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Seasonal dynamics of soil nitrogen availability and phosphorus fractions under urban forest remnants of different vegetation communities in Southern China

Jing Fan[a], Jing-Yuan Wang[b], Xiao-Fei Hu[c], Fu-Sheng Chen[a,*]

[a] Jiangxi Provincial Key Laboratory for Bamboo Germplasm Resources and Utilization, College of Forestry, Jiangxi Agricultural University, Nanchang 330045, China
[b] Qianyanzhou Ecological Station, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[c] Research Center of Central China Economic and Social Development, Nanchang University, Nanchang 330047, China

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ABSTRACT

Urban forest remnants are a useful tool to study forest response to global change with urbanization. Soil nutrient status in urban forests has not been well understood, especially under the pressure of rapid urbanization in developing countries. In this study, ion-exchange resin bags and a modified Hedley P fractionation procedure were used to measure seasonal dynamics of soil N forms (ammonium and nitrate) and P fractions (available, labile, slow, occlude and weathered mineral P) under urban forest remnants across a successional sequence and non-forest land in the city of Nanchang, Southern China. Results showed that soil N availability varied with season and vegetation community ($P < 0.05$). Soil P fractions showed minimal seasonal variation except available P, while their averages generally increased with forest development from non-forest land to coniferous forest to conifer-broadleaf mixed forest to evergreen broad-leaved forest. The ratios of fresh soil N forms to P fractions generally decreased with forest development, while N forms absorbed by resins to P fractions generally increased from non-forest land to coniferous forest, then decreased from conifer-broadleaf mixed forest to evergreen broad-leaved forest. It is suggested that urban older forest remnants could easily move to N saturation status and soil P enrichment, causing urban water pollution due to the accumulative effect of elevated atmospheric N deposition and exogenous P input with urbanization.

Introduction

Since urban forests play a vital role in the environmental and esthetic 'health' of cities (Iverson and Cook, 2000), questions about how to achieve sustainable urban forests are increasingly important (Konijnendijk et al., 2006). Urban forest remnants provide an opportunity to examine the ecosystem structural and functional evolution under pressure of urbanization (Carreiro and Tripler, 2005). As the most common limiting elements in terrestrial ecosystems (Vitousek et al., 2010), nitrogen (N) and phosphorus (P) may closely related with urban vegetation stability and health. Urban areas are experiencing rapid rates of population growth, industrialization (Zang et al., 2011) and consequent elevated levels of N deposition, greenhouse gases, soil P and pollutants, and temperature (Pickett et al., 2001; Lorenz and Lal, 2009), which all affect nutrient cycling by causing N loss (Chen et al., 2010a) and P enrichment (Hu et al., 2011) in the forests grown in or nearby urban areas. However, the degree to which N and P limits or exceeds plant demand has received few studies in urban forest remnants (Michopoulos et al., 2007; Cekstere and Osvalde, 2013).

During the last decade, stoichiometry has extensively been used in ecological studies (Sterner and Elser, 2002; Gusewell et al., 2003; Yang and Luo, 2011). The N/P ratio in plant tissue has successfully been applied to assess nutrient limitation and N saturation (Gusewell et al., 2003; Tessier and Raynal, 2003). The soil N/P ratio has the potential to be an indicator of nutrient limitation or surplus because of the close linkage of soil nutrient supply and plant nutrient contents (Pastor et al., 1984; Wardle et al., 2004). Since

* Corresponding author at: No 1101, Zhiminda Road, Economic & Technological Development Area, Nanchang 330045, China. Tel.: +86 791 83813243; fax: +86 791 83813243.
E-mail address: chenfush@yahoo.com (F.-S. Chen).

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soil nutrient supply usually depends on nutrient availability such as N forms and P fractions, and not on the total amount of the nutrient element (Chen et al., 2010a; Hu et al., 2011), the soil N/P ratio based on availability is more valid than total amounts. Additionally, nutrient supply has significant seasonal dynamics, and the degree to which plant requirements are met with seasonal variation is an important issue to assess resource limitation or surplus (Chen et al., 2012). Clearly, seasonal dynamics of different N forms and P fractions, and their stoichiometry in soils, would be helpful to understand the role of N and P supply and their interaction in urban forests.

The nutrient resources generally depend on soil, climate condition and exogenous input (Reich et al., 1997; Harris et al., 2008), but also vary with plant community (Tilman, 1986; Ren et al., 2011). For example, N is the limiting growth factor and has to be held in the ecosystems and imported via atmosphere and assimilated (Yang et al., 2011). In contrast, as a rock-derived element, P is easily lost or occluded and limits plant growth more than N in older forests (Walker and Syers, 1976; Wardle et al., 2004; Brandtberg et al., 2010). With rapid urbanization across the world, creating healthy urban forests is increasingly important for maintaining quality of life for urban inhabitants (Konijnendijk et al., 2006; Ren et al., 2011). To guide the management of urban forests, many scientists have compared the difference in biodiversity and ecosystem services and functions in various communities (Konijnendijk, 2003). The responses of N and P supply to urban forest community types are not fully understood, but this is very useful to provide information for directing urban forest management (Lorenz and Lal, 2009; Chen et al., 2010a,b; Ren et al., 2011).

Because of advantageous natural conditions and local effective conservation policy, the Chinese city of Nanchang is rich in urban forests with a total vegetation coverage and average greenbelt of 38.2% and 7.5 m^2/person, respectively in 2008 (Chen et al., 2010a,b). Various forest remnants provide an excellent opportunity to study the responses of soil N and P status to forest community type under the pressure of urban environments. The objectives of this study were: (1) to compare the differences in soil N and P supplies among various forest communities in an urban area; (2) to assess soil nutrient limitation or surplus using the ratios of N forms to P fractions; and (3) to explore the seasonal interactions between N and P in urban forest remnants. These results could provide some information about forest response to global changes such as atmosphere N deposition and elevated exogenous P input (Chen et al., 2010a,b; Hu et al., 2011).

Materials and methods

Study area

This study was conducted in Nanchang City (115°27′–116°35′ E, 28°09′–29°11′ N), the capital of Jiangxi Province, in the mid-subtropical zone of China. Nanchang City, with an area of 7402 km^2 and a population of 4.8 million, experienced a rapid population increase from 2.4 million to 4 million between 1970 and 1996 (Chen et al., 2010a). The subtropical monsoon climate is wet and mild with a mean annual precipitation of ∼1600–1800 mm, a mean annual relative humidity of 77%, and a mean annual temperature of 17.5 °C based on the climate data of the past 50 years (Ren et al., 2011). The average useable sunlight is 1900 h/yr, and the frost-free period is 291 d/yr. The monthly dynamics of air temperature and precipitation in the study year are shown in Fig. 1 (Chen, 2013). The soils at each site are ultisols (local name: red soil), which are derived from Quaternary red clay and are a typical soil type in the mid-tropical zone of China. The soil of the area was formed from arenaceous shale and is ∼1 m in depth (Chen et al., 2010b).

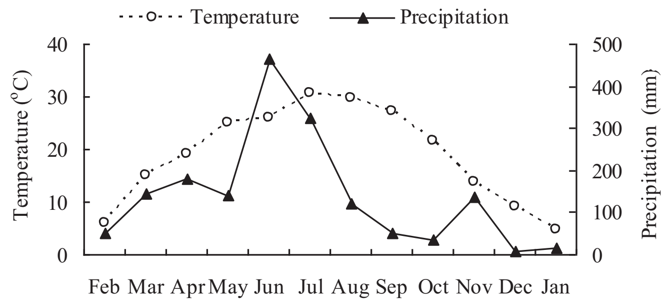

Fig. 1. Monthly dynamics of air temperature and precipitation from February 2008 to January 2009 in Nanchang, China.

Plot establishment

Coniferous forest, conifer-broadleaf mixed forest and evergreen broad-leaved forest are the typical forest communities in the subtropical zone of southeast China (Peng et al., 2003). Eight 20 m × 20 m plots were selected in urban forest remnants representing different forest communities and a non-forest land (two replicate plots for each forest community) in the urban forest park of Nanchang City. All these were randomly distributed on a well-drained upland site (115°48′ E, 28°39′ N; ∼100 ha area in total, Fig. 2), and had no evidence of disturbance such as fire or logging in the last decade. Stand characteristics of these plots were investigated in August 2007. Non-forest land was a typical 'red desert' landform. Both replicate plots of the non-forest land have formed erosion gullies, leaving 80% and 90% of the land area bare with the C-horizon exposed and 10% and 20% covered with mosses and lichens. The coniferous forest remnant was dominated by 16–20-year-old *Pinus massoniana*. Stand density ranged from 800 to 1000 trees/ha, with diameter at breast height (DBH) ranging from 6 to 16 cm, and heights from 5 to 12 m. The biomass of this community was ∼10 kg/m^2. The conifer-broadleaf mixed forest remnant was dominated by ∼30-year-old *P. massoniana*, 20-year-old *Liquidambar formosana* and 15-year-old *Castanopsis sclerophylla*. Stand density ranged from 450 to 750 trees/ha, with an average DBH of 14 cm and height of 12.5 m. The biomass of this community was ∼20 kg/m^2. The evergreen broad-leaved forest remnant has been protected for at least 50 years as a geomantic forest by local residents, and has a complicated community structure. The dominant plants include three evergreen tree species of *Cinnamomum camphora*, *C. sclerophylla* and *Schima superb*. Stand density ranges from 300 to 450 trees/ha, with an average DBH of 20 cm and height of 15 m. The biomass of this community is ∼30 kg/m^2.

Sampling and soil physicochemical properties

The 20 m × 20 m plots were divided into four 10 m × 10 m subplots. In each subplot, after removing the litter layer, five soil cores (2.5 cm in diameter) were randomly collected from the 0–15 cm layer in August 2007 for pH, total soil organic carbon (C), total N and total P analysis (see Table 1). A soil sample was collected within each subplot using a 5 cm high sampling cylinder for determining soil bulk density at 0–5, 5–10, and 10–15 cm. The soil bulk density was determined based on the dry soil weight per unit volume of the soil core at each depth (Liu et al., 1996).

Soil N availability

The dynamics of available N in fresh soil, which are closely correlated with N supply and N loss (Chen et al., 2010a), and soil supply rates were measured using ion exchanged resin bags (IER) from spring to winter (Binkley and Matson, 1983; Chen et al., 2010a).