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Short Communication

Effect of biochar on the presence of nutrients and ryegrass growth in the soil from an abandoned indigenous coking site: The potential role of biochar in the revegetation of contaminated site

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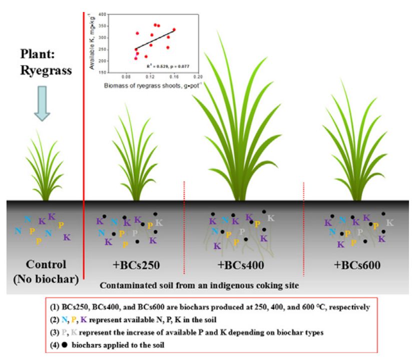
HIGHLIGHTS

- Effect of biochar on nutrients and ryegrass growth in a contaminated soil was studied.
- Biochars only slightly influenced the total N, P, and K.
- Biochars generally increased available P and K, while slightly decreased available N.
- Available P and K were significantly depended on feedstock and pyrolysis temperature.
- Biochars produced at 400 °C more effectively stimulated ryegrass growth.

GRAPHICAL ABSTRACT



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ABSTRACT

Little is known regarding how biochars' feedstock and pyrolysis temperature affect soil function and plant growth. To address this gap in knowledge, 12 biochars (walnut shells, corn cobs, corn straws, and rice straws were separately pyrolyzed at 250, 400, and 600 °C for 4 h) were applied to soil from an indigenous coking site with application rate of 2.5% (w/w) in a pot experiment to determine the impact of biochar types on macronutrients (total and available N, P, and K) and ryegrass growth in the soil from an indigenous coking site. Generally, the total N, P, and K in the soil was not significantly different from that of the control group. However, biochars decreased the available N from 21.76 mg·kg^{-1} for the control to 14.96 mg·kg^{-1}. Corn straw and rice straw biochars increased the available P from 2.14 mg·kg^{-1} for the control to 28.35 mg·kg^{-1}, specifically at higher pyrolysis temperature, while walnut shell and corn cob biochars had little influence on it regardless of pyrolysis temperature. Biochars increased the available K from 173.58 mg·kg^{-1} for the control to 355.64 mg·kg^{-1}, varying as their feedstocks of corn cob > rice straw > corn straw > walnut shell and increasing with the increase of pyrolysis temperature. Correlation analysis suggests that it is responsible for the competition of soluble cations from biochars with K for adsorption sites on the soil surface. Biochars increased the ryegrass biomass from 0.07 g·pot^{-1} for the control to 0.16 g·pot^{-1}, with the generally most effective stimulation by biochars produced at 400 °C. Ryegrass biomass had obviously positive correlation with available K, indicating its essential role in the growth of ryegrass in the studied soil.

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1. Introduction

China is one of the largest coke producers in the world. The country's coke industry has experienced an unprecedented shift in technology during the last few decades as thousands of old, inefficient, and polluting coke ovens in indigenous coking sites have been eliminated (Huo et al., 2012; Kong et al., 2005). In these abandoned sites, long-term coke production has generated widespread ecological damage by altering the soil's structure and composition. Some sites are contaminated with low levels of pollutants such as heavy metals, which do not seriously hinder the growth of vegetation (G. Zhang et al., 2016). However, the plants in these areas are hardly able to grow, which most likely results from soil degradation, such as the damage of soil structure, the loss of soil nutrients, and the changes in pH and cation exchange capacity (CEC). Such problem can cause soil erosion and the loss of ecological functions and services in the local area (An et al., 2013; Jing et al., 2014). Revegetation is considered an effective and practical method for improving the quality of soil and for rehabilitating degraded soil (Jing et al., 2014; Yang et al., 2016). Thus, soil remediation and revegetation are urgently needed to rehabilitate contaminated soils and thus ensure both human and ecosystem health.

Recently, biochar as soil amendment is attracting worldwide interest because of its many advantages, including sequestration of carbon, reduction of greenhouse gases, improvement of soil fertility and crop growth (Gul and Whalen, 2016; Beesley et al., 2011; Vaccari et al., 2015; Manolikaki et al., 2016). Most researches have shown that biochar can increase the essential nutrients in soil, including nitrogen (N), phosphorus (P) and potassium (K), which facilitate the plant growth (Xu et al., 2016; Vaccari et al., 2015; Manolikaki et al., 2016; Jin et al., 2016; H. Zhang et al., 2016; El-Naggar et al., 2015; Gao et al., 2016; Castellini et al., 2015). Nevertheless, the results of applying biochar to soil vary, as the process depends on various factors, such as biochar feedstock, pyrolysis condition, soil type, and biochar application rate. For example, it has been reported that biochars derived from grass-like plants can provide the soil with available P better than biochars derived from wood-like plants can (H. Zhang et al., 2016). The increase of biochar application rates generally increased the available P (Gonzaga et al., 2017). However, few studies have reported how the pyrolysis temperature affects the total and available P in the soil.

Regarding N, the influence of biochar on the total and available N in the soil is related to organic N mineralization, ammonia volatilization, nitrification, and denitrification (Gul and Whalen, 2016). Therefore, application of biochar into soil may not always increase the total and available N in the soil. A recent study showed that although biochar increased the total N in the soil as compared with the control, the available N decreased because the net mineralization of N reduced after biochar addition regardless of application rate (Luo et al., 2016). Another study reported that biochar had little influence on the available N content in the soil (El-Naggar et al., 2015). It has been reported that a large percent of the total N in the biochar is recalcitrant N with very little as available N, resulting in very small contribution of available N by biochar itself (Gao et al., 2016). Nevertheless, biochars derived from nutrient-rich crop residues could most likely stimulate organic N mineralization, while the biochars derived from ligno-cellulose feedstocks with less nutrients commonly resulted in the net immobilization of N in the short term (Gul and Whalen, 2016). However, how the pyrolysis temperature affects the total and available N in the soil is still unclear; thus further studies are needed to determine the mechanism that drives this relationship.

Compared with discussion of N and P, limited studies have been conducted to examine the effect of biochar on both total and available K contents in the soil. A few studies have indicated that biochar can significantly increase the available K content in the soil, which was positively correlated with biochar application rates (El-Naggar et al., 2015; Carvalho et al., 2016; Pandey et al., 2016). It has been reported that biochar elevates the availability of K in soils via biochar's enhancement of CEC (El-Naggar et al., 2015). Generally, CEC of biochar was significantly associated with biochar feedstock and pyrolysis temperature (Lehmann et al., 2011). However, how the biochar feedstock and pyrolysis temperature affect the total and available K content insoil remains unclear.

Although most of studies have reported that biochar can increase plant biomass primarily because of biochar's benefits for soil's physical properties and nutrients (Wang et al., 2015; Carvalho et al., 2016; Lu et al., 2014; Arif et al., 2016; Vaccari et al., 2015; Shen et al., 2016), other studies have also reported that the effect of biochar on plant growth is related to various factors, such as biochar type, availability of nutrients after biochar addition, plant species, and soil texture (Butnan et al., 2015; Xu et al., 2016; Hansen et al., 2016; Hagner et al., 2016; Gonzaga et al., 2017). Some studies have investigated the effects of biochars' feedstocks and pyrolysis temperatures on plant growth (Xu et al., 2016; Hansen et al., 2016; Hagner et al., 2016). However, information regarding the effect of total and available N, P, and K in the soil after biochar addition on the plant growth remains limited. Additionally, most of these studies have focused on the effect of biochar on plant growth in agricultural soil; nonetheless, the knowledge regarding the relationship between these two variables in contaminated sites remains unclear.

Therefore, the primary objective of the present study was to evaluate the effect of biochars' feedstock and pyrolysis temperature on the variation of basic soil properties (pH, EC, and total organic carbon), macronutrient contents (total and available N, P, and K), and ryegrass growth in the contaminated soil from an indigenous coking site.

2. Materials and methods

2.1. Soil sample

The surface soil (0–20 cm depth) for the present study was collected from a former indigenous coke area, which was not favorable for the growth of some plants (in a hilly region in Lin Xian county, Lvliang City, Shanxi Province, China; 37°43′33″N, 110°56′27″E). The soil sample was air dried, homogenized, and sieved (<2 mm). The particle size of the soil was analyzed using a particle size analyzer (clay: 0%, silt: 5.49%, sand: 94.51%, belonging to loamy sandy soil). The soil pH and electric conductivity (EC) values were determined by pH and EC meters, respectively (soil:water = 1:2.5, w/v). The soil pH and EC values were 8.23 and 0.12 $ds \cdot m^{-1}$, respectively. The total organic carbon (TOC) was determined by a total organic carbon analyzer (Analysis Jena N/C 2100) after soil was treated with 2 $mol \cdot L^{-1}$ HCl and dried in a drum wind-drying oven at 105 °C for 2 h. The TOC content was 23.82 $g \cdot kg^{-1}$.

2.2. Biochar

The feedstocks used to produce biochars were walnut shells (WS), corn cobs (CC), corn straws (CS), and rice straw (RS). Each feedstock was washed and dried in an oven at 80 °C. For biochar production, the feedstocks were placed in a muffle and pyrolyzed under oxygen-limited conditions at different temperatures (250, 400, and 600 °C, respectively) for 4 h, with a heating rate of 15 $°C \cdot min^{-1}$ to the target temperature. The biochars were cooled to room temperature inside the furnace, and were then milled to pass a 0.15 mm sieve. The prepared biochars produced from WS, CC, CS, and RS at 250, 400, and 600 °C were thereafter referred to as WS2, WS4, WS6, CC2, CC4, CC6, RS2, RS4, RS6, CS2, CS4, and CS6, respectively.

The pH and EC values of each biochar were measured in a suspension of biochar in water 1:10 (biochar:water = 1:10, w/v) using a pH and EC meter, respectively. The pre-treatment of biochars for the element composition (C, H, and N) analysis was similar to our previous study (Zhang et al., 2011), and their element compositions were determined by an elemental analyzer (Flash EA 1112). The ash contents were measured by heating the biochar in the muffle at 750 °C for 4 h. The oxygen contents were calculated from the mass difference. The total P contents were