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Effect of home construction on soil carbon storage-A chronosequence case study☆

Hamed Majidzadeh*, B. Graeme Lockaby, Robin Governo

School of Forestry and Wildlife Sciences, Auburn University, 602 Duncan Drive, Auburn, AL, 36849-5126, USA

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ABSTRACT

Urbanization results in the rapid expansion of impervious surfaces, therefore a better understanding of biogeochemical consequences of soil sealing is crucial. Previous research documents a significant reduction in soil carbon and nitrogen content, however, it is unclear if this decrease is a result of top soil removal or long-term soil sealing. In this study, soil biogeochemical properties were quantified beneath homes built on a crawl space at two depths (0–10 cm, and 10–20 cm). All homes, 11–114 years in age, were sampled in the Piedmont region of Alabama and Georgia, USA. This age range enabled the use of a chronosequence approach to estimate carbon loss or gain under the sampled homes. The difference in soil carbon content beneath homes and adjoining urban lawns showed a quadratic relation with age. Maximum C loss occurred at approximately fifty years. The same pattern was observed for MBC: C ratio suggesting that the soil carbon content was decreasing beneath the homes for first fifty years, then increased afterward. The average soil C and N content in the top 10 cm were respectively 61.86% (±4.42%), and 65.77% (±5.65%) lower underneath the homes in comparison to urban lawns. Microbial biomass carbon (MBC), and nitrogen (MBN) were significantly lower below the homes compared to the urban lawns, while bulk density and phosphorus content were higher beneath the homes.

1. Introduction

The global urban population increased from 746 million in 1950 to 3.9 billion in 2014 and is expected to surpass 6.4 billion by 2050 (United Nations et al., 2014). One important aspect of urban expansion is its effect on soil carbon (C) storage and the global C cycle (Pataki et al., 2006; Pouyat et al., 2009; West and Six, 2007). Urban expansion has changed native land use and land cover, and substantially increased the area covered by urban lawns and impervious surfaces such as buildings, roads and parking lots (Lorenz and Lal, 2009; Milesi et al., 2003; Scalenghe and Marsan, 2009; Shuster et al., 2005). While soil C storage in lawns has been widely studied in recent years (Kaye et al., 2006; Milesi et al., 2005; Pouyat et al., 2009; Rao et al., 2013), only a few field studies have investigated soil C storage beneath impervious surfaces. Impervious surfaces cover more than 580,000 km^2 globally (Elvidge et al., 2007). In the United States, the impervious surface area is greater than 83,337 km^2 which is larger than the total area of herbaceous wetlands (Elvidge et al., 2004). Installation of impervious surfaces may involve the removal of the top soil which is rich in organic matter (Lorenz and Lal, 2009; Yan et al., 2015), limits the input of organic matter, and alters soil physical properties such as bulk density, temperature, and moisture (Scalenghe and Marsan, 2009; Shuster et al., 2005). Nevertheless, the soil beneath these surfaces may still serve as habitat for microorganisms and insects, and provide space for rooting and leaching (Lehmann and Stahr, 2007).

The current estimations of soil C storage in urban areas are based on assumptions that range from 0 to 3.3 kg m^2 in top 100 cm for soil carbon beneath impervious surfaces (Cannell et al., 1999; Pouyat et al., 2006; Schaldach and Alcamo, 2007; Tomlinson and Milne, 2006). Studies, which have been sampled beneath impervious surfaces (Raciti et al., 2012; Wei et al., 2014a,b; Yan et al., 2015) revealed a significant decrease (up to 75%) beneath impervious surfaces but did not confirm the previously mentioned assumptions. Five studies sampling beneath impervious surfaces reported 2.29 kg C m^{-2} [top 15 cm, New York, U.S. (Raciti et al., 2012)]; 2.35 kg C m^{-2} [top 20 cm, Nanjing City, China (Wei et al., 2014b)]; 2.46 kg C m^{-2} [top 20 cm, Yixing City China (Wei et al.,

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* Corresponding author.

E-mail addresses: hzm0026@auburn.edu (H. Majidzadeh), lockabg@auburn.edu (B.G. Lockaby), goverrm@auburn.edu (R. Governo).

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2014a,b)]; and 3.55 kg C m^{-2} [top 20, Urumqi City, China (Yan et al., 2015)]. Normalized values to the top 100 cm (minimum value of 5.8 kg C m^{-2} in New York reported by Raciti et al., 2012) reveals a significant underestimation of C storage in the studies where sampling did not occur. Although these studies revealed the underestimation of carbon storage beneath impervious surfaces, it is not clear if changes in soil properties beneath impervious surfaces are the result of top soil removal and the initial disturbance or long-term soil sealing that alters soil properties over time. The true gain or loss of carbon beneath these surfaces over time following the disturbance has not been investigated. Thus, a chronosequence study is essential to address this knowledge gap. Moreover, these studies have only sampled beneath road pavements, paved residential squares (Raciti et al., 2012; Wei et al., 2014a,b), and residential driveways (Edmondson et al., 2012; Yan et al., 2015), and have not considered other types of impervious surfaces. For instance, homes cover more than 18,000 km^2 of the United States (U.S. Census Bureau, 2013), which would be approximately 20% of the total impervious surface in the U.S. (Elvidge et al., 2007). Yan et al. (2015), showed that the soil C storage decreased with distance from the edge of impervious surfaces, suggesting that soil C storage beneath narrow impervious surfaces (i.e. sidewalks, residential pavements) may be higher than impervious surfaces with a larger footprint (i.e. buildings and parking lots). Multi-unit homes and tall building construction involve intensive disturbances as well as major top soil removal and is assumed to have zero carbon storage (Yan et al., 2015). However, only 23% of the homes in the United States are multi units. More than 53% of the houses in the United States are manufactured homes, homes built on crawl space, and homes built with a basement (U.S. Census Bureau, 2013) and the zero assumption might not be true for these homes.

In this study soil carbon storage and influential parameters affecting it such as soil nitrogen (N), microbial biomass, volumetric water, and bulk density were quantified beneath homes built on a crawl space that ranged from 11 to 114 years, and compared to adjoining urban lawns. Specific objectives of this study included: 1) determination of C and macronutrient content within 0–10, and 10–20 cm depths beneath homes built on a crawl space and associated lawns; 2) determination of loss or gain of carbon beneath impervious surfaces and in particular beneath homes over time and 3) quantification of soil biogeochemical properties such as soil nitrogen, microbial biomass, bulk density, and soil volumetric water and their interaction with soil carbon beneath the homes and in urban lawns.

2. Materials and methods

2.1. Study area

Samples were collected from Auburn, AL (latitude 32.60° N longitude 85.48° W), and Opelika, AL (latitude 32.64° N longitude 85.38° W), and Barnesville, GA (latitude 33.05° N longitude 84.15° W). Auburn and Opelika are located on the fall line between the Coastal Plain and the Piedmont Plateau. Barnesville is situated in the Piedmont upland section of the Piedmont province of the Appalachian Highlands (Miller and Robinson, 1995). The region has a mean annual air temperature of 17.4 °C and an average precipitation of 1337 mm.

Sampling sites were carefully selected to ensure their representativeness. To that end, all soil cores were collected from the Piedmont plateau with two similar taxonomic classes of Fine, kaolinitic, thermic Typic Kanhapludults (Pacolet, and Cecil series) and Fine-loamy, kaolinitic, thermic Typic Kanhapludults (Marvin series). Moreover, the sampled homes were built on the native soil with no correction or relocation of soil beneath them. However, further studies with more sample numbers, covering various soil and plant types can reduce the uncertainties in the soil beneath impervious surfaces. Trees common on urban properties included red maple (*Acer rubrum* L.), pecan (*Carya illinoensis*), sweetgum (*Liquidambar styraciflua* L.), oaks (*Quercus* spp.), loblolly pine (*Pinus taeda*), and shortleaf pine *(Pinus echinata).* Turf grasses were mostly Bahiagrass, Bermudagrass, Zoysiagrass, and Centipede.

2.2. Soil properties

Twenty-four homes ($n = 17$ in AL and $n = 7$ in GA), constructed on crawl space, were sampled. At each homestead, two soil cores at two depths (0–10 cm and 10–20 cm) were collected for chemical analysis in the crawl space ($n = 4$) and the adjoining lawns ($n = 4$), totaling 192 soil cores collected from the 24 homes. All soil cores collected from beneath the homes were at least two meters from the exterior wall. Bulk density samples were collected next to each chemical soil sample location. The bulk density samples were dried at 105 °C, and soil bulk density was calculated using the core method (Soil Survey Laboratory Staff, 2004). The air-dried soil samples were used to measure pH in a 0.01 M solution of calcium chloride using an automated LabFit AS-3000 pH analyzer. The measured values were converted to 1:1 mixture of soil:water values by adding a conversion factor of 0.6. Using a diluted solution of salts to measure soil pH will result in more stable values between seasons and years (Kissel et al., 2009). The Mehlich-1 method (Jones, 1998) was used to quantify concentrations of extractable P, Ca, K, Mg, Mn, and Zn using inductively coupled plasma optical emission spectrometry (ICAP61E, Madison, WI). Total C and N were measured using a PerkinElmer 2400 Series II CHNS/O analyzer (PerkinElmer, Waltham, MA). Soil gravimetric water (W_m) calculated by drying 10 g of soil in the oven at least for 24 h at 80 °C and using the following equation:

$$W_m = \frac{\textit{Moist soil weight} \ - \textit{dry soil weight}}{\textit{dry soil weight}}$$

Soil percent volumetric water (Wv) was quantified by multiplying W_m and soil bulk density.

2.3. Microbial biomass

The chloroform-fumigation method (Vance et al., 1987) was used for measuring soil microbial biomass C, and N. Soil samples were homogenized by sieving through a 2 mm mesh sieve and divided into two sets of 18.5 g. The first set was fumigated by exposing soil to alcohol-free chloroform for 24 h. Fumigated and unfumigated samples were extracted with 100 mL 0.5 mol L^{-1} K_2SO_4 for 30 min. The extracts were filtered (Whatman no. 42 filters) and then frozen. After thawing, the samples were analyzed for organic C and total N using a Shimadzu TOC-V and total N combustion analyzer (Shimadzu Scientific Instruments, Columbia, MD). The differences between fumigated and unfumigated samples represent microbial C and N.

2.4. Statistical analysis

“R” software, version 3.1.2 was used for all statistical analysis in this study. A linear mixed-effects model using the nlme package of “R” software was utilized to compare soil properties beneath the homes and in urban lawns. The Tukey's honestly significant difference (HSD) following an analysis of variance (ANOVA) test was used to differentiate the means (Agricola package, $\alpha = 0.05$), for soil C, N, microbial biomass C and N, and bulk density between urban lawns and beneath the homes at two depths. There was an