Catena 115 (2014) 39–46

Contents lists available at ScienceDirect

Catena

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

Nutrients and heavy metals in urban soils under different green space types in Anji, China

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ARTICLE INFO

Article history:
Received 1 December 2011
Received in revised form 16 October 2013
Accepted 12 November 2013

Keywords:
Green space soils
Anji
Eco-county
Soil nutrients
Pb and Cr pollution

ABSTRACT

Anji, located in the northwest of Zhejiang Province, was chosen as the first eco-county in China in 2006, as it met the requirements of the ecological assessment criteria enacted by the Ministry of Environmental Protection P.R. China. Soil quality, however, is not included in the environmental criteria of the eco-county assessment. In 2009, a field survey was conducted to evaluate the soil quality in the built-up area of Anji. We investigated the soil pH, bulk density, nutrient content and the concentrations of Cr and Pb in the four main green space types, namely park green (PARK), street green (STREET), attached green space (ATTACH) and protective green (PROT). We believe that this soil quality information will provide a sound basis for eco-county selection in the future. The pH was alkaline, and the bulk density was much higher, in these four green space types than in the local natural soils. Although the soils were fertilized with NPK fertilizer, the amount of soil organic matter, total nitrogen (TN) and total phosphorus (TP) fell into low, moderate to low or extremely low categories in the four green space types. The amount of organic matter is important to restore the soil structure. The TN and TP concentrations were correlated with the concentrations of organic matter ($P < 0.01$). In the PARK and PROT sites, soil organic matter and TN concentrations were higher than in the STREET and ATTACH sites ($P < 0.05$), most likely because the amount of tree coverage was at least 20% in the PARK and PROT. The content of organic matter should be in line with the site conditions. Owing to past use of leaded petrol, the soils of the four green space types have been polluted by Pb in Anji, especially in the STREET and PROT sites. As an eco-county, Anji needs to adapt a soil replacement method and a biological treatment technology to reduce soil Pb pollution to create a favorable environment for the residents of the area. We suggest that soil quality indicators should be brought into the assessment criteria for eco-country establishment in China.

1. Introduction

In recent years, since reform and opening up began in 1978, China's economy has developed rapidly. However, environmental protection has been neglected, which leads to destruction of natural resources and environments. To protect the environment, the Chinese government and environmental protection administrations have made active explorations since 1998. To promote sustainable economic development and achieve the environment protection targets, the Ministry of Environmental Protection of the People's Republic of China has been working to establish nationwide ecological projects at the different scales, namely eco-province, eco-city and eco-county, since 2003. At the same time, it has been stipulated that an eco-city can be established only when 80% of its counties and districts have met the relevant requirements; likewise, an eco-province can be recommended only when 80% of its cities have met the requirements. Therefore, the construction of eco-counties is the basic unit for other ecological constructions. Meanwhile, a set of indicators has been developed that consists of three categories including economic development, environment protection and social progress. Urban public green space area per capita was one of the most important indices in the criterion system (http://www.mep.gov.cn/gzfw/xzzx/wdxz/200305/t20030524_75076.htm). Since its establishment, the green space system has increasingly gained recognition as one of the important means for incorporating such landscape features in eco-provinces, eco-cities and eco-counties; indeed in the recent past, the amount of green space in many Chinese cities has increased.

The quantitative increase in the amount of green space available to the public has changed the appearance of Chinese cities. However, the urban environment can only be improved if the vegetation is alive, can grow well and can provide a useful ecological function. Soil is crucial for plant growth, yet the indicator systems for eco-provinces, eco-cities and eco-counties do not include the soil quality indices. Over recent years, the physical and chemical properties of urban soils have been changed completely due to being extensively modified by artificial filling materials such as building rubble and other substances when constructing urban green space. Many studies have been conducted on the quality of urban green space soils in major cities of China. For example, Fang et al. (2007) showed that the quality of green

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http://dx.doi.org/10.1016/j.catena.2013.11.008

space soil declined due to the use of excessively coarse-textured filling material in Shanghai. In the city of Chongqing, diverse human disturbances to the soil profile and the use of low quality filling materials resulted in degradation of the soil structure and nutrient deficiency in green spaces (Chen and Bao, 2008). Jim (1998) proved that most of the soils in the green spaces in Hong Kong had lost their natural characteristics owing to the use of fill material which had created poor structure and artificial layering. Soil is the main base for vegetation. Its quality has a strong influence on vegetation growth and the landscape function of green spaces, particularly when large amounts of green space areas are constructed over a short time period. In addition, green space soils play an important role in maintaining the environmental quality as they can act as both a source and sink for pollutants that can easily affect human health (De Kimpe and Morel, 2000). These soils receive a large range of contaminants from the concentration of anthropogenic activities in urban settlements (Biasioli et al., 2006; Lorenz and Lal, 2005). Pollutants in soils are a major threat because they can easily enter the food chain by dust ingestion, dermal contact or breathing in urban areas (Abrahams, 2002). Therefore, the potential risk of pollution of the soil environment needs to be addressed when green spaces are being constructed. Soil is a crucial component of urban ecosystems, and can have either a direct or indirect influence on the environmental quality of cities. Therefore, in addition to the green space area index, indices of urban soil quality are a necessary supplement to the existing indicator systems for eco-county selection.

Anji County is in the north–west of Huzhou City, Zhejiang Province of China. In 2006, Anji became one of the first eco-counties and began to play an exemplary role for other counties in China. The concept of green space, as a main landscape feature, is gradually moving towards perfection. By 2008, the green land ratio and per capita green area of the built up zone had reached 39.1% and 36 m^2, respectively. However, most of the green space soils are backfill and the original soil structure and characteristics have been changed. Therefore, in this study we measured nutrients and heavy metals of the green space soils. Bamboo processing is the main industry of Anji and it may cause Cr pollution in urban soils (Dong et al., 2007). Soil Pb, mainly from traffic emissions and the combustion of leaded petrol, is one of the most frequently investigated trace element pollutants in Chinese urban soils. Therefore, our study focuses on Cr and Pb pollution in the green space soils in the city of Anji. Specifically, our objectives were to (1) measure pH, bulk density and nutrients as well as Cr and Pb concentrations in a range of different green space soils in Anji, and (2) assess these soil quality and the soil environment impacts in the green space system.

2. Materials and methods

2.1. Study area

The study site was located in the county town of Anji (30°38′N, 119°41′E). Anji County is located in Huzhou City, Zhejiang Province of China. The average annual temperature of Anji is 13.9 °C and the mean annual precipitation is 1500 mm. The soils in this area are Acrisols, according to the WRB guidelines (WRB, 2007), and are mainly sandy clays (Zhejiang Soil Survey, 1993). The built-up area of Anji covers 13.5 km^2 and, in 2008, the urban population of this county was 147,000. According to the "Maintenance Technology for Vegetation in Green Spaces of Anji (for Trial Implementation)", the ratio of green land to built-up areas had reached 39.1% in 2008. To enhance growth of green space vegetation, the NPK fertilizer is applied to the green spaces in early spring every year. These applications are supplemented by further light fertilizer applications, depending on visible changes in the appearance of the vegetation during the growing season in Anji, not on soil nutrient status. There is no information about the soil nutrient status of the green space soils as no survey has ever been conducted in Anji. There are four main green space types, namely park green (PARK), street green (STREET), attached green space (ATTACH) and protective green space (PROT). 'PARK' is the green space which is open to the public (including community parks) and provides space for education and recreation. 'STREET' refers to the linear corridors between sidewalks, curbs or traffic islands (excluding street trees), which serve to buffer people from traffic, screen noise and solar radiation. 'ATTACH' is the green space which is attached to industrial and commercial areas, including those planted and maintained by the local community (also linear green space in these areas). 'ATTACH' provides an esthetic function as well as a venue for amenity-recreation. 'PROT' is described as the linear corridors along watersheds, which prevent loss of water and soil erosion.

2.2. Sampling and analysis

Green spaces in Anji are managed and maintained by the Anji Garden Bureau. Because electric cables and other public network cables are buried in the soil under the green spaces, we invited a local garden specialist to supervise soil sampling, so that we could avoid destroying the buried infrastructure cables while maintaining a scientific sample distribution. In 2009, we selected a total of 20 green space plots typical of the four green space types, meaning that there were 5 plots of each green space type in Anji (Fig. 1). In each plot, a representative area was selected (400 m^2) and the diameter at breast height (DBH) of the trees and the degree of crown cover of the woody vegetation and grass were measured (Table 1). Fifteen soil cores (35 mm in diameter) were taken following a "z" shape in each 400 m^2 plot (SPCADSP, 1996). Soil cores were obtained at distances of at least 1.5 m from the bases of trees to avoid the main roots. Every five replicates from the topsoil and second layer soil samples were taken and mixed to attain one soil sample for each layer in each plot. A total of 120 soil samples were obtained across 20 green space plots in Anji. The soil cores were divided into two increments: 0–0.1 m and 0.1–0.3 m. Bulk density measurements made were based on the cutting ring method (SPCADSP, 1996).

Soils were air-dried and hand-picked to remove living roots and coarse fragments. Soils were then ground and passed through a 100 mesh nylon sieve. Soil pH was measured using potentiometry and the amount of organic matter present was determined using potassium dichromate oxidation (SPCADSP, 1996). Total nitrogen (TN) was measured using a semi-micro-Kjeldahl method (SPCADSP, 1996) and likewise total phosphorus (TP) was determined by an $HClO_4$ digestion–Mo–Sb colorimetric method (SPCADSP, 1996). Available nitrogen (AN) was measured with an alkali N-proliferation method (ISSAS, 1978) and available phosphorus (AP) was extracted with sodium bicarbonate (SPCADSP, 1996). Total lead (Pb) and chromium (Cr) concentrations were determined by a hydrofluoric acid–nitric acid digestion followed by elemental analysis (SPCADSP, 1996). The Pb and Cr concentrations in the digestion solution were analyzed with flame atomic absorption (Vario 6, Jena Co. Ltd., Germany).

2.3. Statistical analysis

To assess the soil environmental quality, a pollution index (PI) for each metal was assigned to each green space type. The PI was defined as the ratio of the average trace element concentration in the study to the arithmetic mean of the background concentration (BC) for the corresponding metal for Zhejiang (China National Environmental Monitoring Center, 2004). The PI for each metal was calculated and classified as either low ($PI < 1$), intermediate ($1 < PI < 3$) or high ($PI > 3$).

Two-way ANOVA was used to detect the effects of green space type and soil depth on nutrient and trace element concentrations, and their interactions. One-way ANOVA least significant difference (LSD) comparative analysis was used to determine the mean difference between soil nutrient concentrations in the different green spaces. All statistical tests were considered significantly different at $P < 0.05$. All statistical tests were performed using SPSS and OriginPro software.