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Soil Organic Carbon and Nitrogen Status in Peri-urban Landscape

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ABSTRACT
Soil organic carbon (SOC) and nitrogen (N) are imperative to soil quality and are greatly influenced by the dynamic land use patterns in urbanizing peri-urban landscapes. The present study assessed the status of SOC and total nitrogen (TN) in 45 land parcels from five land use types in the peri-urban landscape of the Ghaziabad district. Our results showed the average SOC and TN concentration ranged from 0.17 to 5.49% and 0.006 to 0.36%, respectively. Overall, SOC, TN and C:N ratio showed wide spatial variability across the sites and land use types indicating their heterogeneous distribution pattern in the study area.

Keywords: Peri-urban, Urbanization, Land use change, Soil organic carbon, Total nitrogen

INTRODUCTION

Soil is a major source of biogenic nutrients carbon (C) and nitrogen (N) in the terrestrial ecosystem (Anonymous 2013). Considering their importance in sustaining the ecological processes and productivity of the terrestrial ecosystem, SOC and N have been widely identified as critical factors for the maintenance of soil fertility and health (Schlesinger 1990, Zhu et al. 2021). The terrestrial pool of C and N are highly subjective to human-induced environmental changes. Land use and management activities have been shown to have significant impacts on the availability and form of C and N (Smith et al. 2016). Anthropogenic activities associated with complex and multifaceted urbanization processes directly affect the concentration, chemical form, and distribution pattern of biogenic soil nutrients, i.e., C and N (Pickett and Cadenasso 2009, Yang et al. 2021). The composite sources of nutrients C, N and phosphorus (P) in urban areas such as industrial and domestic waste, fossil fuel burning, NOx deposition and fertilizer/ pesticide application further influence their stoichiometric relations (Yang et al. 2021). While increasing built-up surfaces may result in C loss by replacing organic matter-rich topsoil with artificial materials, the establishment of urban green spaces may significantly enhance the C storage potential (Vasenev and Kuzyakov 2018, Lorenz and Lal 2009). Although the accumulation of trace elements in urban soils has been extensively studied (Nannoni et al. 2014), the changes in pools and fluxes of biogenic elements C and N are largely obscured. Intervening urban landscapes like peri-urban regions are of particular concern because of their dynamicity in land use patterns. Extension of peri-urban settlement onset by urban-led demand for space and resources creates a complex pattern of land use and land cover differing in their biophysical characteristics (Antrop 2000, Hermosilla et al. 2012). Ghaziabad is one the fastest-growing satellite town in India with a million-plus population (Mayors 2014). It has experienced drastic transformation in land use patterns, shifting from rural hinterlands to a prominent industrial centre dominated by built-up utilities in the last decade, due to its good connectivity with urban cities. (Randhawa and Marshall 2014). Hence, the present study aims to investigate the status of soil organic carbon and nitrogen content in the peri-urban setting of the Ghaziabad district, which presents huge heterogeneity in its land use pattern and anthropogenic activities related to socioeconomic development processes.

MATERIAL AND METHODS

Site selection and soil sampling

The study was conducted in the rapidly urbanizing landscape of Ghaziabad district, located in the upper region of the Gangetic plain (28º36’–28º55’ N, 77º12’–77º42’ E) with an area of 1179 km^2. This area belongs to semi-arid ecoregion with a temperate to tropical climate. The soil texture ranges from sandy to stiff clay (Anonymous 2009). To assess the status of soil organic carbon (SOC) and total nitrogen (TN) content, a total of 45 land parcels from different locations (differing in their distances to the urban centre) were sampled for the present study. To cover the heterogeneity of peri-urban settings, the sampling scheme used for sample collection was random. Further, we classified these 45 land parcels into five representative land use categories (i.e., park, residential, industrial, agriculture and bare land). At each site, soil samples were collected in triplicates from three adjacent sampling points, from 0-30 cm soil depth. Three additional undisturbed soil samples were taken from each sampling point for bulk density measurement using a soil corer of known volume. Soil samples were brought to the laboratory, passed through 2 mm sieve and air-dried to estimate the soil physico-chemical properties.

Soil analysis

Soil bulk density (BD) was measured using the soil corer method based on the weight of oven-dried soil divided by the volume of soil corer used. Soil moisture content (SMC) was estimated using the gravimetric method by oven drying soil at 105°C for 12 h and calculating mass difference as a percentage of oven-dried soil. Soil pH was determined by dissolving field moist soil in distilled water in the ratio of 1:2.5 using pH meter (EUTECH pc 800) (Anderson and Ingram 1994). SOC and TN in the air-dried soil were quantified using the CHNS analyser (Elementar vario).

To describe the variability in the data set, standard deviation and coefficient of variation (CV) were computed. Analysis of variance (ANOVA) was performed to analyse the significance of spatial variation in studied soil physico-chemical characteristics across the selected sites. Pearson correlation analysis was done to observe the interrelationship among the soil properties using IBM SPSS (version 20) software.

RESULTS

Mean, standard deviation and coefficient of variation (CV) of each variable measured across all the sites revealed notable spatial variation in soil properties in the peri-urban region of Ghaziabad (Table 1). SOC, TN and C:N ratio with CV values of 49.6, 65.5 and 84.2%, respectively, showed wide variation, while soil pH and BD showed comparatively lower variations (6.8 and 13.7%, respectively). With an average value of 7.42, the soil pH varied from neutral to moderately alkaline. SOC content and C:N ratio ranged from 0.17% to 5.49% and 1.65 to 117.8, respectively, and were on average below the recommended range for most of the soil samples in the study area. Although TN concentration varied between 0.006 and 0.36%, it was observed to be within the range (>0.1%) considered conducive for efficient plant growth.

Our study showed significant variation in SOC and TN across the sites and land use types (Fig. 1, Table 2). Among all the sites SOC and TN content was maximum at site 22 dominated by residential land use and minimum at sites 13 and 33, respectively. The land use-wise comparison showed that soil samples from residential and park land use contained significantly higher SOC content than agricultural land use while industrial and bare land had comparatively lower SOC content. TN content was maximum in residential land use followed by parks and agricultural land while bare land and industrial land use had the lowest. Conversely, C:N ratio was lowest in park while variation between other land use classes was non-significant. Correlation analysis showed that SOC and TN was strongly and positively correlated with SMC ($p>0.01$), while negatively correlated with soil BD ($p<0.01$) (Table 3). SOC and TN content also exhibited a negative correlation with soil pH ($p<0.05$).

DISCUSSION

Dynamic urban development processes and corresponding anthropogenic activities in the peri-urban landscapes create immense pressure on soil resources. As a consequence, the soil quality and related soil attributes under these enterprising regions may exhibit substantial changes depending on the reigning anthropogenic activities (Pickett and Cadenasso 2009). The present investigation showed that the mixed land use pattern of the peri-urban landscape had a significant impact on soil physicochemical properties. We observed that soil BD in more than 95% of samples exceeded the recommended value of 1.5 gm cm^{-3} indicating the

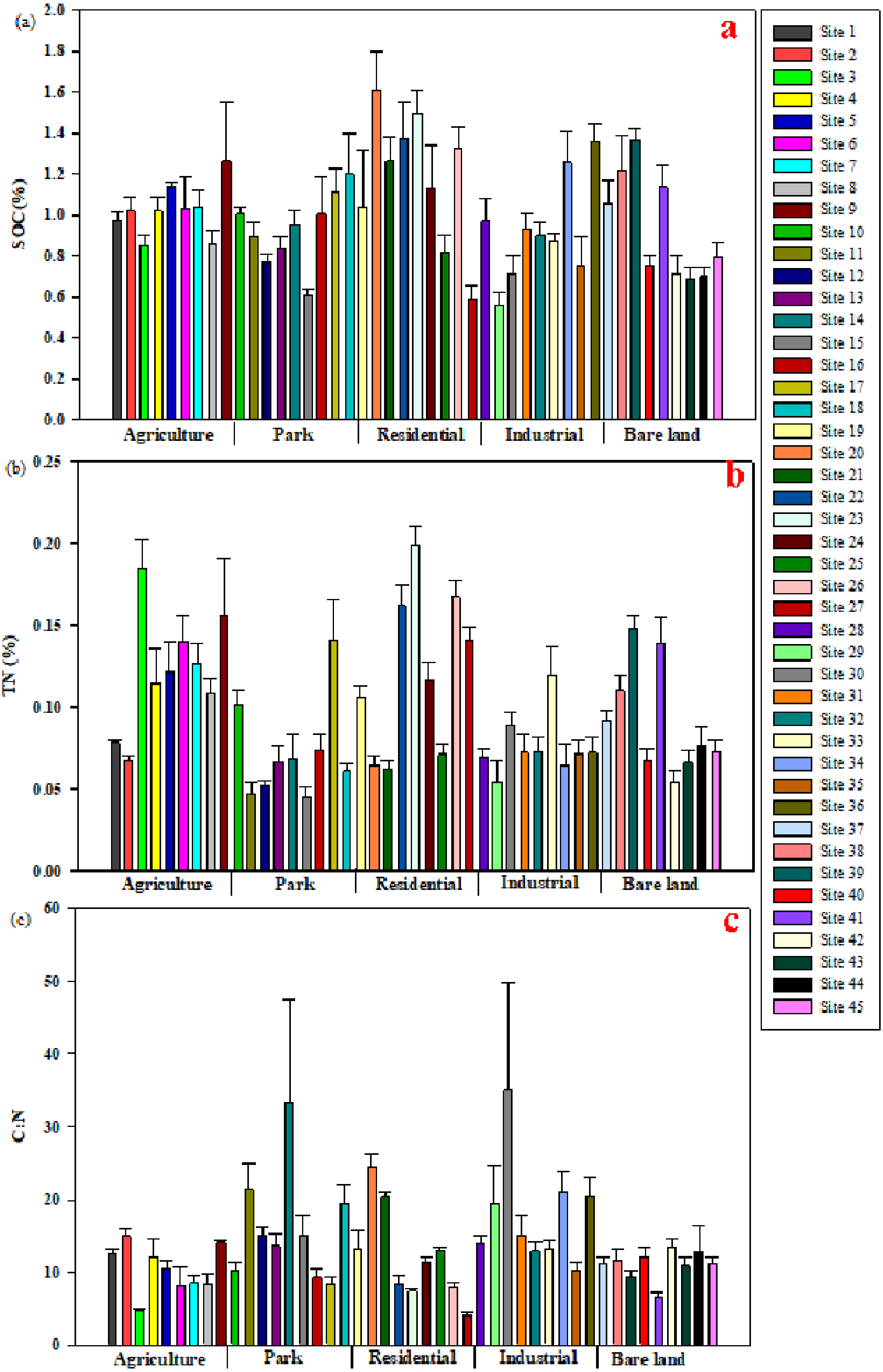

Figure 1. Soil organic carbon (SOC) (a), soil total nitrogen (TN) (b) and C:N ratio (c) in different sites belonging to five land use types. (Data presented are mean ± SE)

Table 1. Descriptive statistics of soil properties (0–30 cm layer) of peri-urban region

Soil properties	Mean	Standard error	Minimum	Maximum	Median	CV (%)	Recommended range*
pH	7.47	0.03	6.05	9.13	7.42	6.82	7
SMC (%)	14.76	0.27	5.39	27.88	15.09	36.24	-
BD (g cm^{-3})	1.40	0.02	1.00	1.96	1.39	13.69	1.5
SOC (%)	1.04	0.03	0.17	5.49	0.96	49.62	>1
TN (%)	0.10	0.00	0.006	0.36	0.09	65.52	0.1–0.15
C:N ratio	13.63	0.57	1.65	117.8	11.75	84.23	24:1

SMC, soil moisture content; BD, bulk density; SOC, soil organic carbon; TN, total nitrogen
* According to Whitcomb (1987), Hunt and Gikes (1992), Horneck et al. (2011)

Table 2. Analysis of variance (ANOVA) for soil organic carbon (SOC), total nitrogen (TN) and C:N ratio across the sites and land use classes

Factor	SOC	TN	C:N ratio
Land use	9.65**	12.11***	3.292*
Site	39.08***	3.49***	5.11***
Land use × Site	3.31**	2.92**	2.22*

P<0.05, **P<0.01, ***P<0.001, ns non-significant

Table 3. Pearson correlation between soil properties

	BD	SMC	pH	SOC	TN
SMC	-0.183*				
pH	0.161	0.160**			
SOC	-0.218*	**0.488****	-0.121*		
TN	**-0.293****	0.**312****	-0.136*	**0.491****	
C:N	0.054	-0.119*	-0.035	0.106*	**-0.454****

* and ** represent significance at the 0.05 and 0.01 (2-tailed) level, respectively. BD, bulk density; SMC, soil moisture content; SOC, soil organic carbon; TN, total nitrogen, C:N, carbon to nitrogen ratio

possible soil compaction (Schoenholtz et al. 2000). This may be attributed to the combination of factors including the replacement of vegetation cover by built-up areas, mechanical disturbances from construction activities and vehicular trampling that are frequent in the urban and adjoining peri-urban landscapes (Scharenbroch et al. 2005, Yang and Zhang 2011, Lorenz 2015). The soil of the studied peri-urban region of Ghaziabad was found to be moderately alkaline (>7) rendering it unsuitable for effective plant growth. This is in consonance with previous studies which reported high pH values in urban soils and linked soil alkalinity to the disposition of alkalizing material such as brick, cement, and mortar (Pouyat et al. 2007, Zhao et al. 2012, Li et al. 2013, Mao et al. 2014).

Spatial distribution of SOC and TN

Characterization of soil samples collected from different locations of peri-urban region Ghaziabad highlighted notable spatial variability in SOC and TN. As revealed by descriptive analysis, the high dispersion in C and N content across the area in our study could be due to the inclusion of a divergent set of sites varying from sites with no vegetation cover and management (bare land) to well-managed sites (park). The mean value of SOC content was found to be below the range recommended to support good plant growth, which points to a general lack of organic matter in the soils of the region (Li et al. 2013). This study demonstrated that more than 75% of sites in the peri-urban landscape had greater SOC concentrations than those in the rural hinterland (Verma et al. 2013, Kumar et al. 2016). This can be explained by anthropogenic activities such as the establishment of recreational areas with high green coverage, organic waste input from residential areas, and disposal of waste from industrial and residue from fossil fuel combustion contributing to relatively stable forms of carbon which further may have implications on nutrient cycling (Yang et al. 2021, Canedoli et al. 2020). Urban land use and accompanying anthropogenic activities have been shown to greatly influence the C fluxes in urban and peri-urban soils (Pouyat et al. 2010, Upadhyay and

Raghuvanshi 2020). The recorded TN content in the present study was comparable to the critical level of nitrogen for efficient plant growth, indicating it is not a limiting factor (Horneck et al. 2011). Urban areas are seen as hotspots for N accumulation contributed by inadvertent N sources including NOx emissions from combustion processes in automobiles and industries, wastewater effluent and extensive use of fertilizers in urban greenspaces, (Zhu et al. 2004, Kaye et al. 2006, Fang et al. 2019). Studies from different cities also evidenced higher C and N levels but with great variability in urban landscapes (Raciti et al. 2011, Edmondson et al. 2014, Vasenev et al. 2013, Smith et al. 2018, Yang et al. 2021).

Spatial variation with respect to different land use categories showed that SOC and TN content was apparently lower in the industrial and bare land in comparison to other anthropogenic land uses, perhaps due to greater surface horizon destruction, low or absent input from vegetation cover, removal of top layer contributing to the reduction of organic matter (Zhao et al. 2012, Livesley et al. 2016, Pereira et al. 2021). Contrarily, the higher SOC and TN content in well-managed green spaces (residential and parks) possibly reflects the synergistic impact of direct and indirect factors including human activities (vegetation management practices, fossil fuel combustion and disposal of domestic waste) and natural processes on the influx and retention of SOC and TN as asserted by other studies also (Vasenev and Kuzyakov 2018, Canedoli et al., 2020). Soil collected from residential sites had relatively higher TN content than the park soils. This can be related to specific sources of N in residential areas such as the deposition of NOx from automobiles, domestic waste, urine and faeces from pets (Lorenz and Lal 2009). Corresponding to our result, Vasenev and Kuzyakov (2018) also reported relatively high N stock in residential soils. Agricultural soils were found to have lower SOC and N concentrations, which was presumably caused by regular tillage, high decomposition, and harvesting of biomass and grains. (Upadhyay et al. 2021).

The addition of extraneous material and removal of parent material leading to alteration in C and N pools in the urbanized landscape may greatly alter C:N ratio which reflects the quality of the available substrate and their decomposition (Lorenz and Kandeler 2005). The observed wide variation in C:N ratio could be partially explained by the varying nature of organic matter ranging from natural humic to completely anthropic material at study sites belonging to different functional zones (Lorenz and Lal 2009). Additionally, observed differences in the C:N ratio across the land use classes indicate a significant influence of urban-related anthropogenic activities on nutrient stoichiometry. The low C:N ratio in park land use in our study may enhance the abundance and activity of nitrifying bacteria, which may lead to N loss in the form of NO_3 (Zhang et al. 2010). C:N ratio is a crucial factor in influencing microbial activity and nutrient availability (Wan et al. 2020). Livesley et al. (2016) hypothesised that soil with a low C:N ratio may have the capacity to alleviate the N enrichment in urban greenspaces which is speculated to have an impact on crucial soil processes like decomposition and nutrient cycling.

SOC and N are affected by a number of factors including soil physicochemical properties like soil aggregate stability, soil particles and vegetation cover contributing to root exudates and carbon input (Zhu et al. 2021). We identified SMC as the key soil physical properties associated with the availability of SOC and TN. A positive correlation between SOC and SMC implies that maintenance of optimum soil conditions by management practices like irrigation may increase the possible C storage potential of urban soil as in the case of the park and residential land use.

CONCLUSION

Both SOC and TN showed significant variation across the sites. Observed spatial variability across the region at regional scales observed in our study indicates the heterogeneous distribution of soil properties engendered by locally relevant urban factors. Therefore, more efforts are required to comprehend the magnitude and extent of the influence of urban land use on biogenic nutrients for better maintenance of soil conditions in urban systems.

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Authors' contributions: MC completed data acquision, analysis and prepared the first draft. KSR supervised the work. Both the authors read and approved the manuscript.

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