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Soil Organic Carbon Transformation and Related Properties in Urban Soil Under Impervious Surfaces*[1]

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ABSTRACT

Installation of impervious surface in urban area prevents the exchange of material and energy between soil and other environmental counterparts, thereby resulting in negative effects on soil function and urban environment. Soil samples were collected at 0–20 cm depth in Nanjing City, China, in which seven sites were selected for urban open soils, and fourteen sites with similar parent material were selected for the impervious-covered soils, to examine the effect of impervious surface on soil properties and microbial activities, and to determine the most important soil properties associated with soil organic carbon (SOC) transformation in the urban soils covered by impervious surfaces. Soil organic carbon and water-soluble organic carbon (WSOC) concentrations, potential carbon (C) and nitrogen (N) mineralization rates, basal respiration, and physicochemical properties with respect to C transformation were measured. Installation of impervious surface severely affected soil physicochemical properties and microbial activities, *e.g.*, it significantly decreased total N contents, potential C mineralization and basal respiration rate ($P < 0.01$), while increased pH, clay and Olsen-P concentrations. Soil organic carbon in the sealed soils at 0–20 cm was 2.35 kg m^{-2}, which was significantly lower than the value of 4.52 kg m^{-2} in the open soils ($P < 0.05$). Canonical correlation analysis showed WSOC played a major role in determining SOC transformation in the impervious-covered soil, and it was highly correlated with total N content and potential C mineralization rate. These findings demonstrate that installation of impervious surface in urban area, which will result in decreases of SOC and total N concentrations and soil microbial activities, has certain negative consequences for soil fertility and long-term storage of SOC.

Key Words: carbon mineralization, microbial activity, soil fertility, soil sealing, water-soluble organic carbon

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The rapidly expanding urban areas have caused large areas of agricultural, pasture, or forest soil to be changed to urban soil (Pan and Zhao, 2007; Su *et al.*, 2011). Compared to natural soil, urban soil is more perturbed by human activities, *e.g.*, sealing, compaction, degradation, land filling, and mixing (Lorenz and Lal, 2009). Sealing of soils, described as land covering by housing, roads, or other construction work, is one of the main characterizations of urbanization and changes of urban land cover. It hinders chemical reactions and the exchange of material and energy between soil and other environments, thereby resulting in negative impacts on soil functioning and urban environment (Scalenghe and Ajmone-Marsan, 2009). In the Thematic Strategy for Soil Protection, released by the European Commission (2006), soil sealing is identified as one of the eight most important threats to soil. In the previous studies for urban soil, physical and chemical properties (Schleuβ *et al.*, 1998; Lehmann and Stahr, 2007; Sela *et al.*, 2012), biochemical characteristics (Lorenz and Kandeler, 2005; Zhao *et al.*, 2012), and some properties with respect to contamination (Lu *et al.*, 2003; Beesley and Dickenson, 2011) were largely investigated. This information was mainly for urban open soils (without a sealing surface), although large areas of urban soil are covered by tar, pavement, or buildings. Details of properties and quality of urban impervious-covered soil, and the effects of soil sealing on biogeochemical cycling, especially the carbon (C) cycle and biogeochemical components in urban areas are still poorly understood.

Changes in land use/cover that are commonly associated with urbanization can influence the amount, chemical form, and spatial distribution of C stocks (Scalenghe *et al.*, 2011). Researchers have demonstrated that an increase in population density in urban areas might result in an increase in the proportion of total C stored in anthropogenic stocks accompanied

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by a major shift in stocks from organic to inorganic C (Scalenghe *et al.*, 2011). Churkina *et al.* (2010) reported that C storage capacity of urban areas was similar to that of forests, in which urban open soil stored the largest part of C pool. Unfortunately, the information of concentration and decomposition of soil organic carbon (SOC) in urban soil underneath the impervious areas is not available, giving difficulties for estimating C storage at regional or global scale (Pouyat *et al.*, 2006). In the impervious-covered soil, exchange of gases between the soil and atmosphere is limited, whereas interaction still exists between the soil and groundwater, implying that water-soluble organic carbon (WSOC) might play a key role in determining the turnover and retention of SOC in impervious areas. Soil properties, *e.g.*, pH, clay, total nitrogen (TN), and calcium carbonate, are likely to play a more significant role in affecting WSOC turnover in the impervious-covered soils as the importation of plant litter is limited. In addition, soil microorganisms may be more important in controlling SOC degradation and nutrient cycling, as the rare soil fauna and flora exist in the impervious environment. However, so far, the information about the link between SOC transformation and soil biochemical properties in the impervious-covered soils is still limited.

Here soil samples were collected from the impervious and open sites at 0–20 cm soil depth in Nanjing City, China to investigate SOC transformation, physicochemical properties, and microbial activities in urban soils. By comparing soil properties and key process between the urban impervious and open soils, it is easy to find the main factors that were significantly changed after soil sealing and identify the critical soil properties and functions that play major role in affecting SOC transformation (Zhao *et al.*, 2012). The objectives of this study were to examine the effect of soil sealing in urban area on soil properties and microbial activities, and to determine the most important soil properties associated with SOC transformation in the urban sealed soils.

MATERIALS AND METHODS

Study area

The study area was located at 31°14′–32°37′ N and 118°22′–119°14′ E in Nanjing City, China. The study area is on the plain of the lower reaches of the Yangtze River, and has a subtropical and humid monsoon climate with four distinctive seasons: dry and rainless in spring, warm and rainy in summer, crisp in autumn, and dry and mild in winter. The annual average temperature is 15.4 °C with the lowest mean monthly temperature occurring in January (−13.1 °C) and the highest in July (39.7 °C). The mean annual precipitation is 1 106 mm.

The soils in the study area mainly develop from the alluvium of the Yangtze River and are perturbed by human activities (Gong *et al.*, 1999). According to the World Reference Base for Soil Resources (FAO, 2006), they can be classified as Technosols or Anthorosols. The impervious-covered soils collected have impermeable surfaces that cover more than 95% of the horizon extent, in which exchanges of gas, water and sunlight between soil and atmosphere were supposed to be rare. Generally, the soils under impervious surfaces have block structures along with large abundance of artifacts such as bricks, tiles, and ceramics. The original soil horizons under road pavements were often completely destroyed or removed. For the open soils, the upper soil layers are also heavily influenced by anthropogenic activities and are always covered with a former natural soil and about 10% volume of artifacts. The vegetation on the open soils is primarily grass or bush-grass.

Nanjing has had a rapid urbanization in recent decades. Before 1949, the urban zone was about 42 km^2, with a population of only about 700 000. However, with social-economic development, the population in Nanjing increased to 5 459 700 by 2009. Simultaneously, the urban area has increased to 577 km^2 mainly at the expense of agricultural land. Urban land cover type and environment have been altered in Nanjing due to the rapid economic development and drastic increase of urban population. For example, natural forest vegetation was replaced by bush-grass communities, and most green areas have been replaced by impervious land. This provides good conditions to study the changes of properties of urban soil after sealing.

Soil sampling

The soils in this study were sampled in April, 2011. Seven sites were selected for urban open soils, and fourteen sites with similar soil parent material were selected for urban impervious-covered soils (Fig. 1). Each sample, consisting of 3 separated soil cores (5 cm in diameter), was taken from 0–20 cm depth. In the impervious sites, we punched holes on the hard ground and removed the padding to make the covered soil accessible for sampling. After careful removal of the litter layer, roots, artifacts and stones that corresponded about 20%–40% of volume for impervious soils and 10% for open soils, the samples from the same layer of each plot at each site were combined to give one sa-