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Estimation of soil organic carbon stocks of two cities, New York City and Paris

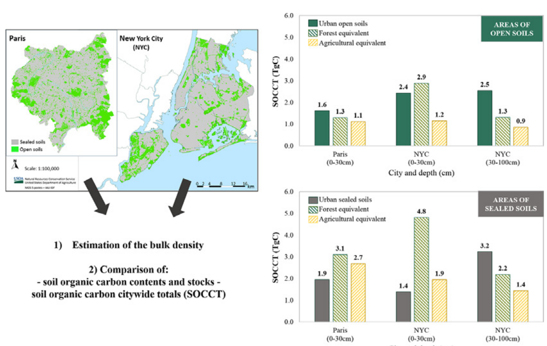
Aurélie Cambou [a,b,h], Richard K. Shaw [c], Hermine Huot [d,e], Laure Vidal-Beaudet [a,*], Gilles Hunault [f], Patrice Cannavo [a], François Nold [g], Christophe Schwartz [b]

[a] EPHor, IRSTV, AGROCAMPUS OUEST, 49045 Angers, France
[b] Université de Lorraine, Inra, Laboratoire Sols et Environnement, F-54000 Nancy, France
[c] United States Department of Agriculture, Natural Resources Conservation Service, Somerset, NJ 08873, USA
[d] School of Environmental Science and Engineering, Sun Yat-sen University, Guangzhou 510275, People's Republic of China
[e] Department of Earth and Environmental Sciences, Brooklyn College of City University of New York, Brooklyn, NY 11210, USA
[f] Laboratoire HIFIH, UPRES EA 3859, SFR 4208, Université d'Angers, Institut de Biologie en Santé PBH-IRIS CHU, 4, Rue Larrey, 49933 Angers Cedex, France
[g] Laboratory of Agronomy of the Paris City, Paris Green Space and Environmental Division (DEVE), Parc Floral - Pavillon 5 – Rond-Point de la Pyramide, 75012 Paris, France
[h] Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME), 75015 Paris, France

HIGHLIGHTS

- Urban soils represent important pools of organic carbon.
- Two different soil organic carbon stock assessment methods with similar results
- Similar soil organic carbon citywide totals between New York City (NYC) and Paris
- Soil organic carbon stocks of NYC and Paris equivalent to those of non-urban soils

GRAPHICAL ABSTRACT



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ABSTRACT

In cities, the strong heterogeneity of soils, added to the lack of standardized assessment methods, serves as a barrier to the estimation of their soil organic carbon content (SOC), soil organic carbon stocks (SOCS; kgC m^{-2}) and soil organic carbon citywide totals (SOCCT; kgC). Are urban soils, even the subsoils and sealed soils, contributing to the global stock of C? To address this question, the SOCS and SOCCT of two cities, New York City (NYC) and Paris, were compared. In NYC, soil samples were collected with a pedological standardized method to 1 m depth. The bulk density (D_b) was measured; SOC and SOCS were calculated for 0–30 cm and 30–100 cm depths in open (unsealed) soils and sealed soils. In Paris, the samples were collected for 0–30 cm depth in open soils and sealed soils by different sampling methods. If SOC was measured, D_b had to be estimated using pedotransfer functions (PTFs) refitted from the literature on NYC data; hence, SOCS was estimated. Globally, SOCS for open soils were not significantly different between both cities (11.3 ± 11.5 kgC m^{-2} in NYC; 9.9 ± 3.9 kgC m^{-2} in Paris). Nevertheless, SOCS was lower in sealed soils (2.9 ± 2.6 kgC m^{-2} in NYC and 3.4 ± 1.2 kgC m^{-2} in Paris). The SOCCT was similar between both cities for 0–30 cm (3.8 TgC in NYC and 3.5 TgC in Paris) and was also significant for the 30–100 cm layer in NYC (5.8 TgC). A comparison with estimated SOCCT in agricultural and forest soils demonstrated that the city's open soils represent important pools of organic carbon (respectively 110.4% and

* Corresponding author.
E-mail address: laure.beaudet@agrocampus-ouest.fr (L. Vidal-Beaudet).

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44.5% more C in NYC and Paris than in agricultural soils, for 0–30 cm depth). That was mainly observable for the 1 m depth (146.6% more C in NYC than in agricultural soils). The methodology to assess urban SOCS was also discussed.

1. Introduction

The increase of greenhouse gases, including CO_2, in the atmosphere is responsible for the global warming. Moreover, recent anthropogenic emissions of greenhouse gases are higher than ever observed before (IPCC, 2014). In this context, soils appear to be a solution to mitigate climate change since they represent the largest terrestrial pool of organic carbon and they are in strong interaction with the atmosphere (Jacobson et al., 2000; Scharlemann et al., 2014). Indeed, they can indirectly provide the ecosystem service of regulation of the climate, behaving as a sink or a source of atmospheric CO_2, according to different factors, such as land use (Dignac et al., 2017).

In that respect, soil organic carbon maintenance is a major issue. In this way, the recent “4 per 1000” initiative was launched at the COP21, to support states and non-governmental actors to allow for a better management of soils, for a long-term maintenance of soil organic carbon stocks (SOCS; kgC m^{-2}). However, the efforts are mainly focusing on cultivated and forested soils (http://4p1000.org; Minasny et al., 2017; Paustian et al., 2016). Nowadays, the Soils of Urban, Industrial, Traffic, Mining and Military Areas (SUITMAs) represent nearly 3% of the world's territory. By 2030, as compared to the 2000s, the urban surface area alone is expected to increase by 1.2 million km^2 worldwide, which represents 110 km^2 a day (*i.e.* Paris city area; Morel et al., 2015; Seto et al., 2012). Since the 2000s, some initial attention has been paid to SOCS in urban soils. All over the world, research results have displayed a similar trend: in urban open (unsealed) soils, SOCS was generally higher than in agricultural soils, and could be in the same order of magnitude as the forest or grassland SOCS (Edmondson et al., 2012; Pouyat et al., 2009; Vasenev et al., 2014). However, the C stock estimation in cities should include the sealed soils, which represent a large part of highly human-altered areas (*e.g.,* nearly 64% in France in 2014; Service de la Statistique et de la Prospective, 2015). Thus, instead of SOCS, the soil organic carbon citywide totals (SOCCT, provided in mass units of carbon) should be estimated, to really understand the city's contribution to the Earth global stock of carbon and to be compared to non-urban soils (*e.g.,* forest and agricultural soils). Three barriers limit this understanding: first, the sealed soils are very difficult to sample, because the sampling campaigns often have to be based on opportunities (tree planting, Raciti et al., 2012; reconstruction projects, Yan et al., 2015). Then, urban soils are globally very heterogeneous and SOCCT may depend on the city, in link with its history, culture, geography and geological background. Finally, there is not one standardized method to describe and characterize urban soils: for example, the depths studied in the literature are very heterogeneous, the sampling can be performed either per horizon or per depth, and even the formula to calculate SOCS is not harmonized (per horizon, Huot et al., 2017; at a given depth, Pouyat et al., 2009; different methods to calculate SOCS, Edmondson et al., 2012; Yan et al., 2015). Hence, the possibility to compare results between cities or even with non-urban soils is restricted.

This study focused on two cities, New York City (NYC) and Paris (more precisely, the Grand Paris Metropolis), in order to compare their soil organic carbon content (SOC), SOCS, and SOCCT. Similar surface areas and global population characterize these two major cities of the world, but they display a different climate. They are also very different in terms of their basement geology, history and urban management policies. In each city, a database of urban soil properties, including SOC, has been built since the 1990s, but with extremely different assessment methods. In Paris, the database displays at this time thousands of data points collected by different actors, following non-standardized methodology. Some important parameters, such as bulk density, which is a main parameter to calculate SOCS, are not available. On the contrary, the NYC database was created following a standardized and pedological approach, but includes a smaller amount of data. In both cities, most of the samples were collected from open soils, and only a few were from sealed soils; however, the latter were kept in this study, because of their importance to calculate SOCCT and the difficulty to sample them, leading to a paucity of data.

Hence, the first objective of the present study was to compare SOC of open soils between these two major cities, at a given point in time. The second objective was to assess SOCS and SOCCT in the urban open soils, but also in sealed soils, through the example of these two cities of western industrialized countries. Finally, a discussion about the limits resulting from these different methodological approaches was proposed.

2. Materials and methods

2.1. New York City open soils

2.1.1. Study area

New York City (NYC; 40°42′46″N 74°00′21″W) is the most populated city in the United States with 8.5 million inhabitants in 2016 (U.S. Census Bureau). The city covers a land area of 772 km^2, divided into five boroughs (Brooklyn, Bronx, Manhattan, Queens, and Staten Island), four of which are located on islands. The total population density is 10,756 inhabitants km^{-2}. The elevation ranges from sea level to 122 m. The climate in the area is humid continental (Dfa according to Köppen climate classification system) to humid subtropical within the city (Cfa), characterized by cold winters and hot and humid summers, with annual mean precipitation of 1270 mm and mean air temperature of 12.9 °C (annual low and high temperatures: +8.9 °C and +16.8 °C). The NYC geomorphic setting includes three physiographic provinces: i) the crystalline bedrock (gneiss, schist, marble), which outcrops in Manhattan and the Bronx; ii) the Triassic and Jurassic sedimentary and igneous rocks in the northeastern part of Staten Island; and iii) the Atlantic coastal plain composed of unconsolidated deposits of late Cretaceous on Staten Island and Long Island (Brooklyn and Queens). Several glacial episodes deposited surficial materials for soil formation and shaped the landscape. Parent materials of NYC soils also include post-glacial deposits, such as tidal marsh deposits, organic materials and anthropogenic materials (NYC Soil Survey Staff, 2005).

By nature of its geography, the New York City has had limited room for expansion. Draining and filling of wetlands and extension of the shoreline have been common, often resulting in soils enriched in human artifacts and waste materials. The completion of the Erie Canal made the city the nation's commercial capital, and the population also grew rapidly during the 19th century due to immigration. To address the increasing demand for green spaces, several parks were established, including a large central park in Manhattan (Central Park), completed in 1876, Prospect Park in Brooklyn in 1867, as well as several areas “of a rural character” in the Bronx in the 1880s (New York City Department of Parks and Recreation, n.d.). In addition to parkland, comprised of both active recreational and “natural” areas, the larger contiguous parcels of open space in the city include cemeteries and golf courses.