the chamber near the ambient air when chamber was closed (Griffis et al., 2004). A cylinder was positioned within each chamber and driven by high pressure from a compressor to control the chamber lid open and close. Air sample was pumped from one chamber closed to pass through a multi-channel valve, the buffer tube, the desiccant tube, the filter, the flow controller into IRGA (Li-820, Li-Cor Inc., Lincoln, NE, USA) for measuring CO_2 concentration within the chamber, and then returned the chamber. A Programmable Logical Controller (Master-K120S, LG, Korea) was deployed to control a series of solenoid valves to control the target chamber open and close, and air gas sample from and return to the target chamber. Each chamber was closed for 3 min (Drewitt et al., 2002) for the measurement. The flow rate was controlled at 1 L/min. The CO_2 concentrations were monitored continuously by the IRGA and recorded at the interval of 10 sec with a data logger (CR1000, Campbell Scientific Inc., Logan, UT, USA).

1.4 Environmental measurement

Copper-constantan thermocouples were used to measure the soil temperature at the depth of 5 cm near each chamber and air temperature inside chamber. Photosynthetic photon flux density (PPFD, 400–700 nm wave bands) was measured with Quantum Sensor (LI-190SA, Li-Cor Inc., Lincoln, NE, USA). The air and soil temperatures and photosynthetic active radiation (PAR) were recorded at an interval of 3 min in the data logger. The ambient air temperature and air pressure data were derived from meteorological station 300 m south of the plots which was managed by Beijing Urban Ecosystem Research Station.

1.5 Data processing and statistical analysis

Data were downloaded every day from the data logger. The CO_2 concentrations from 1 min after the chamber closed and 20 sec before the chamber opening were used to calculate the change in CO_2 concentration, which is the slope of the linear regression of CO_2 concentration and time when their correlation coefficient is larger than 0.95. NEE was calculated by Eq. (1) (Davidson et al., 1998):

$$F_c = dc/dt \times VP/SRT \tag{1}$$

where, F_c (μmol/(m^2·sec)) is the CO_2 flux rate; c (μmol/mol) is the CO_2 content, dc/dt (μmol/(mol·sec) is the change rate of CO_2 concentrations; V (m^3) is the volume of the chamber; P (kPa) is the atmospheric pressure inside the chamber; S (m^2) is the ground surface area enclosed by the chamber; R (8.3×10^{-3} (m^3·kPa)/(mol·K)) is the universal gas constant; T (K) is the air temperature inside the chamber.

The NEE was averaged for four measurements of four chambers. One way analysis of variance (ANOVA) was used to assess the effects of heating treatment on NEE. The statistical analyses were carried out using the SAS 8.0 software package (SAS Institute, Cary, North Carolina, USA).

Nocturnal NEE (the NEE when the PPFD $<$ 100 μmol/(m^2·sec)) and diurnal NEE (the NEE when the PPFD $>$ 100 μmol/(m^2·sec)) were separated to assess the NEE response to air temperature and PPFD. The relationship between the nocturnal NEE and soil temperature (T_{soil}) is modeled by the following exponential Eq. (2):

$$F_c = b_0 \times \exp(b\,T_{soil}) \tag{2}$$

where, b_0 and b are regression parameters. The temperature sensitivity of ecosystem respiration (Q_{10}) can be estimated from parameter b by Eq. (3):

$$Q_{10} = \exp(10b) \tag{3}$$

The relationship between diurnal NEE and PPFD (μmol/(m^2·sec)) can be modeled by following hyperbola Eq. (4):

$$F_c = R_{eco} - (A_{max} \times \alpha \times \text{PPFD}) \div (\alpha \times \text{PPFD} + A_{max}) \tag{4}$$

where, R_{eco} (mol/(m^2·sec)) is ecosystem respiration in daytime, A_{max} (μmol/(m^2·sec)) is the maximum NEE at infinite light, and α (μmol CO_2/μmol photon) is the apparent quantum yield.

The above regression relationships were parameterized by bivariate regression analyses, including linear, hyperbola and exponential models using SigmaPlot 10.0 (Systat, San Jose, CA, USA).

2 Results

2.1 Air and soil temperature

In the period of the experiment, the average, maximum and minimum air temperature were 1.69°C, 16.67°C (21-Feb-2010), and –9.06°C (17-Jan-2010), respectively (Table 1). The variation of air temperature is shown in Fig. 1.

The soil warming increased the soil temperature significantly ($p < 0.0001$). Soil temperature was increased

Table 1 Mean and range of air and soil temperature, photosynthetic photon flux density (PPFD), and diurnal, nocturnal and daily net ecosystem exchange (NEE) under heating treatment and control

	Heating treatment		Control	
	Mean	Range	Mean	Range
Air temperature (°C)	1.69	–9.06~16.67	1.69	–9.06~16.67
Soil temperature (°C)	8.41	16.22–2.65	3.87	–0.73~16.19
PPFD (mol/(m^2·day))	13.43	31.16–1.63	13.43	31.16–1.63
Diurnal NEE (μmol/(m^2·sec))	–3.15	–7.57~0.09	–1.63	–6.27~0.65
Nocturnal NEE (μmol/(m^2·sec))	0.81	0.34–1.91	1.08	0.31–2.97
Daily NEE (μmol/(m^2·sec))	–0.71	–3.48~1.78	0.13	–2.39~2.87

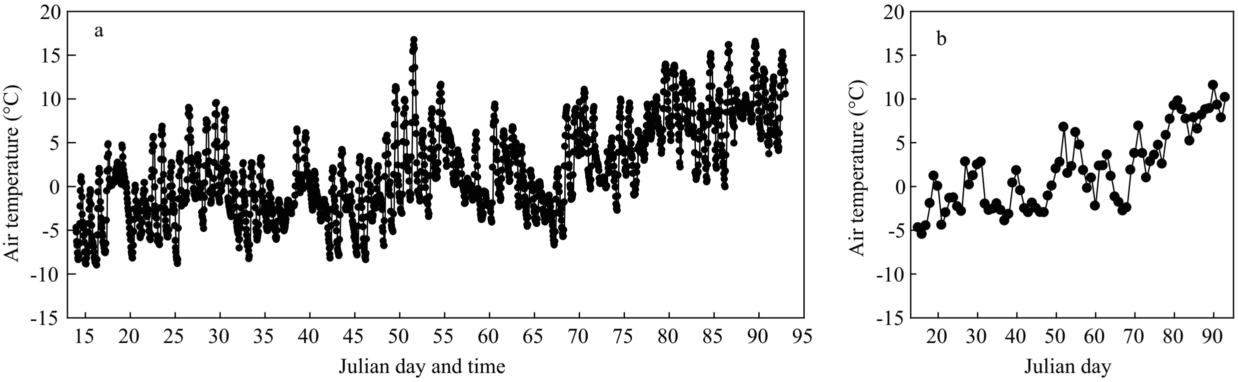

Fig. 1 Hourly averaged (a) and daily averaged (b) air temperature during the experiment period.

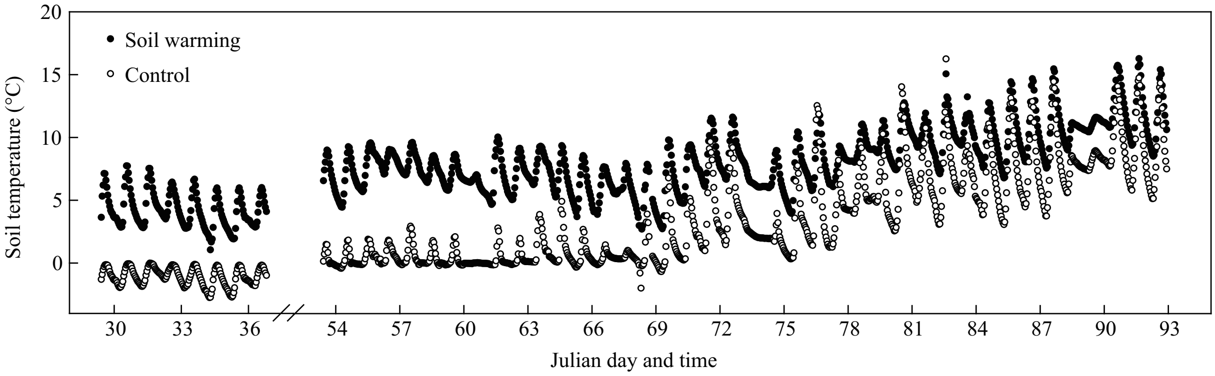

Fig. 2 Hourly soil temperature under control and soil warming regimes, the break (//) stands for the data missing period during DOY (day of year) 38–DOY 52.

by 4.7°C in average, 8.8°C in maximum and 0.02°C in minimum. The enhanced temperature declined with the air temperature rise (Fig. 2).

2.2 Soil warming effect on NEE

In the experimental period, significant diurnal variation in NEE occurred for both control and soil warming treatment and there were negative NEE in daytime, indicating carbon uptake by lawn regardless of soil warming or not (Fig. 3). On daily scale, nearly all NEE under soil warming treatment were negative except few cloud or raining days while NEE under control transformed from source to sink on DOY (the day of year) 74 (15-Mar-2010) (Fig. 4a). In either diurnal (Fig. 4b), or nocturnal (Fig. 4c) scale, NEE under soil warming treatment were lower than that under control significantly ($p < 0.0001$).

The average daily NEE and diurnal NEE were significantly decreased by the soil warming treatment ($p < 0.0001$). The average NEE under the soil warming treatment was –0.71 μmol/(m^2·sec), it indicated that the lawn ecosystem was a CO_2 sink under the warming treatment. The lawn ecosystem under the control was a CO_2 source (0.13 μmol/(m^2·sec)) (Table 1). The average diurnal NEE under heating treatment was –3.15 μmol/(m^2·sec), which was about two times of control (–1.63 μmol/(m^2·sec)) (Table 1), indicated that heating treatment increased the CO_2 uptake. The average nocturnal NEE was 0.81 μmol/(m^2·sec) under heating treatment, the average nocturnal NEE was 1.08 μmol/(m^2·sec) under the control, The difference between the nocturnal NEE under the soil warming treatment and control was not significant (Table 1).

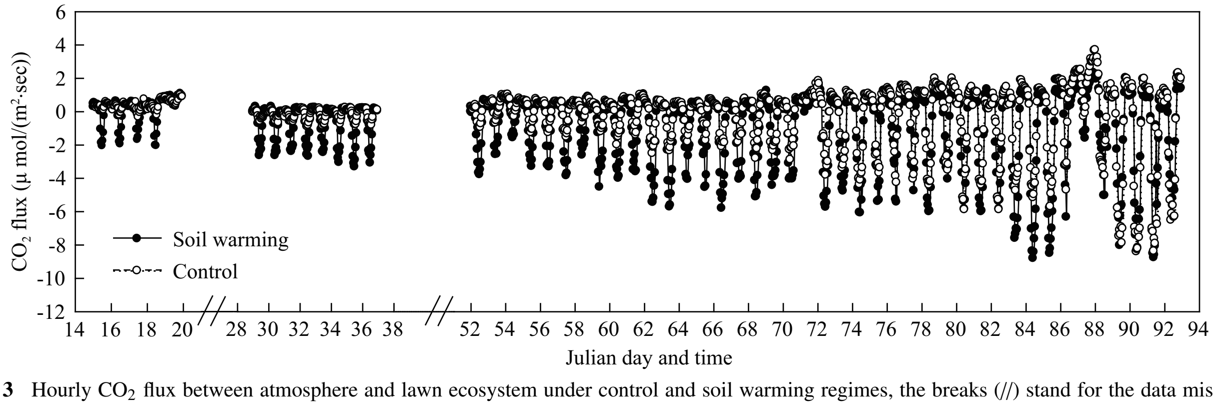

Fig. 3 Hourly CO_2 flux between atmosphere and lawn ecosystem under control and soil warming regimes, the breaks (//) stand for the data missing periods during DOY 20–28 and DOY 38–52.

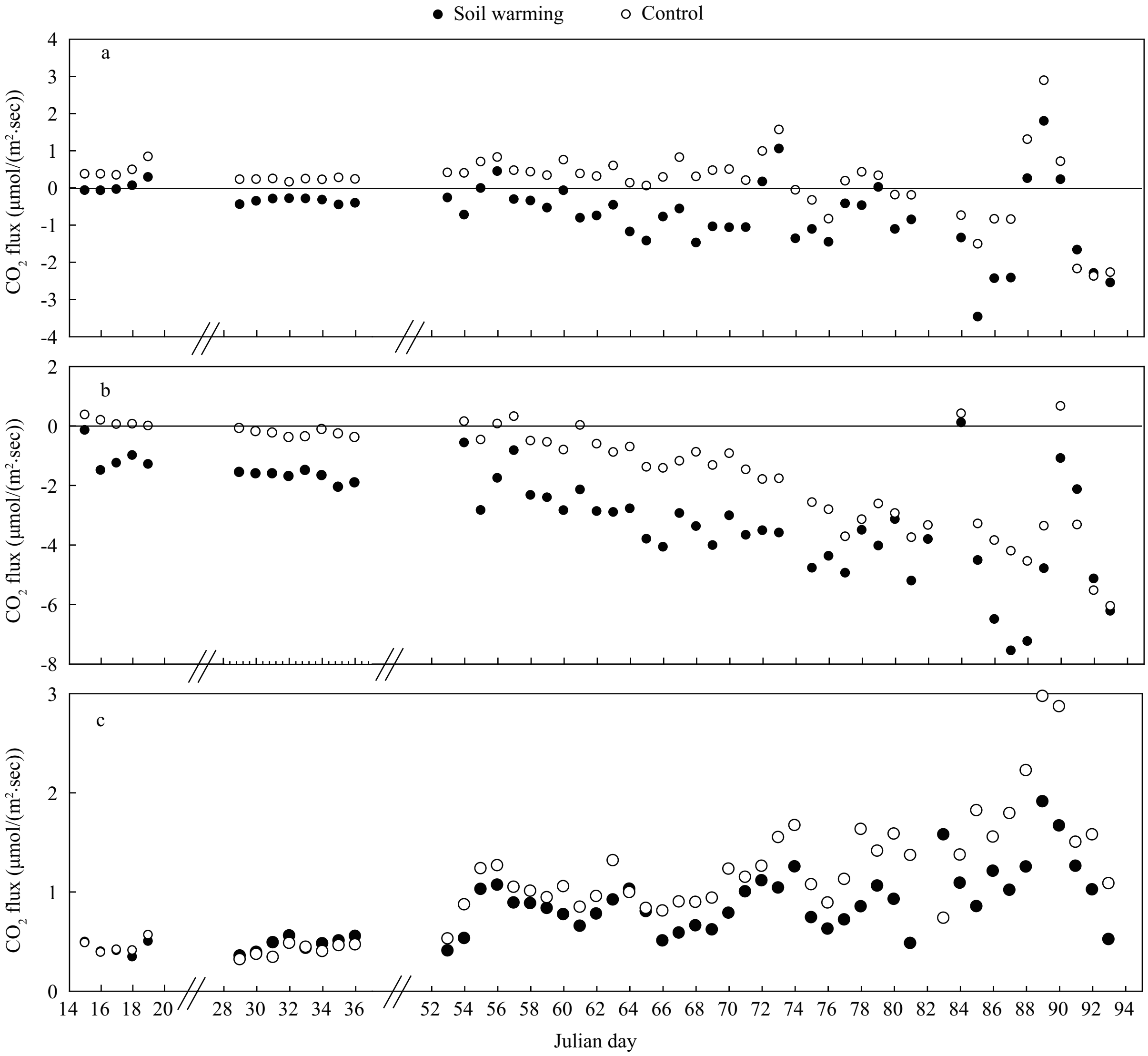

Fig. 4 Effect of soil warming on daily (a), diurnal (b) and nocturnal (c) CO_2 flux between atmosphere and lawn ecosystem (n = 51) that was without warming (control) compared to soil warming treatment (soil warming), the breaks (//) stand for the data missing periods during DOY 20–28 and DOY 38–52.

2.3 Relationships of NEE to soil temperature and PPFD

There were significant exponential relationships between nocturnal NEE and soil temperature under both heating treatment (R^2 = 0.43, P < 0.0001) and the control (R^2 = 0.35, P < 0.0001) (Fig. 5). The soil temperature sensitivities of nocturnal NEE (Q_{10}) was 3.86 under heating treatment, which only 54% of that under the control (Q_{10} = 7.03).

The diurnal NEE decreased with the increased PPFD under both heating treatment and the control during the study period (Fig. 6). Although the correlations between diurnal NEE and PPFD were well fit with the rectangular hyperbola functions, the correlation coefficient under heating treatment (R^2 = 0.68) was larger than that under the control (R^2 = 0.44), the parameters α and $A_{\max}$ under heating treatment were 0.05 μmol CO_2/μmol photon and 7.21 μmol/(m²·sec), respectively, and nearly doubled that of control (α = 0.03 μmol CO_2/μmol photon, $A_{\max}$ = 3.50 μmol/(m²·sec)).

3 Discussion

3.1 Lawn NEE during the transition period from winter to spring

In the experiment period, the daily NEE under control was 0.44–1.55 μmol/(m²·sec) before 1-Mar-2010, indicating the lawn ecosystem was a carbon source with 0.37 μmol/(m²·sec) (1.41 g CO_2/(m²·day)) in winter, even though it absorbed CO_2 at the daytime. This result was well within the range of similar ecosystem, such as humid-temperate pastures (2.88 g CO_2/(m²·day); Skinner, 2007) and sagebrush-steppe ecosystems (0.68–1.31g CO_2/(m²·day); Gilmanov et al., 2004).

Regehr and Bazzaz (1976) suggested two possible photosynthetic acclimation strategies for over-wintering plants: limiting the photosynthesis with completely dormancy during the winter months or keeping photosynthetic capacity during winter time when the climate conditions were favorable for CO_2 uptake. The study of Kato et

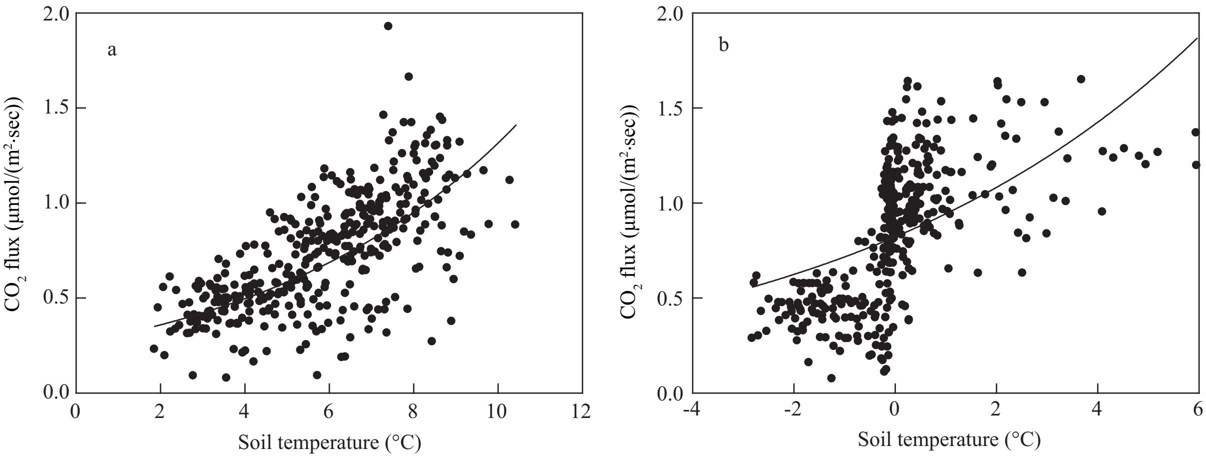

Fig. 5 Relationship between nighttime CO_2 fluxes and soil temperature under soil warming treatment (a) and control (b). Soil warming treatment: $Fc = 0.328 \times \exp(0.135T)$; $R^2 = 0.43$; $P < 0.0001$. Control: $Fc = 0.841 \times \exp(0.195T)$, $R^2 = 0.35$, $P < 0.0001$.

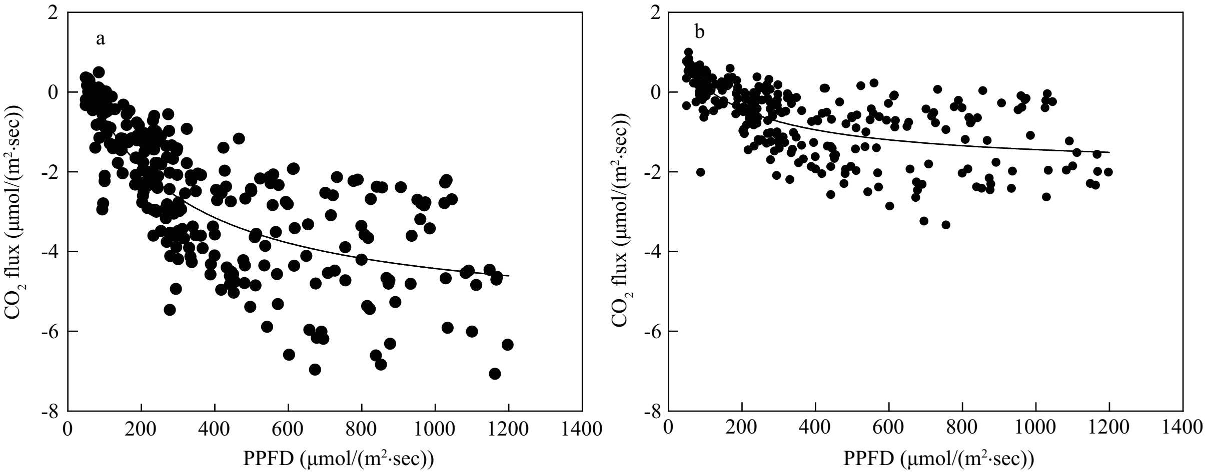

Fig. 6 Relationships between daytime CO_2 fluxes and PPFD (photosynthetic photon flux density) under soil warming treatment (a) and control (b). Soil warming treatment: $F_c = 2.18 - (0.05 \times 7.72 \times \text{PPFD}) \div (0.05 \times \text{PPFD} + 7.72)$; $R^2 = 0.68$, $p < 0.0001$. Control: $F_c = 1.65 - (0.03 \times 3.50 \times \text{PPFD}) \div (0.03 \times \text{PPFD} + 3.50)$; $R^2 = 0.44$; $p < 0.0001$.

al. (2005) has indicated that no photosynthesis could be detected during winter under *Kobresia* meadow ecosystem on the Qinghai-Tibetan plateau. Yang et al. (2008) reported that the daytime NEE of the *Stipa krylovii* steppe ecosystem in Inner Mongolia was positive and larger than night in winter period. The lawn ecosystem of this study adapt to winter by the latter acclimation strategies of Regehr and Bazzaz, which indicated by the negative NEE detected during daytime irrespective of heating or not since DOY 16 (Fig. 3). The similar result that photosynthesis commenced 1.5 months before soil temperatures above 0°C in the boreal forest (Tanja et al., 2003). Different ecosystems have different minimum air temperatures for photosynthesis. Pisek (1973) reported that the range for air temperate evergreen tree species varied from –4 to –8°C. Skinner (2007) reported that the photosynthesis could occur in temperate grasses at the air temperature about –4°C, even the grasses underwent the night low air temperature about –11°C. Larsen et al. (2007) reported that subarctic heath ecosystem kept photosynthetic capacity during whole winter. In this study, the lawn ecosystem kept photosynthetic capacity during whole experiment period, with the minimum air temperature –9.1°C. The CO_2 uptake is mainly controlled by PPFD, which have been extensively confirmed. In our study, the correlations between diurnal NEE and PPFD were well fit using the rectangular hyperbola functions, and the regressive parameters α and $A_{\max}$ were increased with increasing temperature and development of the lawn.

The nocturnal NEE, i.e., ecosystem respiration, were averaged to be 1.08 μmol/(m^2·sec), which was lower than soil respirations of urban lawn reported in Shanghai (1.16–5.95 μmol/(m^2·sec)) and Fuzhou (0.85–7.4 μmol/(m^2·sec); Sun et al., 2009). This discrepancy may be due to the higher temperature in those Chinese cities than that in Beijing.

The transition from winter to spring has been considered as critical period influencing ecosystem carbon cycle, especially for soil respiration, when the soil was in daily freeze-thaw cycle. In this study, the nocturnal NEE increased significantly in later period of the experiment, especially after March 15, due to soil freeze-thaw cycle. The rapid increase of CO_2 efflux during freeze-thaw cycle has also been found in tundra heath ecosystem (Elberling et al., 2003) and forest ecosystem (Hubbard et al., 2005; Schindlbacher et al., 2007). The increase of root and microbial activity resulted from the soil temperature rise and free water availability would stimulate the rapid increase of CO_2 effluxes (Ostroumov and Siegert, 1996; Hanson et al., 2003).

The temperature was the most important factor that drives NEE of ecosystem. There were significant exponential relationships between nocturnal NEE and soil temperature considering whole experiment period (R^2 = 0.35, $P < 0.0001$) (Fig. 5), however, the further analysis indicated that no obvious relationship occurred between winter soil CO_2 efflux and soil temperature when soil temperature lower than –0.5°C (data not showed here). This result was consistent with the report that soil temperature had no direct effect on soil respiration in winter (Wang et al., 2010).

3.2 Feedback of winter NEE to climate change

The positive feedback of terrestrial ecosystem to climate warming means that the warming increased the carbon release from ecosystem and the negative feedback means that the warming increased the carbon storage in ecosystems (Luo, 2007). The response of carbon flux to climate warming varied and depended mainly on which climatological factor was the limiting factor of plant growth to the ecosystem (Boeck et al., 2007). The climate warming could benefit to the plant metabolic activity that was limited by the low temperatures in winter time and in polar regions (Marchand et al., 2004), but aggravate the heat and drought stress and then decrease the photosynthetic capacity of the ecosystem in warmer and drier climate condition (Arnone et al., 2008; Llorens et al., 2003). The difference of the responses of the gross primary productivity (GPP) and ecosystem respiration to climate warming resulted in the complexity of effect of climate warming on NEE. Kharin and Zwiers (2000) reported that the increase of air temperature at night was larger than day, this could resulted in that the increase of ecosystem respiration was larger than GPP, and the increase of GPP would be limited by the lower PPFD in winter (Welp et al., 2007). However, our results showed that CO_2 uptake of lawn ecosystem increased and the ecosystem respiration had less response to warming, and the NEE showed a negative feedback on climate change during the transition period from winter to spring. Similar results were also observed in other warming experiments. An analysis of a decade of eddy covariance data from six European forests stands indicated that the GPP was the maximum in a exceptionally warm spring, the ecosystem respiration was less anomalous to climate warming, and the net uptake in warm spring was larger than the long term mean uptake (Delpierre et al., 2009). Huxman et al. (2003) reported that climate warming increased the photosynthesis of a subalpine, coniferous forest during spring, but the ecosystem respiration was not increased significantly leading to the increase of CO_2 uptake. The similar result was observed in tundra during spring in a low Arctic tundra (Lafleur and Humphreys, 2008). The GPP was increased by the climate warming through increasing the photosynthetic capacity and the lengthening the growing season (Welker et al., 2004; Berninger, 1997; Randerson et al., 1999; Idso et al., 2000; White et al., 2000; Saxe et al., 2001), which defined by the first continuous 3-day period of net carbon uptake (Welp et al., 2007), but the winter and spring climate warming was not always increased the growing season, for example, Yu et al. (2001) reported that the dormancy period of a alpine meadow in Tibetan Plateau was lengthened by the continued winter warming.

Our study indicated that warming increased the α and $A_{\max}$ by about 2 times, which stimulate CO_2 uptake of the lawn. The onset of the growing season for the control was on DOY 74, but the lawn ecosystem under warming was net carbon uptake during almost the whole experiment period. Welker et al. (2004) reported that the growing season was increased by 2 weeks and the gross ecosystem productivity was increased by the warming. Previous study indicated that GPP was reduced by the climate warming due to climate warming resulting in drought stress and reduction in photosynthetic capacity, and ecosystem respiration was increased by climate warming (Zhou et al., 2010). In our study, the lawn was irrigated before winter, so no water stress was observed. The global warming stimulated plant growth and increased the photosynthetic capacity and GPP.

No significant ecosystem respiration difference was found between the warming treatment and control. In lawn, the biomass accumulation was moved away from the ecosystem by grass mowing, which would decrease the grass litter and soil labile carbon content (Luo et al., 2009), this might be one of the reasons of no heating effect on the ecosystem respiration. Bokhorst et al. (2010) suggest that winter warming events do not affect fresh litter decomposition in a sub-Arctic heath land. On the other hand, the soil would undergo the froze-thaw cycle in later winter, and induce more CO_2 emission, but this would not occur in heating treatment lawn. The Q_{10} was decreased by heating treatment that would lead to the decrease of ecosystem respiration.

4 Conclusions

The present study investigated the lawn NEE and its response to climate warming during the transition period from winter to spring. Lawn ecosystem provided a negative feedback to climate warming. Lawn photosynthesis was consistently stimulated by warming almost the whole experiment period, $A_{\max}$ and α under the warming treatment were about 2 times compared to the control. But the ecosystem respiration had no significant difference in response to heating treatment, which would be attributed to less lawn litter and soil labile carbon content due to lawn mowing. Heating treatment speeded up the lawn ecosystem converting from a CO_2 source to a CO_2 sink in early spring and lengthened the growing season of lawn ecosystem. The daily NEE were negative under heating treatment in winter, suggesting that the winter photosynthesis should not be ignored, especially under climate warming. In urban ecosystems, the compounding effects of management measures (irrigation, clipping, fertilization, etc.) and climate change on ecosystem carbon cycle need more investigation to provide more information for decision makers to achieve urban sustainable development.

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