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Effect of sewage sludge hydrochar on soil properties and Cd immobilization in a contaminated soil

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HIGHLIGHTS

- Sewage sludge hydrochar can improve soil quality.
- The stability of Cd in soil was improved by sewage sludge hydrochar.
- The phyto-availability of Cd was decreased by sewage sludge hydrochar.
- Sewage sludge hydrochar can inhibit plant uptake of Cd.

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ABSTRACT

To investigate hydrochar as a soil amendment for the immobilization of Cd, the characteristics of hydrochars (HCs) under three temperatures and residence times, were studied, with a particular interest in soil properties, as well as the speciation, availability and plant uptake of Cd. HCs were obtained by a hydrothermal carbonization (HTC) reaction of sewage sludge (SS). Based on the study of HC properties, we found that HCs present weak acidity with relatively high ash content and low electrical conductivity (EC) values. The addition of HCs to soil decreased soil pH and EC values but increased the abundance of soil microorganism. HCs also promoted the transformation of Cd from unstable to stable speciation and can decrease the content of phyto-available Cd (optimum condition and efficiency: A13,[2] 15.38%), which restrained cabbage from assimilating Cd from soil both the aboveground (optimum condition and efficiency: A35, 52.29%) and underground (optimum condition and efficiency: C15, 57.53%) parts of it.

1. Introduction

With the rapid increase in human water consumption, continually more sewage treatment plants are being constructed, resulting in a rapid increase in the production of sewage sludge (SS). Traditional disposal methods of SS include incineration, sanitary landfill, land utilization, construction material utilization and anaerobic digestion for methane recycling (Chen et al., 2014; Song et al., 2014). Each of the above methods have deficiencies. SS is a complex substance composed of organic debris, inorganic particles, pathogens, colloid sludge and moisture. It also contains heavy metals (HMs) and other poisonous and pernicious substances. Without proper treatment, it may pose a potential threat to the environment and human health. In addition, Cd is one of the most toxic metals. Mineral mining and other anthropogenic activities lead to its continual entry into the environment. Cd can be

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[2] Letters (A, B, C) represent temperature (220 °C, 250 °C, 280 °C); the first number (1, 2, 3) represents residence time (1 h, 2 h, 3 h); and the second number (3, 5) represents application rate (3%, 5%).

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assimilated by plants, inhibit the growth of plants and reduce the production of agricultural products (Liu et al., 2010); it can also enter the food chain to cause human health problems such as itai-itai disease (Bolan et al., 2013). Therefore, rational and environmentally friendly approaches are urgently needed to solve these problems.

In the last decade, academics have used pyrolytic technique (300–900 °C) to dispose of SS and produce biochar as the solid byproduct. Pyrolysis can immobilize HMs in SS and decrease leaching the toxicity and bioavailability of HMs in SS (Abdelhafez et al., 2014; Shao et al., 2015). Biochar from SS is a proper soil amendment that can sequester carbon, increase soil carbon content, regulate soil pH, enhance soil fertility, increase microbial activity and even reduce the availability of heavy metals in soil (Glaser et al., in press; Liu et al., 2014; Zhang et al., 2013). However, relatively less attention has been paid to the HTC of SS. In fact, HTC is one of the most promising methods in SS disposal (Zhai et al., 2016). Unlike pyrolytic techniques, HTC does not require pre-drying of the feedstock. Thus, HTC is more suitable for the treatment of wet SS. It can degrade organic contaminants, sterilize and dewater SS and stabilize HMs in raw materials (Zhang et al., 2014). HTC is conducted under relatively mild conditions (180–350 °C) (Berge et al., 2011) compared to pyrolysis. Currently, HCs are mainly used in catalysis (Titirici et al., 2006), activated carbon synthesis (Sevilla and Fuertes, 2011), adsorbents (Leng et al., 2015; Qi et al., 2013), nutrient recycling (Heilmann et al., 2014), energy recycling (Peng et al., 2016) and as a soil conditioner (Libra et al., 2011). Fewer studies are related to soil amendment. Rillig found that HC applied to soil at a rate of 20% can stimulate spore germination and root colonization of the fungal symbiont (Rillig et al., 2010). Röhrdanz and Titirici discovered that HC can absorb water, with a high water holding capacity (WHC) and cation exchange capacity (CEC) that are beneficial for soil (Röhrdanz et al., 2016; Titirici et al., 2007). In fact, as a soil amendment, HC has a lower content of aromatic compounds and higher content of labile carbon than biochar, and thus provides soil with more nutrients (Breulmann et al., 2017). In addition, though HC and biochar both have many exchange and adsorption sites, HCs have more oxygen-containing functional groups that can bond with metals. Thus, HCs also have an impact on the transformation of the metal fraction. However, research on these aspects is lacking. Therefore, the purposes of this study are (1) to investigate the influence of HCs on soil pH, EC and the abundance of soil microorganisms; (2) to uncover the influence of HCs on the transformation of the Cd fraction and the plant availability of Cd; and (3) to explore the influence of HCs on the uptake and distribution of Cd in plants (cabbage).

2. Material and methods

2.1. Preparation of soil and SS

In this study, polluted soil (red loam) was collected from a metal smelter in Changsha, China. A surface soil sample was collected at a depth from 0 to 20 cm. After air-drying, the soil was sieved through a 2-mm sieve and homogenized. A glass electrode was used to measure soil pH and EC by mixing 2 g soil with 20 mL de-ionized (DI) water after 30 min of shaking. The quantitative analysis of Cd was conducted with an atomic absorption spectrometer (PEAA700).

SS was obtained from the Yuelu district sewage treatment plant in Changsha, China. In this plant, waste water received secondary treatment using a traditional activated sludge treatment process. Excess sludge was collected with an initial water content of 87.29% after dewatering in the plant. SS was dried in a circulation oven at a temperature of 105 °C for 24 h. After complete drying, SS was crushed and separated from other impurities. EC, pH and Cd contents of SS were also measured as in soil. Ash and volatile matter content were detected with a muffle furnace (Méndez et al., 2012).

2.2. Hydrothermal carbonization process

Hydrothermal carbonization is conducted in a 500-mL high-pressure stainless-steel reactor with an automatic magnetic stirrer and an independent temperature controller that can maintain a constant temperature inside the kettle. Feedstock and DI water was placed in the kettle in a ratio of 1:9 and sealed after thorough mixing. The target temperature (220 °C, 250 °C, 280 °C) and residence time (1 h、2 h、3 h) was set in advance (a total of nine experiment groups). The reactor was turned off and left to cool to room temperature. The sample is vacuum-filtered through a funnel and dried in an oven (105 °C) overnight. The pH, EC, and Cd contents as well as ash value and volatile matter content of the HCs were determined using the methods above.

2.3. Incubation procedure

2.3.1. Incubation procedure

First, 200 g dried soil was added to a 500-mL beaker, and HC or SS was added at 0%, 3%, or 5% w/w (220 °C abbreviated as A, 250 °C abbreviated as B, 280 °C abbreviated as C, e.g.: 5% w/w HC at 220 °C with a residence time of 1 h can be referred to as A15). Each treatment was performed in triplicate. Soil and amendments were mixed and stirred completely during the addition of DI water (60 g). All samples were placed in an automated incubator (25 °C) for 90 d. During the incubation phase, samples were kept in the dark and the soil moisture content was maintained at 30% of the maximum water holding capacity. Each sample was air dried and sieved for chemical analysis.

2.3.2. Soil microorganism

To reveal the influence of amendments on soil microorganisms during the immobilization of Cd, 5% w/w of HCs (A25, B25, and C25) or SS was added to soil, respectively. After two months of conditioning, soil samples (including control group (CP): soil with no amendment) were removed and stored at 4 °C until analysis. The changes in microbial abundance were analysed by pyrosequencing of the 16S rRNA gene using the Illumina high-throughput sequencing platform.

2.4. Metal extraction

2.4.1. BCR sequential extraction

The modified BCR-three step sequential extraction method was applied to study the effect of HCs and SS on soil Cd speciation. In this method, metal is divided into four species: exchangeable and acid-soluble fraction (F1), reducible fraction (F2), oxidizable fraction (F3), and residual fraction (F4). Detailed extraction steps can be found in the work of Zhai (Zhai et al., 2014) and are briefly described as follows: F1, 0.5 g of HTC or SS were added to a centrifuge tube and extracted with 20 mL of 0.11 M acetic acid (CH_3COOH). Mixed liquor was centrifuged 20 min at 3000 rpm after 16 h of shaking. The supernatant was F1 and the residue was washed for the next step. For F2, 20 mL of 0.5 M hydroxylammonium chloride ($NH_2OH \cdot HCL$) was blended with residue from F1 and shaken for 16 h before centrifugation. The supernatant was separated as F2 and the residue was washed for the next step. For F3, 5 mL of 8.8 M H_2O_2 mixed with F2 residue was maintained 1 h at room temperature, and another 5 mL of the same reagent was added and heated in a water bath (85 °C) for 1 h. The sample was concentrated to approximately 1 mL via evaporation, and 25 mL of