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Seasonal spatial pattern of soil respiration in a temperate urban forest in Beijing

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ABSTRACT

Urban forests play an important role in mitigating climate change in urban ecosystems. In order to obtain greater carbon sequestration benefits, it is crucial to advance the understanding of soil CO_2 efflux from urban forests. This study was undertaken to identify biotic and abiotic parameters that explained spatial variation in soil respiration, especially the effect of forest stand structure. To this aim, we measured soil respiration at 44 points in a 30 m × 50 m plot in an urban forest in Beijing over a 10 month period. The spatial variations of soil respiration were investigated, relating to soil climate, soil nutrients, root biomass and forest structural traits. The highest spatial variation in soil respiration was observed during the summer dry period, and similar degrees of variability were shown both in the growing and dormant season. Vegetation area index, soil moisture and nitrate nitrogen were the determinable parameters that influenced the spatial variation in soil respiration in the growing season, while nitrate nitrogen and soil temperature in the dormant season. Soil temperature, sulfur and roots biomass also affected the soil respiration during the growing season. Moreover, mean DBH and tree number within a 6-m radius had a significant influence on the spatial pattern of soil respiration at sub-plot level. Our results suggest that decreasing the soil CO_2 efflux might be an optional way to increase carbon sequestration potential for urban forest. This can be achieved by regulating forest stand structure and applying appropriate maintenance practices.

1. Introduction

There is no doubt that urbanization is a pervasive environmental issue. It is against the background of the swift growth of the urban population and the rapid expansion and regional densification of urban areas (United Nations, 2010), together with the need for better habitat and sustainable development, that the ecosystem services of green spaces are of increasing concern (Gaston et al., 2013). For example, recent research has demonstrated that urban areas are capable of storing much larger quantities of carbon than previously realized (Nowak and Crane, 2002; Scharenbroch, 2012; Nowak et al., 2013; Edmondson et al., 2014), which means they can make a greater contribution to greenhouse gas (GHG) mitigation. To take full advantage of these services, researchers have focused efforts on designing and implementing ecosystem-services-based green infrastructure in urban areas (McPherson et al., 2005; Oberndorfer et al., 2007). Although in most cases the environmental benefits of the green space have been well documented, they are still poorly supported by empirical evidence (Pataki et al., 2011). Substantially, the ecosystems services, especially the regulating services (e.g. GHG mitigation, air and water pollutants removal, local climate regulation, etc.) rely on fundamental ecological processes, including but not limited to the carbon, nutrients and water cycles and transformation. Studies of urban biogeochemistry are greatly needed to improve green space design and management in meeting local environmental goals in different regions and urban settings (Pataki et al., 2011).

In the case of the carbon cycle, soil respiration is the main pathway for carbon moving from the ecosystem to the atmosphere (Ryan and Law, 2005), and is about ten times greater than anthropogenic fossil fuel combustion (Boden et al., 2009). It is therefore a key determinant in regulating the feedback between terrestrial ecosystems and the atmosphere (Canadell et al., 2007). A large body of literature has developed, particularly over the past two decades, on the mechanism of soil respiration in natural ecosystems. It has

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been well documented that soil respiration varies greatly with time and locations. Temporal patterns of soil respiration have been simulated by using the continuous records of temperature, moisture and other variables. By comparison, methods in quantifying spatial variation in soil respiration are limited and have proved to be difficult (Luo and Zhou, 2010). The main factors influencing spatial variation already identified are soil moisture (Martin and Bolstad, 2009), physical soil properties that controls gas diffusivity and nutrient availability (Epron et al., 2006; Kosugi et al., 2007), concentrations of macro-nutrients in the soil, such as nitrogen and phosphorus (Xu and Qi, 2001; Søe and Buchmann, 2005), and soil topography or aspect, which strongly impacts both soil water content and physical soil properties at smaller scales (Epron et al., 2006). Recent reviews have highlighted the significance of plant communities as drivers of soil respiration (Metcalfe et al., 2011). Faster growing plants generally produced more litter, richer in nitrogen (N) but poorer in carbon (C) rich structural compounds, which is more easily broken down by soil microbes and hence respired as soil respiration loss rates (Hättenschwiler, 2005). Moreover, soil properties and habitat microclimate can be strongly modified by species composition, the spatial arrangement of trees, canopy architecture and leaf traits (Law et al., 2001; Kara et al., 2008; Arx et al., 2013). In turn, these characteristics might contribute in various ways (e.g. fine root distribution, microbial activity, litter quality and quantity) to the soil respiration of the whole forest (Shibistova et al., 2002; Murphy et al., 2008).

The spatial variability of soil CO_2 efflux has to be understood, not only to derive a representative estimate of the regional carbon budget (Ryan and Law, 2005), but also to provide detailed information on which ecological management policy and practice can be built (Luo and Zhou, 2010). Considering the GHG mitigation goals of city authorities, urban forest as the major carbon pool in city should be planted to optimize its carbon sequestration potential through selection of the right tree species, development of sound community structure, and performance of appropriate maintenance (Scharenbroch, 2012). However, the factors that significantly affect soil respiration in urban forest have not yet been systematically studied, only a few preliminary studies (e.g. Koerner and Klopatek, 2010; Bowne and Johnson, 2013; Chen et al., 2013).

Here, we provide a detailed investigation of the spatial variability in soil respiration of urban forest. During July 2012–June 2013, we conducted monthly observations of soil respiration at 44 measurement points in a planted forest in a suburban park. Soil parameters, root biomass and forest structures were used to determine the contribution to spatial variation of soil respiration. We hypothesized that soil respiration is spatially auto-correlated and regulated by some specific qualitative characteristics of stand structure as well as soil nutrients and root biomass, as in a natural forest ecosystem (Søe and Buchmann, 2005; Katayama et al., 2009; Bréchet et al., 2011). This research seeks to improve our understanding of soil carbon efflux in urban forest, and the results obtained may help us to evaluate the effectiveness of green spaces, to identify areas of weakness, and to design appropriate management measures.

2. Methods

2.1. Study site

The study site is located in the Bajia Suburban Park (40°01′04″ N, 116°20′05″ E) in Beijing, China. The City is situated in a warm temperate zone and has a typical continental monsoon climate. Air temperature averaged 14.96 °C and precipitation was 622.6 mm (mostly in July–September) during the experiment period (July 2012–June 2013).

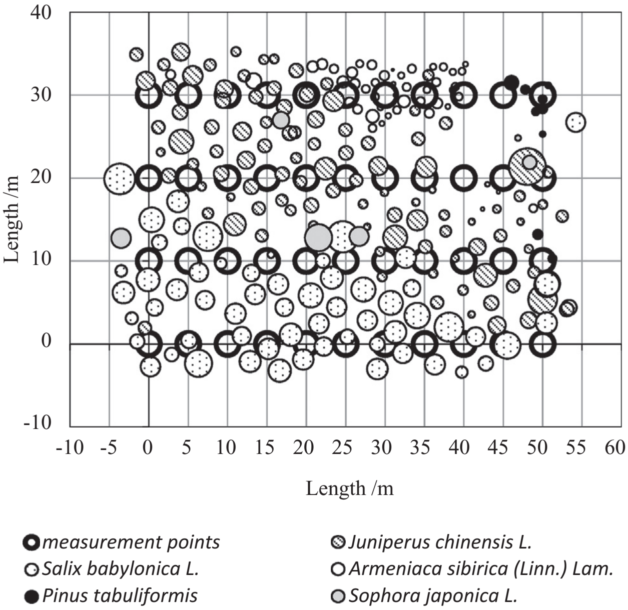

Fig. 1. Location of trees and measuring points with in a 30 m × 50 m plot in an urban forest in Bajia Suburban Park, Beijing, China. Symbol size indicates the diameter at breast height of trees.

The Bajia Suburban Park, covering an area of about 104 ha, was established in 2007 based on the former forest plantation that was planted as an urban segregating belt. A 30 m × 50 m plot was set in one of the tree patches. Most of the 224 inventoried trees belonged to three species: 45.9% *Juniperus chinensis* L., 26.7% *Salix babylonica* L. and 20.5% *Armeniaca sibirica* (Linn.) Lam., with a few of *Sophora japonica* L. and *Pinus tabuliformis* (Fig. 1). The mean diameters at breast height (DBH) were 11.5 ± 4.3 cm, 17.3 ± 4.3 cm, 6.7 ± 2.3 cm, 14.8 ± 6.2 cm and 7.3 ± 2.1 cm respectively. The dominate understory vegetation was *Viola philippica* Car., a low herbaceous amenity plant. Compared with an unmanaged forest, there was little debris and litter on the forest floor because of litter-fall sweeping in autumn. Reclaimed water was used for irrigation to mitigate drought, but on an irregular basis. Soil bulk density was determined by drying 15 samples (volume of 100 cm^3 and at 0–7 cm depth) at 105 °C, which were randomly collected in the plot. Then, soil texture was measured with a Mastersizer 2000 (Malvern Instruments Limited, Worcestershire, UK). The soil was sandy loam and the mean bulk density was 1.44 ± 0.10 g cm^{-3}.

2.2. Data collection

In July 2012, the study plot was divided into grid system using a 5 m × 5 m quadrat size, and each tree species and its geographic coordinates were determined in the 0.15-ha plot (Fig. 1). Intersections of the 5 m × 10 m square grids were used as permanent sampling points. PVC collars (diameter of 20.0 cm and height of 10.0 cm) were inserted into the forest floor to a depth of 3–4 cm at each sampling point in July 2012. Meanwhile, all the plants in each collar were removed by hand. All collars were kept at the site for the entire study period. The diameters of all trees were measured at breast height (DBH, 1.30 m above ground level) with the exception of *J. chinensis* L., which were measured at the base of the trunk because of very low crown. VAI (Vegetation area index, i.e. leaf plus stem area) were measured with a LAI 2000 canopy analyzer (LI-COR Inc., Lincoln, NE) several days after the measuring campaigns in August and November 2012 respectively, as described in the study by Thimonier et al. (2010).