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Efficiency of sewage sludge biochar in improving urban soil properties and promoting grass growth

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HIGHLIGHTS

- Sewage sludge biochar could improve urban soil properties.
- Biochar could stimulate turf grass growth even at a rate of 50%.
- The plant uptake of heavy metals was the lowest at the application ratio of 5%.

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ABSTRACT

It is meaningful to quickly improve poor urban soil fertility in order to establish the green land vegetation. In this study, a series rates (0%, 1%, 5%, 10%, 20% and 50%, in mass ratio) of biochar derived from municipal sewage sludge was applied into an urban soil and then turf grass was grown in pots. The results showed that biochar amendment induced significant increases in soil total nitrogen, organic carbon, black carbon, and available phosphorus and potassium by more than 1.5, 1.9, 4.5, 5.6 and 0.4 times, respectively. Turf grass dry matter increased proportionally with increasing amount of added biochar (by an average of 74%), due to the improvement in plant mineral nutrition. Biochar amendment largely increased the total amounts of soil heavy metals. However, 43–97% of the heavy metals in the amended soil were concentrated in the residual fraction with low bioavailability. So the accumulation of heavy metals in turf grass aboveground biomass was highly reduced by the addition of biochar. These results indicated that sewage sludge biochar could be recommended in the poor urban raw soil as a soil conditioner at a rate of 50%. However, the environmental risk of heavy metal accumulation in soil amended with sewage sludge biochar should be carefully considered.

1. Introduction

Urban soil, one of the most violently and artificially disturbed soils, usually consists of parent materials, concrete, brick, plastic etc., and it is often structureless and low fertility (Zhang et al., 2007). It is thus usually difficult to establish vegetation in this soil and costly in maintenance of green land as well (Zou et al., 2012; Miao and Shi, 2015). For example, frequent irrigation of 14,000 hm^2 of lawn area in Beijing annually consumes up to 10,808 million m^3 water, which is not sustainable because of the limited water resources of the city (Qi and Jin, 2011; Sun et al., 2014). The poor permeability and low retention capacity of the green land soil sometimes induce in runoff and flood disasters (Yuan et al., 2003). Peat and garbage compost are often used to improve urban soil quality in developed countries (Diaz et al., 1994). However, the resource of peat is limited in China. Garbage compost is not enough to meet the requirement for establishing the green land vegetation. It is therefore valuable and meaningful to develop innovative methods for improving urban soil quality.

Biochar is biological residue combusted under low oxygen condition, resulting in a porous, low density carbon rich material, which has attracted an increasing attention from scientists due to its benefits as a soil amendment. Increasing data have shown that biochar amendment remarkably influences on soil physical, chemical and biological characteristics. The porous structure and low density of biochar enables reduced bulk density while enhanced soil aeration, soil permeability and water availability (Herath et al., 2013). The rich functional groups on the biochar surface contribute to the enhancement of cation exchange capacity

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(CEC) and nutrient use efficiency (Hossain et al., 2015; Liu et al., 2016; Macdonald et al., 2014), and even the reduction of pollutant mobility in contaminated soils (Al-Wabel et al., 2015; Paz-Ferreiro et al., 2014). The significant liming effects often reduce soil active acidity together with decreasing the activities of Al^{3+}, Mn^{2+} and some heavy metals (Al-Wabel et al., 2015; Dong et al., 2013). Either biomass or yield of crops such as cereals, tubers, roots, fibres can be significantly improved by biochar amendment in tropical, subtropical and even temperate regions (Biederman & Harpole, 2013). Furthermore, biochar as a highly recalcitrant aromatic carbon material has a long residence time of hundreds of years in soil. Biochar soil amendment can enlarge the soil carbon pools (Borchard et al., 2014; Wang et al., 2015) and reduces emission of greenhouse gases such as CH_4 and N_2O as well (Mukherjee et al., 2014). Biochar amendment is thus considered to be one of the most feasible methods for carbon sequestration and reduction of greenhouse gas emissions from soil (El-Naggar et al., 2015; Purakayastha et al., 2016).

Most of organic wastes including municipal sewage sludge can be used as feedstock for producing biochar typically through a slow pyrolysis process (Jin et al., 2016; Lu et al., 2014). China annually releases more than 30 million tons of municipal sewage sludge with more than 10% increase rate during recent decades (Yue et al., 2016). More than 20% is stocked outdoor around town, which often induces in serious sanitary, social and environmental problems (Yue et al., 2016). Therefore, safe disposal and resource utilization of municipal sewage sludge becomes an urgent problem in many cities of China. Our former study showed that pyrolysis stabilized all the heavy metals in municipal sewage sludge (Ma et al., 2013). However, it is not known whether this biochar can be amended into urban soil and improve soil quality.

In this study, dried municipal sewage sludge collected from a pilot plant for spray-drying dewatered sludge with a capacity of 600 t d^{-1} was slowly pyrolyzed at 500 °C for 2 h (Wang et al., 2013). The collected biochar was applied into urban soil, in which the turf grass was grown in pots. The aims of this study were (1) to understand the effects of sewage sludge biochar on urban soil properties and grass growth, (2) to investigate heavy metal accumulation in soil and grass, and (3) to determine a suitable rate of sludge biochar amendment in urban soil.

2. Materials and methods

2.1. Preparation of sewage sludge biochar

Bulk of spray-dried sludge (<2 mm) collected from Gaobeidian Wastewater Treatment Plant in Beijing was tightly filled into a steel cylinder (65 mm in inner diameter, 105 mm in height). The cylinder was covered at both ends (one end had a small 2-mm hole) and placed into a muffle furnace with the hole-end facing upward. Pyrolysis was performed at 500 °C for 2 h with a heating rate of 10 °C min^{-1}. The collected biochar had the following characteristics: pH 8.70; electrical conductivity (EC), 737.70 μS cm^{-1}; 15.26% C; 0.73% H; 3.28% O; 1.73% N; available phosphorous (P), 181.27 mg kg^{-1}; available potassium (K), 12,652.02 mg kg^{-1}. Heavy metals in the biochar were shown in Ma et al. (2013).

2.2. Soil

The urban soil was collected from the soil layer of 20–40 cm at the west campus of China Agricultural University. The collected soil had a loamy texture, pH 8.40, EC 164.70 μS cm^{-1}, organic carbon (SOC) 3.37 g kg^{-1}, black carbon (BC) 0.67 g kg^{-1}, total nitrogen (N) 0.27 g kg^{-1}, available P 7.80 mg kg^{-1}, and available K 64.22 mg kg^{-1}. The heavy metal contents were shown in Table 1. Most of the heavy metals were lower than the national limits of GB15618-1995, except Cd.

Table 1
Fractions and concentration of heavy metals in soil (mg kg^{-1}) and the environmental quality limits for soils (GB15618-1995).

Fractions	Zn	Cu	Cr	Pb	As	Cd
Acid-soluble	0.63	0.03	0.08	0.44	0.00	0.01
Oxidizable	0.42	0.64	0.82	0.09	0.42	0.00
Reducible	1.16	0.00	0.01	0.15	0.16	0.02
Residue	48.01	36.06	31.29	14.04	3.05	1.04
Sum	50.22	36.74	32.19	14.72	3.63	1.07
GB15618-1995	300.00	100.00	250.00	350.00	25.00	1.00

2.3. Pot experiments

Portions of 1.2 kg soil (<2 mm) were evenly mixed with sewage sludge biochar (0%, 1%, 5%, 10%, 20% or 50%; namely B0, B1, B5, B10, B20 and B50, respectively) and urea (66.67 mg N kg^{-1}) in pottery pots (12 cm in height, 13 cm in inner diameter). Each biochar amendment rate was assessed by four replications. Each pot was sown with 0.27 g (approximately equal to 200 kg ha^{-1}) of mixed grass seeds of *Poa pratensis* L., midnight *Poa pratensis* L., liberator *Poa pratensis* L. and Nuglade *Poa pratensis* L. at the same proportion. The pots were buried into a field with a distance of 2 cm to the soil surface and watered regularly. The aboveground biomass of turf grass was cut when it grew to approximate 15–20 cm in height, washed with deionized water, and then oven-dried, and subjected to assays of total nitrogen, phosphorus, potassium, and heavy metals. At the end of the experiment in mid-October, soil samples were collected and then assayed for texture, pH, EC, black carbon, organic carbon, total nitrogen, available phosphorus and potassium, and heavy metals.

2.4. Assays

The pH and EC values of the biochar were measured in a mixture with 1:10 ratio of biochar to water (w/v) by a glass electrode and conductivity meter, respectively. Total C, H and N were determined by an elemental analyzer, whereas ash was measured according to the method of Yue et al. (2016). Oxygen was calculated by the difference between 100 and the sum of C, H, N and ash. Total P and K were determined by ascorbic molybdate blue spectrometry and flame photometry respectively, following wet digestion.

The total N, P and K in the grass samples were determined by the Kjeldahl method, ascorbic molybdate blue spectrometry and flame photometry, respectively, following wet digestion with H_2SO_4-H_2O_2. Heavy metals were measured by inductively coupled plasma spectrometry (ICP) (ICP 6000 SERIES; Thermo Company, Rockford, IL, USA) following digestion with $HClO_4$-HNO_3.

Soil texture was determined by the pipette method. The pH value (1:2.5 of soil to water, w/v) was estimated with a glass electrode. The EC (1:5 of soil to water, w:v) was measured with a conductivity meter. Soil organic carbon was determined using the potassium dichromate volumetry method. Total nitrogen was determined using the Kjeldahl method. Available P and K were determined using Olsen's method and flame photometer, respectively. Black carbon was determined by the benzene polycarboxylic acid (BPCA) method. Briefly, 0.5 g of each soil-biochar mixture (<0.15 mm) was digested with 10 mL of 4 M trifluoroacetic acid (TFA) at 105 °C for 4 h under a pressure of 3 MPa. The residue was collected, dried at 65 °C for 12 h and then added 2 mL of 65% HNO_3. The mixture was digested at 170 °C for 8 h under a pressure of 3 MPa and then filtered into a 200 mL volumetric flask through ash-