African Journal of Agricultural Research Vol. 7(18), pp. 2810-2817, 12 May, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR11.1725
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

Dissolved organic carbon and its controls of urban soil in Hefei, Eastern China

Xiao Tao[1], Hongfei Zhao[1], Kai Zhang[1,2] and Xiaoniu Xu[1]*

[1]Department of Forestry, Anhui Agricultural University, Hefei 230036, China.
[2]Post-doctoral station, Tianjin TEDA Landscape Construction Co., Ltd., Tianjin 300457, China.

Accepted 17 January, 2012

Soil dissolved organic carbon (DOC) plays an important role in biogeochemical cycling and energy transformation in the ecosystem. The objectives of the study are to assess the impacts of land use types and planation modes on carbon dynamics and to determine the major soil factors influencing the DOC concentration in urban soils. The spatial pattern of DOC was studied with soil samples collected from a suburban natural forest park and urban green-lands (including campus green-land, park green-land, residential green-land, roadside green-land and factory green-land) in Hefei, Eastern China. The results showed that green-land types significantly impact on the DOC concentration ($P<0.05$) and that DOC concentration in suburban forest (44.28 mg kg^{-1}) is obviously higher than that in the urban site (27.45 mg kg^{-1}). The soil under arbor-lawn mode had the highest DOC concentration with an average of 44.96 mg kg^{-1} at the 0 to 30 cm soil depth. Land use change resulted in an obvious variation in soil DOC concentration (0 to 30 cm) across the environmental gradient. Results from regression analysis indicate that soil DOC concentration is significantly and positively correlated with soil moisture, soil NH_4^+-N, microbial biomass nitrogen (MBN), dissolved organic nitrogen (DON), and negatively correlated with soil pH, bulk density, electric conductivity and total phosphorus. It is suggested that the expansion of the urban area may lead to the loss of DOC in the soil.

Key words: Urban soil, dissolved organic carbon, green-land types, planation mode, plant-soil interaction.

INTRODUCTION

Human intervention could interrupt or adjust the process of soil biogeochemical cycles, alter microbial metabolism and the intensity, quality, process of original soil nutrient cycles, leading to the changes of soil biological quality (Kong et al., 2006). However, it is not sufficient and timely to use total content of nutrients to evaluate the changes of soil quality, especially when the soil has a high content of nutrients (Maria, 2005). So it is essential to select a sensitive indicator for monitoring soil quality (Haynes, 1999). As one part of active organic carbon, dissolved organic carbon (DOC) has been considered to be one of the key indicators of carbon availability to soil micro-organism (Iqbal et al., 2010), due to its quick circulation, ready availability for uptake, and sensitivity to environmental changes. In addition, DOC plays an important role in the soil formation, nutrient element (e.g. N, P and S) cycles, heavy metal adsorption, degradation of organic pollutants, mineral weathering, microbial growth and metabolism (Dawson et al., 1978; Qualls et al., 1991; Kalbitz et al., 2000).

With the acceleration of global-scale urbanization, urban soils are sources of environmental risks and sometimes the pools of aerial pollutants (Zhang et al., 2010). Urban soils experience dramatic changes, for cities themselves represent microcosms of changes in land use and plant cover, biogeochemical cycles, climate, and biodiversity, which eventually alter the soil carbon cycling (Grimm et al., 2008). Spatial-temporal patterns and the controlling factors of DOC have been quantified in forest, grassland and agricultural ecosystems (Kalbitz et al., 2000; Michalzik et al., 2001; Dou et al., 2008), but seldom in urban ecosystems.

Hefei was chosen as the case study because it is

*Corresponding author. E-mail: xnxu61@yahoo.com.cn or bbhyyxiaotao@gmail.com.

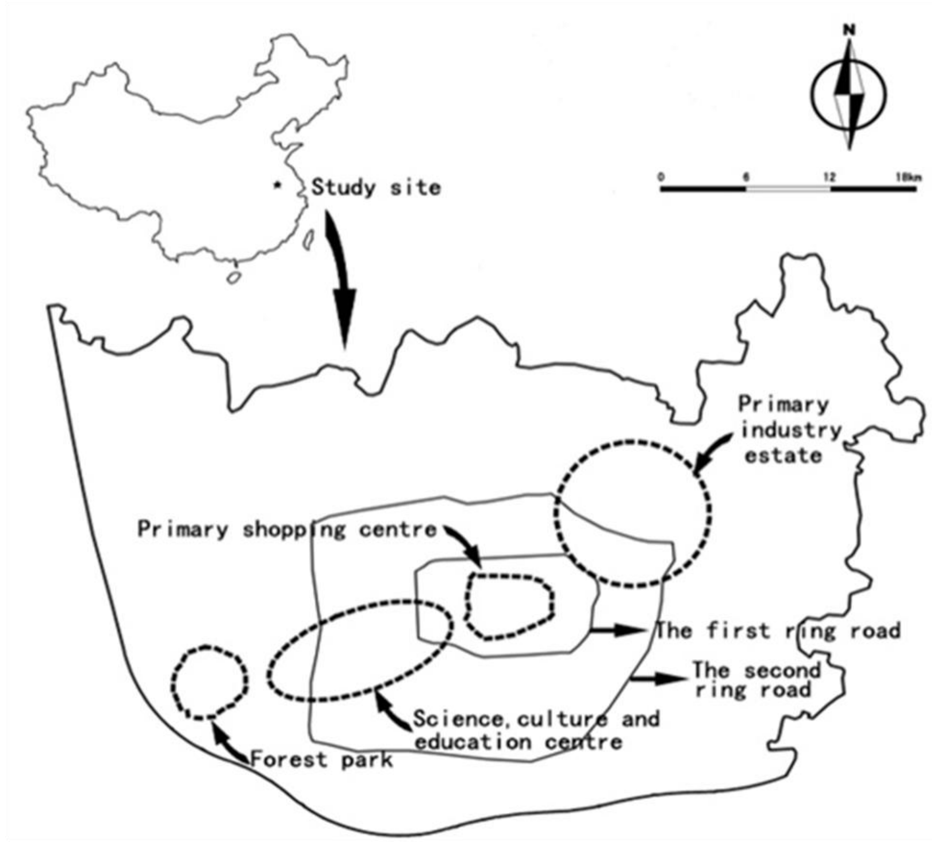

Figure 1. Sampling locations and functional areas in built-up districts of Hefei, PR. China.

undergoing rapid expansion. This transformation could lead to the changes in soil nutrients especially DOC concentration. The primary objective of this study is to explain the DOC spatial variability, assess the effect of urbanisation on the soil DOC concentration, and to determine the major soil factors controlling DOC dynamics in urban soil.

MATERIALS AND METHODS

Study sites

This study was conducted in Hefei, eastern China (117°11′, 117°22′ E; 31°48′, 31°58′ N) (Figure 1). The total area of the city is 7266 km^2, with 34.5% green land ratio, 39.5% greenery coverage and 9.3 m^2 public green areas per capita in the urban area. The climate of the region is north subtropical monsoon with mean annual temperature of 15.7°C. The mean annual precipitation is 1000 mm and mean total solar radiation is 119 kcal cm^{-2}. The zonal soil type is yellow brown soil which corresponds to Alfisols according to the USDA classification (Soil Survey Staff, 1999).

Soil sampling

In accordance with city administrative planning, the sample sites were located in built-up areas of the city. In January 2010, soils were sampled in different types of green lands that belong to the different periods excluding the newly-reconstructed ones. In order to have a better understanding of the changes of urban soil under urbanization, a suburban site, Shushan natural forest park, was studied as a reference point. The green-land types included forest park, campus green-land, park green-land, residential green-land, roadside green-land and factory green-land.

Planation modes included arbor-lawn, shrub-lawn, lawn and arbor-shrub-lawn modes. All the soil sections were divided into three layers according to the soil depth, which was 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm, respectively. At each site, the soil was sampled using an auger with an internal diameter of about 6.0 cm, three replicates were randomly selected, and finally, a total of 536 samples were collected. The soil properties were summarized in Table 1.

Chemical analysis

All the samples in the present study were analyzed for soil electric conductivity, soil bulk density, soil moisture content, total phosphorus, soil pH (H_2O) and pH (KCl). The concentrations of DOC and total dissolved nitrogen (TDN) were measured in solution by shaking 30 g of field-moist soil with 50 ml 2 M KCl for 15 min in 100 ml polypropylene bottles on a reciprocating shaker at a speed of 200 rev min-1 (Jone and Willett, 2006), and then was determined by MultiC/N3100 TOC analyser. This solution was also used for the measurement of NO_3^-–N and NH_4^+–N by FIAStar5000 flow injection analyser. Microbial biomass nitrogen (MBN) and microbial biomass carbon (MBC) were determined by the chloroform fumigation-extraction method (Brookes et al., 1985; Wu et al., 1990). The following equation was used for estimate:

$$MBC = 2.22EC, \quad (1)$$

Where EC is the difference between the amount of dissolved organic

Table 1. Basic physicochemical properties of the sampling sites in 0 to 30 cm soil.

Green-land type	BD (g cm^{-3})	EC (μS cm^{-1})	pH (H_2O)	pH (KCl)	SM (%)	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})	Total P (mg kg^{-1})
Forest park	1.25 (0.01)	83.69 (5.40)	6.48 (0.02)	5.33 (0.03)	30.35 (0.35)	7.48 (0.81)	6.76 (0.99)	242.61 (22.0)
Roadside	1.36 (0.03)	168.14 (5.67)	8.93 (0.14)	8.04 (0.13)	22.06 (1.35)	7.10 (1.14)	8.71 (1.35)	431.87 (44.1)
Factory	1.47 (0.02)	188.07 (9.80)	7.87 (0.04)	7.32 (0.09)	21.91 (0.70)	14.07 (1.80)	6.54 (1.07)	220.58 (10.3)
Park	1.39 (0.01)	131.39 (5.00)	8.40 (0.04)	7.58 (0.05)	22.97 (0.38)	7.64 (0.84)	8.20 (1.05)	924.10 (75.7)
Residential	1.44 (0.02)	174.92 (5.85)	8.83 (0.04)	8.01 (0.03)	22.60 (0.35)	6.87 (0.72)	5.52 (0.72)	293.53 (15.9)
Campus	1.40 (0.01)	129.12 (4.04)	8.64 (0.05)	7.68 (6.70)	23.61 (0.40)	15.87 (1.80)	4.98 (0.48)	530.85 (55.5)

Note: numbers in brackets represent standard deviation; EC means electric conductivity; BD, bulk density; SM, soil moisture content; total P, total phosphorus.

Table 2. DOC concentrations in the different soil layers for different types of green- lands (mg kg^{-1}).

Green-land type	0 to 10 cm		10 to 20 cm		20 to 30 cm		Mean	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Forest park	50.99[b]	6.50	48.49[b]	4.49	33.36[a]	4.12	44.28[b]	3.57
Roadside	29.62[a]	2.23	27.03[a]	2.75	23.51[a]	2.25	26.72[a]	1.41
Factory	27.33[a]	3.51	22.42[a]	2.99	17.88[a]	2.36	22.88[a]	1.84
Park	30.44[a]	2.91	29.22[a]	2.0	25.52[a]	1.92	28.39[a]	1.35
Residential	27.77[a]	2.67	27.91[a]	2.48	24.72[a]	3.06	26.82[a]	1.57
Campus	32.57[a]	2.44	28.00[a]	2.77	28.94[a]	2.61	29.84[a]	1.51
Means	33.12	1.22	28.89	1.21	25.57	1.14	28.58	4.69

Note: values suffixed with the same letters in each column in the table mean no significant difference at P<0.05 level; SD represents standard deviation.

carbon extracted from fumigated and non-fumigated soils (Wu et al., 1990) and:

$$MBN = \frac{E_N}{0.45} \quad (2)$$

Where EN is the difference of extractable total nitrogen between fumigated and non-fumigated soils; 0.45 is the fraction of extracted biomass N after chloroform fumigation (Solaiman, 2007).

$$DON = TDN-(NO_3^- \text{-N}+NH_4^+\text{-N}) \quad (3)$$

Where DON is the dissolved organic nitrogen (Shepherd et al., 2001).

Statistical analysis

Statistical analyses were performed using the computer package SPSS software (Guner et al., 2010). Concentrations between the different components were compared using one-way analysis of variance. Tukey's HSD tests were applied for multiple comparisons to examine the significant differences among components (Yuko et al., 2006). The relationships between variables were analyzed through the use of Pearson correlation coefficients (Kane et al., 2003). Where P<0.05, the relationships were considered to be at a significant level for statistical analysis (Yuko et al., 2006).

RESULTS

The impacts of green-land types on DOC concentration and distribution

The average concentration of DOC in soil (0 to 30cm) was 28.58 mg kg^{-1}, and mainly distributed between 12.15 and 45.01 mg kg^{-1} (Table 2). The average DOC concentration were ranked in the order of suburban forest park > campus green-

Table 3. DOC concentrations under the different planting modes in 0 to 30 cm soil (mg kg^{-1}).

Planting mode	Lawn		Shrub-lawn		Arbor-shrub-lawn		Arbor-lawn	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Forest park	-	-	-	-	-	-	44.28	3.57
Roadside			28.74	2.58	25.11	1.46		
Factory	-	-	-	-	22.88	1.84	-	-
Park	25.99	2.83	27.86	1.97	25.91	1.69	47.68	6.81
Residential	39.87	9.63	28.45	2.32	23.99	2.11	-	-
Campus	-	-	27.76	1.64	31.91	2.51	-	-
Means	28.16	2.89	28.24	1.11	26.05	0.90	44.96	3.14

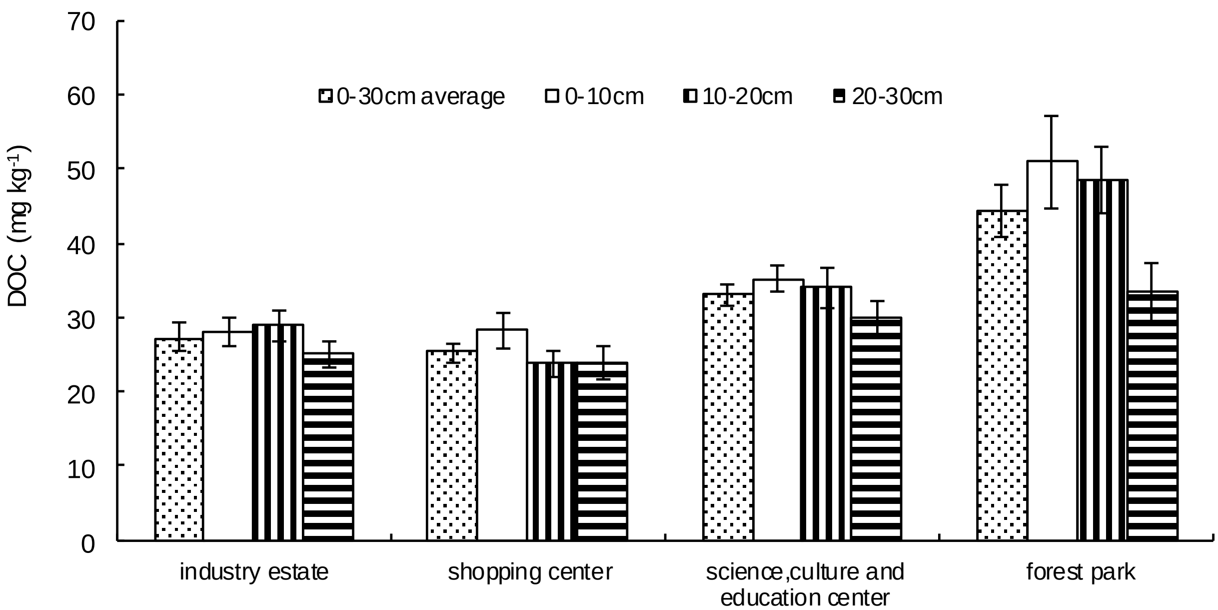

Figure 2. Soil DOC concentrations under the different functional areas.

land > park green-land > residential green-land > roadside green-land > factory green-land. The concentration of DOC in the forest park was 1.48, 1.56, 1.65, 1.66, 1.94 as larger as the above-mentioned other five urban green-land types, respectively. Results from the multiple comparisons showed that there were significant difference in the soil DOC among roadside, factory, park, residential and campus green-land (P>0.05).

The DOC concentration for each soil layer was highest in the forest park. The average concentration of soil DOC was significantly higher on the surface than in the deeper layers (P< 0.05). The vertical distribution of DOC changed irregularly in the residential and campus green-lands. Multiple comparisons showed that there were no significant differences between 0 to 10 cm and 10 to 20 cm layers (P>0.05) in the study sites. However, the DOC concentration was significantly lower in the 20 to 30 cm layer than that in the 0 to 10 cm and 10 to 20 cm layers.

The impact of planting modes on DOC concentration and distribution

The average concentration of DOC under the different planting modes decreased with soil depth. The DOC concentration under arbor-lawn mode was the highest (Table 3), which was 59.21%, 59.66%, and 72.59% higher than under the shrub-lawn, lawn and arbor-shrub-lawn modes, respectively. However, the effect of planting modes on DOC concentration was slightly different for the different green-land types. In the residential, the DOC concentration under lawn mode was 40.14% higher than under the shrub-lawn mode; while in the campus, the DOC concentration under arbor-shrub-lawn mode was 14.95% higher than under shrub-lawn mode. Multiple comparisons revealed that there were no significant differences among lawn, shrub-lawn and arbor-shrub-lawn modes (P>0.05), while arbor-lawn mode had

Table 4. Analysis of variance.

Impact factor	Square of type III	Freedom degree	Mean square	F	Sig.
Green-land types	11205.50	5	2241.10	8.91	0.00
Planting mode	13753.77	3	4584.59	18.66	0.00
Soil depth	2861.57	2	1430.79	5.39	0.00
Green-land types *Planting mode	1698.06	4	424.51	1.81	0.13
Green-land types * Soil depth	1637.69	10	163.77	0.70	0.73
Planting mode* Soil depth	1744.98	6	290.83	1.24	0.29
Green-land types* Planting mode* Soil depth	593.95	8	74.24	0.32	0.96
Error	116667.68	497	234.74		

significantly higher DOC than the other three modes.

The DOC concentrations in different functional areas

Based on the different land use type, the city had four functional areas with the primary shopping centre located within the first ring-road. The primary industrial estate is located in the northeast, the science, culture and education centre located in the southwest, and the forest park located in the western suburban area (Figure 1). These four functional areas were along an urban-suburban environmental gradient from the east to the west of the city. Results showed that the land use changes made an obvious change in soil DOC concentration (0 to 30 cm) across the environmental gradient, with the greatest DOC concentration in the forest park which was 61.84%, 169.67%, 182.76%, respectively, higher than the concentration in the industrial estate, shopping centre, and the science, culture and education centre (Figure 2).

Controls of DOC concentration

Results from analysis of variance (Table 4) showed that green-land types, planting mode, and soil depth, impacted significantly on the DOC concentration ($P<0.05$). The interaction amongst green-land type, planting mode and soil depth had no significant impact on DOC concentration ($P>0.05$).

Results from the linear regression analysis showed that at the 0 to 30 cm soil depth, the average concentrations of DOC were significantly and positively correlated with soil moisture, NH_4^+-N, MBN, DON, and negatively correlated with soil pH, bulk density, EC, and total phosphorus (Figure 3).

DISCUSSION

Effects of green-lands types on soil DOC concentration

The present study showed that green-land types have clear influences on DOC concentrations. In the urban sites, factory, residential and street green-lands had relatively lower DOC concentrations compared with the park and campus green-lands. For the former, the decrease of organic matter in soil profile and fewer new organic matter supplements might be due to serious soil compaction (Gruber and Galloway, 2008) and particularly the periodic removal of litter fall. For the latter, the better manual management and protection measures improved the soil DOC to some extent. When compared with the natural site, the DOC concentration in the suburban forest park was significantly higher than in the urban sites, which might be due to its higher vegetation cover, less human disturbance and the addition of more fresh organic matter to the soil. However, in the urban sites, the frequent human disturbances, disappearance of dense grass cover, and reduced inputs of soil organic matter and root exudates resulted in fewer sources of organic carbon. Previous studies also showed that DOC concentrations are related to the soil organic matter which mainly originated from recent plant litter and humus (McDowell and Likens, 1988; Kalbitz et al., 2000; Michalzik et al., 2001). In addition, during urbanization, conversion from the suburban natural green-land to urban construction land can result in alteration of soil moisture-temperature conditions, soil structure, nutrient cycles, and ultimately influence the soil DOC concentrations.

At the study sites, the average concentration of DOC decreased with soil depth. It was most likely attributed to the preferential sorption of high C: N hydrophobic dissolved organic matter in upper horizon (Lajtha et al., 2005), and to the retention by particle surfaces (Qualls and Haines, 1992).

Effects of land use change on soil DOC concentration

Vegetation is known to effectively control soil erosion, roots and microbial secretions and the vegetation type is the primary factor influencing the amount and composition of DOC (Qualls et al., 2000; Chantigny, 2003). Our findings showed that vegetation planting mode had a significant influence on DOC concentrations

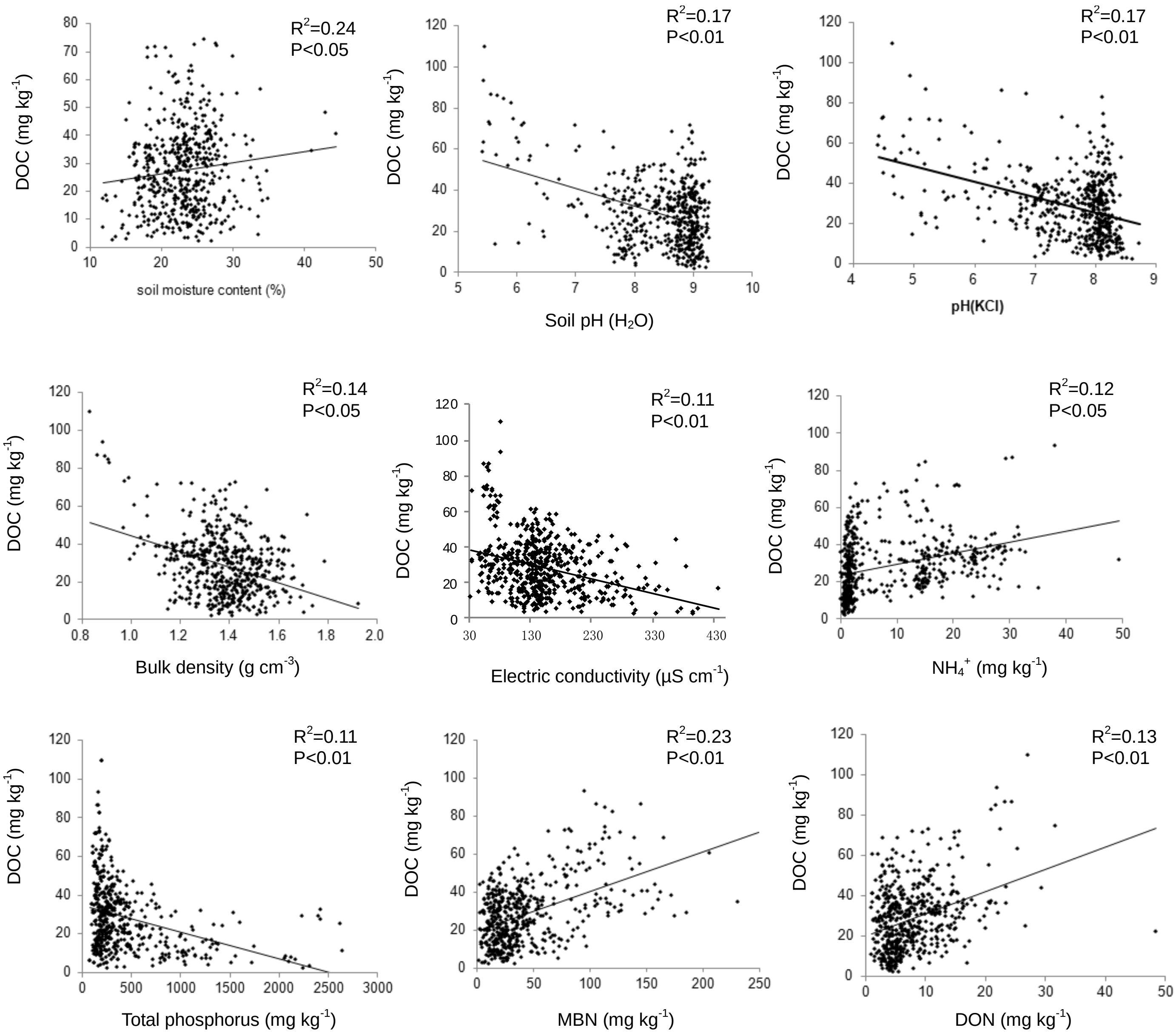

Figure 3. Relationships between DOC concentration and physicochemical parameters in 0 to 30 cm soil.

($P<0.05$). The DOC concentration in the 0 to 30 cm soil layer ranked as: arbor-lawn > shrub-lawn > lawn > arbor-shrub-lawn. It resulted from differences in the existing vegetation intensity which influence the root system, and the quality and quantity of litter fall.

Soil DOC concentrations (0 to 30 cm) in four functional areas made an obvious change across the urban-suburban environmental gradient. This could be caused by the changes of land use, which alter the environmental conditions and vegetation types, resulting in the changes of biodegradation, leaching processes, the quantity and quality of soil organic matter, which affects the DOC concentrations. (Houghton et al., 1999; Post and Kwon, 2000; Guo and Gifford, 2002).

Relationships between soil DOC and nutrients

Own results showed that DOC concentration was significantly and positivity correlated with soil moisture, while negatively correlated with total phosphorus, which was in agreement with previous studies. Neff et al. (2000) found that fertilization with phosphorus increased dissolved organic phosphorus leaching and decrease DOC fluxes. Falkengren-Grerup and Tyler (1993) suggested that in well-drained soil, high water content can raise microbial activity, thus increasing the formation of water-soluble compound.

Huang et al. (2008) revealed that DOC is significantly correlated with MBC, MBN and DON in different land-use types. Wang et al. (2006) showed that DOC is significantly correlated with MBC, as being due to the death of microbial cells. In the present study, DOC concentration was significantly and positively correlated with MBN, and DON. However, no statistically significant relationship between DOC and MBC concentrations (P=0.963) were found (data not shown), which might have contributed to the different spatial and temporal resolution of observations, synergistic or antagonistic effects of several controls relating to environmental conditions, or to the dominance of a new control when changing spatial and temporal scales.

With regard to pH on DOC concentration, the results are inconsistent. In the present study, DOC concentration was significantly and negatively correlated with pH, indicating that the suburban forest park with the lower pH relative to urban soil tended to accelerate the accumulation of DOC to some extent. Similarly, Guggenberger et al. (1994) showed that DOC is significantly and negatively correlated with pH in the podzol solid stage of a mineral layer. In contrast, Hajnos et al. (1999) and You et al. (1999) observed a positive relationship between the release of DOC and soil pH in organic soil, which was also confirmed by Michalzik et al. (2001) who found the content of DOC leachates on the forest floor is positively correlated with soil pH. This suggested that higher pH values are more favourable degradation conditions for decomposer communities on the forest floor (Andersson et al., 2000). Curtin et al. (1998) reported that there is no significant correlation between carbon mineralisation and pH within a pH range of 5.1 to 7.9. In addition, Cronan (1985) reported no differences in the amounts of mobilized DOC at a pH range of 3.5 to 5.7. Michalzik and Matzner (1999) found that relationships between DOC and pH are not consistent at the plot-level in the field studies. Reasons for this discrepancy could be a bias in temporal or spatial of observations, unknown synergistic effects (encompassed physical, chemical and biological processes), non-consideration of hydrological or differences in microbiology (Michalzik et al., 2001).

The average concentration of DOC was 27.45 mg kg^{-1} in urban sites and 44.28 mg kg-1 in suburban sites, which were lower compared to the previous studies in forest, farmland, grassland and the Karst region (Kalbit et al., 2000; Michalzik et al., 2001; Liu et al., 2009; Dou et al., 2009). This difference might not be only related to rainfall, anthropogenic disturbance, soil type and fertility but also to the sampling time (in January, the temperature was -2 to -7°C in the present study). Previous studies showed that temperature can control the flux and concentration of DOC through regulating the soil microbial biomass resulting in the seasonal change of DOC content. Under normal circumstances the soil DOC concentration was higher in summer than in winter (Scott et al., 1998; Tippin et al., 1999). In contrast, a study by Jones and Willett (2006) showed that the soil DOC concentration vary with the different experimental methods. In the present study, 2 M KCl was used for the extraction, while in some other studies (Bolan et al., 1996; Christ and David, 1996) distilled water or 0.5 M K_2SO_4 was used for extracting soil samples. The shaking and extraction time may also influence the concentration of soil DOC. Therefore, it is crucial to standardize experimental method for DOC to reduce the uncertainty when comparing different studies.

Conclusion

Results from this study demonstrated that DOC concentrations decreased with soil depth. Vegetation planting modes as well as green-land types have significant effects on DOC concentration (P<0.05). Land use changes made soil DOC concentration (0 to 30 cm) enjoy an obvious change across the environmental gradient. The concentration of DOC is obviously higher in suburban site than in urban sites, which indicates that under urbanization, the conversion of natural green-land to the urban green-land is not conducive to the accumulation of soil active carbon. And also, planting more trees, reserving litter, avoiding soil compaction, increasing plant coverage, and enhancing soil moisture content are helpful for DOC accumulation.

ACKNOWLEDGEMENTS

This research was supported by the National Natural Science Foundation of China, (No. 31070558 and 30771719). We are grateful to Weibin Yin, Zhengliang Ding, Lingmei Zeng, Lei Wang, and Leilei Wang for field work, Yang Zhao, Jiajia Zhou, Yan Yue and Hao Chen for laboratory assistance. We also would like to thank the reviewers and editors for constructive comments and suggestions.

REFERENCES

Andersson S, Nilsson SI, Saetre P (2000). Leaching of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) in mor humus as affected by temperature an pH. Soil Biol. Biochem., 32(1): 1-10.

Bolan NS, Baskaran S, Thiagarajan S (1996). An evaluation of the measure method dissolved organic carbon in soils, manures, sludge, and stream water. Commun. Soil Sci. Plan. 27: 2732-2737.

Brookes PC, Landman A, Pruden G, Jenkinson DS (1985) Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biol. Biochem., 17: 837-842

Chantigny MH (2003). Dissolved and water-extractable organic matter in soils: a review on the influence of land use and management practices. Geoderma, 113: 357-380.

Christ MJ, David MB (1996). Dynamics of extractable organic carbon in spodosol forest floors. Soil Biol. Biochem., 28(9): 1171-1179.

Curtin D, Campbell CA, Jalil A (1998). Effects of acidity on mineralization: pH-dependence of organic matter mineralization in weakly acidic soils. Soil Biol. Biochem., 30(1): 57-64.

Cronan CS (1985). Comparative effects of precipitation acidity on three forest soils: carbon cycling responses. Plant. Soil., 88(1): 101-112.

Dawson HJ, Ugolini FC, HrutfioRd BF, Zachara J (1978). Role of soluble organics in the soil processes of podzol. Central Cascades, Washington. Soil Sci., 126(5): 290-296.

Dou FG, Wright AL, Hons FM (2008). Dissolved and Soil Organic Carbon after Long-Term Conventional and No-Tillage Sorghum Cropping. Commun. Soil Sci. Plann., 39: 667–679.

Falkengren-Grerup U, Tyler G (1993). The importance of soil acidity, moisture, exchangeable cation pools and organic matter solubility to the cationic composition of beech forest (*Fagus sylvatica* L.) soil solution. J. Plant Nutr. Soil Sc., 156(4): 365-370.

Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu JG, Bai XM, Briggs JM (2008). Global change and the ecology of cities. Science, 319: 756-760.

Gruber N, Galloway JN (2008). An earth-system perspective of the global nitrogen cycle. Nature, 451: 293-296.

Guggenberger G, Glaser B, Zech W (1994). Heavy metal binding by hydrophobic and hydrophilic dissolved organic carbon fractions in a Spodosol A and B horizon. Water Air. Soil Poll., 72: 111-127.

Guner S, Tufekcioglu A, Gulenay S, Kucuk M (2010). Land - use type and slope position effects on soil respiration in black locust plantations in Artvin, Turkey. Afr. J. Agr. Res., 5(8): 719-724.

Guo LB, Gifford RM (2002). Soil carbon stocks and land use change: a meta analysis. Global Change. Biol., 8(4): 345-360.

Hajnos M, Sokoloeska Z, Jozefaciuk G, Hoffmann C, Renger M (1999). Effect of leaching of DOC on pore characteristic of a sandy soil. J. Plant Nutr. Soil Sc., 162(1): 19-25.

Haynes RJ (1999). Size and activity of the soil microbial biomass under grass and arable management. Biol Fert Soils., 30(3): 210-216.

Houghton RA, hackler JL, Lawrence KT (1999). The U.S. carbon budget: contributions from land-use change. Science, 285: 574-578.

Huang JY, Song CC. Song YY, Liu DY, Wan ZM, Liao YJ. 2008. Influence of freshwater marsh tillage on microbial biomass and dissolved organic carbon and nitrogen. Chin. J. Environ. Sci., 29(5): 1380-1387 (in Chinese, with English summary).

Iqbal J, Hu RG, Feng ML, Lin S, Malghani S, Ali IM (2010). Microbial biomass, and dissolved organic carbon and nitrogen strongly affect soil respiration in different land use: a case study at Three Gorges Reservoir Area. South China. Agr. Ecosyst. Environ., 137(3-4): 294-307.

Jones DL, Willett VB (2006). Experimental evaluation of methods to quantify dissolves organic nitrogen (TON) and dissolved organic carbon (DOC) in soil. Soil Biol. Biochem., 38(5): 991-999.

Kalbitz K, Solinger S, Park JH, Michalzik B, Matzner E (2000). Controls on the dynamics of dissolved organic matter in soils: a review. Soil Sci. 165(4): 277-304.

Kong XB, Zhang FR, Wei Q, Xu Y, Hui JG (2006). Influence of land use change on soil nutrients in an intersive agricultural region of North China. Soil Till. Res., 88(1-2): 85-94.

Lajtha K, Crow S E, Yano Y, Kaushal SS, Sulzman E, Sollins P, Spears JDH (2005). Detrital controls on soil solution N and dissolved organic matter in soils: A field experiment. Biogeochemistry, 76(2): 261 – 281.

Liu TZ, Liu CQ, Zhang W, Tu CL (2009). Concentrations and migration features of dissolved organic carbon in the soils of slope lands in Karst area. China Environ. Sci., 29(3): 248-253. (In Chinese, with English summary).

Kane ES, Pregitzer KS, Burton AJ (2003). Soil respiration along environmental gradients in Olympic national park. Ecosystems, 6: 326–335.

Maria LAS (2005). Dissolved organic carbon and bioavailability of N and P as indicators of soil quality. Sci. Agr., 62(5):502-508.

McDowell WH, Likens GE (1988). Origin, composition, and flux of dissolved organic carbon in the Hubbard Brook Valley. Ecol. Monogr., 58(3): 177-195.

Michalzik B, Matzner E (1999). Dynamics of dissolved organic nitrogen and carbon in a central European Norway spruce ecosystem. Eur. J. Soil Sci., 50(4): 579-590.

Michalzik B, Kalbitz K, Park JH, Solinger S, Matzner E (2001). Fluxes and concentrations of dissolved organic carbon and nitrogen-a synthesis for temperate forests. Biogeochemistry, 52(2): 173-205.

Neff JC, Hobbie SE, VitousekPM (2000). Nutrient and mineralogical control on dissolved organic C, N and P fluxes and stoichiometry in Hawaiian soils. Biogeochemistry, 51: 283-302.

Post WM, Kwon KC (2000). Soil carbon sequestration and land-use change: processes and potential. Global Change. Biol., 6(3): 317-327.

Qualls RG, Haines BL (1991). Geochemistry of dissolved organic nutrients in water percolating through a forest ecosystem. Soil Sci. Soc .Am. J., 55: 1112-1123.

Qualls RG, Haines BL (1992). Measuring adsorption isotherms using continuous, unsaturated flow through intact soil cores. Soil Sci. Soc .Am. J., 56: 456-460.

Qualls RG, Haines BL, Swank WT, Tyler SW (2000). Soluble organic and inorganic nutrient fluxes in clear cut and mature deciduous forest. Soil Sci. Soc. Am. J., 64: 1968-1977.

Scott MJ, Jones MN, Woof C, Tippin E (1998). Concentrations and fluxes of dissolved organic carbon in drainage water from an upland peat system. Environ Int., 24(5-6): 537-546.

Soil Survey Staff. (1999). Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys (2nd ed.), Agriculture Handbook Number 436, US Department of Agriculture and Natural Resources Conservation Service, US Gov. Print. Office,Washington, DC, pp,854- 869.

Solaiman Z (2007). Measurement of microbial biomass and activity in soil. Adc. Tech. Soil Microbiol., 11: 201-21.

Shepherd M, Bhogal A, Barrett G, Dyer C (2001). Dissolved organic nitrogen in agricultural soil: effects of sample preparation on measure valves. Commun. Soil. Sci. Plant Anal., 32(9＆10): 1523-1542.

Tippin E, Woof C, Rigg E, Harrison AF, Ineson P, Taylor K, Benham D, Poskitt J, Rowland AP, Bol R, Harkness DD (1999). Climatic influences on the leaching of dissolved organic matter from upland UK moorland soils, investigated by a field manipulation experiment. Environ Int. 25(1): 83-95.

Wang WX, Zhou JB, Yan DY, Ma QA (2006). Contents of soil microbial biomass C, N and K2SO4-extractable organic C, N and their relations in different soil types on Loess plateau of China. J. Soil Water. Conserv., 20(6): 103-106,132 (In Chinese, with English summary).

Wu J, Joergensen RG, Pommerening B, Chaussod R, Brookes PC (1990). Measurement of soil microbial biomass C by fumigation-extraction-an automated procedure. Soil Biol. Biochem., 22(8): 1167-l169.

You SJ, Yin YJ, Allen HE (1999). Partitioning of organic matter in soils: effect of pH and water/soil ration. Science Total. Environ., 227(2-3): 155-160.

Yuko Y, Hideaki S, Yojiro M, Takayoshi K (2006). Effects of Soil and Vegetation Types on Soil Respiration Rate in Larch Plantations and a Mature Deciduous Broadleaved Forest in Northern Japan. Eurasian J. For. Res., 9(2): 79-95.

Zhang K, Xu XN, Wang Q (2010). Characteristics of N mineralization in urban soils of Hefei, East China. Pedosphere, 20(2): 236-244.