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Research paper

Land use and land cover changes explain spatial and temporal variations of the soil organic carbon stocks in a constructed urban park

Jeehwan Bae[a], Youngryel Ryu[a,b,c,d,*]

[a] Department of Landscape Architecture and Rural Systems Engineering, Seoul National University, Seoul, South Korea
[b] Interdisciplinary Program in Agricultural and Forest Meteorology, Seoul National University, Seoul, South Korea
[c] Interdisciplinary Program in Landscape Architecture, Seoul National University, Seoul, South Korea
[d] Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul, South Korea

HIGHLIGHTS

- Soil organic carbon (SOC) was measured in an urban park.
- SOC stock showed ten-fold difference across different land cover types.
- Average topsoil SOC concentration increased 256% over the ten years.
- Land use change mainly contributed to increase in topsoil SOC concentration.

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ABSTRACT

Urban parks offer valuable ecosystem services to citizens and they have long been recognized for their recreational service; however, less attention has been paid to their carbon sequestration value. Here, we report on soil organic carbon (SOC) stocks in an urban park, Seoul Forest Park, which was built in 2004. We had two objectives: (1) to estimate SOC stocks (to a depth of 1 m) in different land-cover types (wetland, forest, lawn, and bare soil) and (2) quantify the change in the SOC concentration in topsoil in different land-use types over a 10 year period (2003–2013). We found a tenfold difference in SOC stocks across the different land-cover types within the park. Wetland soils had the highest stocks of SOC (13.99 ± 1.05 kg m^{-2}), followed by forest, lawn, and bare soils. We found that a "cultural layer" that preserved previous land use history located deep in the soil profile substantially increased SOC stocks in the wetland. SOC concentrations in the topsoil were approximately three times higher in 2013 than in 2003 (256 ± 130%). The normalized difference vegetation index (NDVI) derived from MODIS and Landsat satellite images revealed that land-use history, expansion of plant areas and growth of plants could explain the increase in SOC concentrations in topsoil over the 10 year period. These findings imply that urban park soils could act as a carbon sink, and understanding the land-use history and the choice of land-cover types in park planning can substantially influence the carbon budget of urban parks.

1. Introduction

The atmospheric carbon dioxide (CO_2) concentration surpasses its previous record every year, exceeding 400 ppm in 2013. Stocks of soil organic carbon (SOC) are a key component in carbon capture and storage to mitigate increasing atmospheric CO_2 concentration (Ingram & Fernandes, 2001; Lal, 2004). However, most soil surveys do not include urban areas, instead delineating them as partially empty space in regional soil monitoring systems (Rawlins et al., 2008; Rossiter, 2007). Most soil carbon studies have focused on agricultural and natural ecosystems (Don, Schumacher, & Freibauer, 2011; Guo & Gifford, 2002; Li, Niu, & Luo, 2012), whereas SOC stocks in urban areas have rarely been quantified (Jo & McPherson, 1995; Raciti et al., 2011). Consequently, the lack of SOC data for urban areas has made it difficult to estimate or predict the regional carbon budget in urban ecosystems.

Emerging evidence indicates that urban ecosystems could sequester large amounts of atmospheric CO_2. Churkina, Brown, and Keoleian (2010) confirmed high organic carbon densities (23–42 kg m^{-2} in urban areas and 7–16 kg m^{-2} in exurban areas)

* Corresponding author at: Department of Landscape Architecture and Rural Systems Engineering, Seoul National University, Seoul 151-921, South Korea.
Tel.: +82 2 880 4871; fax: +82 2 873 5113.
E-mail addresses: yryu@snu.ac.kr, ryuyr77@gmail.com (Y. Ryu).

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in developed areas of the United States. Pouyat, Yesilonis, and Nowak (2006) compared the variability in the SOC stocks in six different cities and found that urban soils have the potential to sequester a large amount of atmospheric CO_2. In particular, urban green spaces contained larger SOC stocks than native grasslands, agricultural, or forested areas in Colorado, U.S.A. (Golubiewski, 2006). Hutyra, Yoon, and Alberti (2011) reported that aboveground carbon stocks in Seattle's urban forests were comparable to those of the Amazon rain forest. Kaye, McCulley, and Burke (2005) measured aboveground net primary productivity in urban lawns and found it was four to five times higher than in nearby agricultural lands and grasslands. Furthermore, Mestdagh, Sleutel, Lootens, Van Cleemput, and Carlier (2005) found that SOC stocks of grassy roadsides, waterways, and railways in urban areas accounted for 15% of the total SOC stocks in a city. The soils beneath impervious surfaces in urban areas offered another, often overlooked, source of SOC (Edmondson, Davies, McHugh, Gaston, and Leake, 2012; Raciti, Hutyra, & Finzi, 2012a).

Urban parks are important natural assets in urban ecosystems and are major components of carbon sequestration strategies (Millward & Sabir, 2011). Urban parks include a large proportion of green space, which can store considerable amounts of SOC (Strohbach, Arnold, & Haase, 2012). In addition, the area of urban parks is expected to expand over time due to increasing urbanization and citizens' desire for a better quality of life. However, little effort has been made to quantify SOC stocks in urban parks.

Due to the lack of quantitative data, the effects of land-use history have rarely been assessed as a determining factor for estimating regional SOC stocks (Schulp & Verburg, 2009). However, historical land-use changes have been shown to affect current SOC stocks in constructed urban parks (Takahashi, Amano, Kuchimura, & Kobayashi, 2008). In fact, many land-use changes are accompanied by anthropogenic belowground disturbances (Raciti, Hutyra, Rao, & Finzi, 2012b). In particular, the construction process can substantially alter natural soil profiles (Chen et al., 2013; Jim, 1998). For example, aggressive land clearing (Neill et al., 1997) and replanting (De Jong, Ochoa-Gaona, Castillo-Santiago, Ramirez-Marcial, & Cairns, 2000; Pongratz, Reick, Raddatz, & Claussen, 2009; Schimel et al., 2001) can affect SOC stocks by changing soil properties and the dominant plant functional types (Hobbie et al., 2007; Palmroth et al., 2006). Constructed urban parks have heterogeneous land-cover types such as woody plants, shrubs, lawns, bare land, and ponds. As a result, soil disturbance during park construction is one of the primary reasons for differences in SOC stocks of each land-cover type. Therefore, without a detailed investigation of previous land-use and current land management, the SOC budgets of urban parks cannot be accurately predicted for inclusion in the regional carbon databases of urban ecosystems.

In this study, we report SOC stocks for the Seoul Forest Park, which was built in Seoul, South Korea, in 2004. The objectives of this study were (1) to quantify SOC stocks (to a depth of 1 m) in different land-cover types (wetland, forest, lawn, and bare soil) and (2) estimate the changes in SOC concentrations (to a depth of 0.3 m) in different land-use types over a 10 year period (2003–2013). The scientific questions that we addressed included the following: (1) what controls spatial heterogeneity of SOC stocks among different land-cover types in the constructed urban park? and (2) how does land-use history influence temporal variations in SOC concentrations?

2. Methods

2.1. Site description

This study was conducted in the 115.6 ha Seoul Forest Park, Seoul, Republic of Korea (37.545031°N, 127.038249°E). The site has a temperate monsoon climate with a mean annual temperature of 12.5 °C and mean annual precipitation of 1450 mm (Korean Meteorological Administration). The parent material of soil in the Seoul Forest Park is underlain by Daebo Granite dating to the Quaternary period. According to the Soil and Environmental Information System of Korea (http://soil.rda.go.kr), the soils in the park are classified to Entisol.

Land-use is defined as a series of operations on land by people. The Seoul Forest Park was a royal hunting ground since the reign of the Joseon Dynasty (1392–1910). In 1908, this historic site was developed into a water purification plant, horse racing course, and golf course. In 2004, the site was converted to an urban park after intensive construction and was opened to the public in June 2005. The current and previous land-use types are shown in Fig. 1 and Table 1. We quantify changes in SOC concentrations of topsoil over the 10 years, according to land-use type.

Land-cover is defined as the physical land type such as vegetation types. To quantify spatial variations of SOC stocks in 2012, we used the land-cover types instead of land-use types because one land-use type may include contrasted land-cover types (e.g. bare land and mixed forest). The proportions of the each land-cover type in the Seoul Forest Park were 2% bare land, 14.9% lawn, 27.4% mixed forest, 10% evergreen needle-leaf forest, 17.6% deciduous broadleaf forest, and 4.5% wetland. The dominant plant species included *Zoysia japonica* in lawn, *Quercus acutissima*, *Quercus mongolica*, and *Pinus rigida* in mixed forest, *P. rigida* and *Pinus strobus* in evergreen needle-leaf forest, *Q. acutissima*, *Q. mongolica*, and *Quercus serrata* in deciduous broadleaf forest, and *Phragmites japonica*, *Phragmites communis*, and *Miscanthus sacchariflorus* in wetland.

2.2. Data collection

Soil samples were collected from June 2012 and July 2013. We estimated SOC stocks to a depth of 1 m in the six land-cover types described above. We randomly determined 12 plots (10 × 10 m quadrat) within each land-cover type. At each point, we removed the litter layer, dug out soils to a 1 m depth, and collected four soil samples along the soil vertical profile (0–0.1, 0.1–0.3, 0.3–0.7, and 0.7–1.0 m) using a soil corer (Soil Sampler; Shinill Science Inc., Seoul, Korea) with a 50 mm inner diameter, 51 mm length, and 100 cm^3 volume. We also collected six root samples from each vertical soil layer of each land-cover type for a total of 168 root samples collected in June 2012. To quantify the changes in SOC concentrations in the topsoil between 2003 and 2013, we combined a literature survey and field observations. We used data from the soil survey report by the Seoul Forest Development Corporation (2004) to determine the SOC concentration and soil texture of the topsoil before the park was constructed. A total of 22 topsoil samples were collected in six different land-use districts in July 2003. We repeated the topsoil measurements in the same land-use districts by randomly collecting six samples in each district.

To understand plant growths in the park, we estimated the changes of diameter at breast height (DBH) with a diameter tape at a height of 1.3 m between August 2012 and August 2014. The 22 monitoring plots (10 × 10 m square) were distributed randomly in District 2, 3 and 5 which experienced significant land-use changes and plantations (Fig. 1 and Table 1). We selected a total of 690 trees which include seven species such as *Ginkgo biloba* L., *Pinus densiflora* Siebold & Zucc., *Pinus strobes* L., *Metasequoia glyptostroboides* Hu & Cheng., *Acer buergerianum* MIQ., *Zelkova serrata* (Thunb.) Makino., *Quercus palustris* Munchh., *Ulmus davidiana* Planch. var. *japonica* (Rehder) Nakai., *Magnolia kobus* A. P. DC. The sampled trees were mainly planted during park construction. To infer plant growths before 2012, we used the data of the changes in DBH between 2005