Applied Soil Ecology 75 (2014) 181–188

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Phosphorus enrichment helps increase soil carbon mineralization in vegetation along an urban-to-rural gradient, Nanchang, China

Fu-Sheng Chen[a,*], Joseph Yavitt[b], Xiao-Fei Hu[c]

[a] College of Forestry, Jiangxi Agricultural University, Nanchang 330045, PR China
[b] Department of Natural Resources, Cornell University, Ithaca, NY 14853-3001, USA
[c] College of Life Sciences, Nanchang University, Nanchang 330031, PR China

ARTICLE INFO

Article history:
Received 29 July 2013
Received in revised form
14 November 2013
Accepted 15 November 2013

Keywords:
Biogeochemistry
Forest
Soil carbon mineralization
Soil phosphorus
Urbanization

ABSTRACT

We used four vegetation types located along an urban–suburban–rural gradient in Nanchang, China to study how the deposition of nitrogen (N) and phosphorus (P) in the urban area affected soil carbon (C) cycling. We found that total P, nitrate (NO_3^-–N), available P, and the abundances of culturable bacteria, actinobacteria, and nitrifying bacteria in soils, collected to 15 cm depth in August of 2008, decreased along the urban-to-rural gradient ($P < 0.05$); the C/P and N/P ratios, ammonium (NH_4^+–N), and culturable fungi abundance showed the reverse trends; whereas soil organic C, total N, C/N, mineral N, and the activities of sucrase and neutraland acid phosphatase showed no pattern with gradient and vegetation type. Compared to suburban and rural sites, total and available P in soil increased 168% and 131%, 47% and 139%, respectively in urban sites. The cumulative amount of CO_2 emission per gram of soil (C_{min}, incubated from 2 to 43 days) varied little along the urban-to-rural gradient, but showed positive correlations with organic C, total N, total P, nitrate, mineral N concentrations, C/N, bacteria and actinobacteria abundances, sucrase and acid phosphatase activities. In contrast, the cumulative amount of CO_2 produced per gram organic C (C_{min}/OC) within the incubation period was influenced by gradient, vegetation type, and their interaction, and values were about 35% greater in the urban than in suburban and rural sites. The relationship between elevated C_{min}/OC in urban vegetations and the enrichment of P in organic matter (P/C ratio) suggests that P coming from urban household waste can degrade the stability of organic C in urban soils.

1. Introduction

Biogeochemical studies in urban and suburban areas often find high nitrogen (N) deposition to soils (Chen et al., 2010a; Groffman et al., 2006; Liu et al., 2011), and the linkages between biogeochemical cycles of N and carbon (C) (Schlesinger et al., 2011) suggest that added N could alter soil C dynamics. However, urban and suburban areas also can experience disturbed phosphorus (P) cycles (Baxter et al., 2002; Chen et al., 2010b), and P also influences soil C dynamics. Here we explore the consequences of elevated N and P for soil C mineralization in soil located along an urban-suburban-rural gradient in Nanchang, China.

There is evidence that added N in mesic forests and grasslands leads to an increase in soil C storage (Nave et al., 2009). One reason is that plant growth and litter production (leaf and root) increase with added N (Fornara and Tilman, 2012; Thomas et al., 2010); although, with no additional P, the increase in plant growth could decrease available P in soil (Lu et al., 2012; Vitousek et al., 2010). Indeed interactions between N and C cycles could account for reports that available P is less (Baxter et al., 2002) or greater (Hu et al., 2011) in urban and suburban areas than in adjoining rural areas, and among other reasons. Moreover, additional N can stabilize soil organic matter (Cusack et al., 2011; Nave et al., 2009), given that N increases rates of litter decomposition only if there is an abundance of decomposable organic compounds with a high C/N ratio. In contrast, experiments with added P in tropical forests suggest enhanced rates of microbial action in litter decomposition (Cleveland et al., 2006; Kaspari et al., 2008), but it is unclear if results from tropical forests could be applied to other ecosystems.

China presents a unique opportunity to examine how soil C dynamics are being altered by urbanization. Areas have urbanized quickly, temporally, and spatially, and thus forests established many years ago in a rural setting now occur within urban and suburban settings (Chen et al., 2010b). Thus changes in ecosystem structure and function between urban and rural settings can be attributed to urbanization rather than pre-existing conditions. Urbanization produces multiple environmental effects, including

* Corresponding author. Tel.: +86 791 83813243; fax: +86 791 83813243.
E-mail address: chenfush@yahoo.com (F.-S. Chen).

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http://dx.doi.org/10.1016/j.apsoil.2013.11.011

climate change, atmospheric pollution, human disturbance and soil alterations (Pouyat et al., 2006). Chen et al. (2010a,b) found that soil N transformation and P availability showed an increasing tend along the short rural-to-urban gradient in a rapidly developing city of southern China due to elevated vehicles, dustfall, dry and wet depositions and various anthropogenic waste deposits in urban areas. In contrast, recent literatures have demonstrated that urbanization had significant effect on soil C storage in terrestrial ecosystems (Kong et al., 2009; Pouyat et al., 2002; Raciti et al., 2012). In this study we address whether alterations in N and P associated with urbanization will impact soil C mineralization in soil.

The study also allowed us to address interactions among several different factors that are known to control soil C mineralization. For instance, there is evidence in the literature that urbanization alters litter quality (Carreiro et al., 1999), earthworm abundance (Steinberg et al., 1994, 1997), soil nematode (Pavao-Zuckerman and Coleman, 2007) and fungal densities (Pouyat et al., 1994), accumulations of trace metal elements (Pouyat and McDonnell, 1991), soil N mineralization (Zhu and Carreiro, 2004a,b), and plant growth (Gregg et al., 1997), among other factors. Given the multiple factors involved, it is not clear which ones play significant roles on soil organic matter quality and on rates of soil C mineralization. These are important issues because human activities do not impose a singular impact on urban environments.

We sampled soil along an urban–suburban–rural gradient in Nanchang city, China (Chen et al., 2010b) to study the effect of urbanization on organic C mineralization potential, N and P supply, culturable microbial abundances and major enzyme activities in four vegetation types: Shrubs, Masson pine (*Pinus massoniana*) forest, conifer and broadleaf mixed forest, and evergreen broadleaved forest. We expected that: (1) Soil C mineralization potential (CO_2 emission per gram of soil, C_{min}; or per gram organic carbon in soil, C_{min}/OC) was greater in urban than in rural environments given greater amounts of N and P in the urban area (Chen et al., 2010a,b); and, (2) soil biochemical variables and organic C stability depend on the position along the urban-suburban-rural gradient rather than vegetation type. Thus, the results provide insight into ecosystem functions in urban forests and should help improve management in urbanizing areas.

2. Material and methods

2.1. Study area

The study was done in and around Nanchang city (115°27′-116°35′E, 28°09′ - 29°11′N), the capital of Jiangxi Province, China. The region has a wet and mild, subtropical monsoon climate. Mean annual precipitation is about 1700 mm, with mean annual relative humidity about 77%. Mean annual temperature is 17.5 °C, and the frost-free period averages 291 days per year. Nanchang is about 25 m above sea level and vegetation cover is high (38%) with green space area of 7.5 m^2 per capita. The total metropolitan area is 7402 km^2. This is a typical rapidly city undergoing urbanization, with population increasing from 2.4 million in 1970 to more than 5 million in 2010. The number of motor vehicles increased more than eight-fold between 1995 and 2006, with about 200,000 cars and trucks registered in the city (Chen et al., 2010a; Ren et al., 2011).

2.2. Plot selection

We selected four vegetation types: Shrubs, Masson pine forest, conifer and broadleaf mixed forest, and evergreen broadleaved forest, which are the most important communities in subtropics of China. Sites were located along a 35 km by 7 km belt transect extending from central urban, through suburban, and rural sites (Chen et al., 2010a). Each vegetation type had two replicate plots (each 400 m^2) in urban, suburban, and rural areas (Table 1). The 24 plots were on well-drained sites with no evidence of disturbances, such as fire or tree cutting, in the past decade. All sites are located on low hills with an elevation range of 30–80 m in the hilly red soil region and underlain by Ultisols (local name is red soil), which is a typical soil type in the mid-tropical region of China. These soils are derived from quaternary red clay and are about 1 m deep. We found that litter layers on the soil surface are between 4.1 and 6.3 t ha^{-1} in the suburban and rural pine forests, whereas litter collections by people have removed the surface layer in the urban area (Chen et al., 2010a).

2.3. Soil sampling

Surface soil samples (0–15 cm) were collected using a soil core sampler with 4.8 cm diameter in August 2008. Each soil sample was the result of composite soil sampling in which nine subsamples collected at randomly selected locations in each plot. Soils were taken to the laboratory within six hours of collection, sieved through a 2 mm sieve, and divided into three portions stored separately at room temperature, 4 °C, and–20 °C until analysis.

2.4. Soil organic C, total N and total P concentrations

The soil samples stored at room temperature were air-dried prior to chemical analyses. After removal of visible plant residue, the soil samples were further ground to pass a 0.2 mm sieve and analyzed for organic C, total N, and total P. Soil organic C was determined by dichromate oxidation and titration with ferrous ammonium sulfate. Total N was determined by the micro-Kjeldahl method. Total P was determined by a phosphomolybdic acid blue color method (Allen, 1989).

2.5. Soil available nutrients

The soil samples stored in a refrigerator at 4 °C within 3 days were used to determine mineral N (NH_4^+–N plus NO_3^-–N) and available P. A 25 g portion was mixed with 100 mL 2 mol L^{-1} KCl, shaken for 0.5 h, allowed to settle overnight at 4 °C. The liquid was collected, and NH_4^+–N and NO_3^-–N were determined by spectrophotometry at 625 nm and 540 nm, respectively following filtration using the indophenol blue method and cadmium reduction method (Allen, 1989). A separate 5 g portion was mixed with 100 mL of 0.5 mol L^{-1} $NaHCO_3$ at pH = 8.5, and available P in the liquid was determined using the molybdate blue method (Allen, 1989).

2.6. Soil biological properties

The soil samples stored in a freezer at −20 °C within 15 days and 7 days were used to measure soil microbial groups and enzyme activity, respectively. Five culturable microbial groups were determined by heterotrophic plate counts (cfu g^{-1} dry soil): bacteria using beef and protein anointed agar; fungi using Gao's No.1 agar; actinobacteria using Martin's agar; azotobacter using improved Ashby agar without N; and nitrifying bacteria using improved Stephenson agar (ISSCAS, 1985).

The activity of sucrase was measured by the Hoffmann–Seegerer method, and neutral and acid phosphatases were measured by the disodium phenyl phosphate ($C_6H_5Na_2O_4P$) colorimetric method (Guan and Shen, 1984).