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The effects of rice straw biochar on indigenous microbial community and enzymes activity in heavy metal-contaminated sediment

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HIGHLIGHTS

- Invertase and alkaline phosphatase were decreased by high concentration of biochar.
- Intensities of dominant bacteria declined when biochar rate was 50 mg kg^{-1}.
- pH might be related to the decreases in enzymes activity and microbial abundance.
- OM explained the 45% of the variations of microbial community structure by RDA.

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ABSTRACT

Owning to the potential in carbon sequestration and other environmental benefits, biochar has been widely used for in-situ environmental remediation. Understanding the biological effects of biochar is essential. The goal of this study was to explore the response of indigenous microbes under the stress of different concentrations of biochar. The results showed that biochar could significantly change physicochemical properties, enzymes activity and microbial community composition depending on biochar concentration and incubation time. When the concentration of biochar was 50 mg kg^{-1}, the activities of invertase and alkaline phosphatase were obviously inhibited. Meanwhile, bacterial 16S rRNA and fungal 18S rRNA coding gene copies were decreased by 74% and 25%, respectively after 90 days of incubation. Additionally, the bacterial community succession occurred and the relative intensity of dominant species decreased when treated with high concentration of biochar. However, the activity of urease and alkaline phosphatase, as well as bacterial and fungal abundance, were increased when sediment was treated with 10 mg kg^{-1} biochar. Relationships among physicochemical properties, heavy metals and microbes were analyzed by correlation analysis and redundancy analysis (RDA). Correlations between invertase activity and pH value in the experiment were significantly negative. Redundancy analysis showed physicochemical properties and heavy metals explained 92% of the variation in the bacterial DGGE profiles and organic matter content explained the majority (45%) of the variation. This study indicated that indigenous microbes could be affected by biochar either directly or indirectly via changing the physicochemical properties and heavy metals of sediment.

1. Introduction

River sediments are generally considered as the ultimate repositories of past and ongoing discharges of heavy metals (Ghosh et al., 2011). In the south of China, heavy metal pollution in the sediment of Xiangjiang River has been reported in recent years due to the rapid development of metallurgical industry, mining activities and sewage irrigation (Xu et al., 2012). Extensive attention has been paid to heavy metal pollution and a large number of advanced materials have shown their advantages for pollution remediation (Cao et al., 2011; Zhang et al., 2016a; Tang et al., 2012; Tang et al., 2014). As an attractive waste management option, biochar has been used to amend polluted sediment

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recently (Chiang et al., 2012; Ghosh et al., 2011; Lou et al., 2011). Biochar is a not fully carbonized product produced by pyrolysis of biomass (such as crop residues, manure and organic waste) under oxygen-limited condition. Besides, it can promote nutrient availability and increase carbon sequestration as well as soil fertility (Tian et al., 2016). Biochar has been universally applied in soil amendment and its utility in the remediation of heavy metal pollution in soil and sediment is being increasingly considered due to its large surface area, complex porosity and variable surface composition (Oleszczuk et al., 2012; Huang et al., 2017).

Although being successful in pollution remediation, the application of advanced materials always adversely affect the behavior of indigenous microbes (Huang et al., 2016; Zhang et al., 2016b). Das et al. (2012) reported that silver nanoparticles could inhibit natural bacterioplankton production. Fajardo et al. (2012) found that nanoscale zero-valent iron would exert selective pressure on the microbial community. These investigations arouse our interests in the study of the effects on indigenous microbes when heavy metal-contaminated sediment was amended by biochar. Recently, variable effects have been observed on soil microbial community caused by biochar (Jindo et al., 2012; Gul et al., 2015) and the effects mainly depended on soil type, biochar source, biochar concentration and detection method. However, the mechanism of the effects was still unknown and few attention was paid to the effects on sediment microbes.

In surface layer of sediment, bacteria and fungi generally account for the most part of the total sediment microbial biomass (Tong et al., 2012). Indigenous microbes played an important role in nutrient cycling, energy flow and organic matter turnover via ecological processes (Huang et al., 2008). Sediment microbial communities provide important functions in sediment ecosystems and always act as the primary regulators of many sediment processes. Therefore, studying the effects of biochar on sediment microbes is important, which can benefit to the application of biochar. Additionally, being sensitive to environmental changes, enzymes activity are directly related to soil or sediment functionality and widely used to evaluate the microbial activity (Durenkamp et al., 2016). Urease, invertase and alkaline phosphatase are ubiquitous enzymes in soil and sediment, which can be used to study the changes of microbial activity and element cycle related to nitrogen (N), carbon (C) and phosphorus (P). Many researchers indicated that microbial activity and community composition could be affected by soil physicochemical properties (soil organic matter content, moisture, pH, soil type and so on) (Jindo et al., 2012; Abujabhah et al., 2016). Meanwhile, physicochemical properties could be affected by biochar addition (Gul et al., 2015; Sigua et al., 2016). However, the relationship among physicochemical parameters, microbial parameters and biochar concentration has not been evaluated simultaneously (Xian et al., 2015).

In the current study, the responses of indigenous microbes were investigated when heavy metal-contaminated sediment was amended with biochar. The aims of the investigation were to (a) examine the changes of physicochemical properties and microbial enzymes activity upon biochar addition, (b) explore the changes of microbial community composition induced by exogenous biochar using polymerase chain reaction-denaturing gradient gel electrophoresis (PCR-DGGE), (c) discuss the mechanism of the biological effects of biochar by analyzing the relationship among biochar concentration, physicochemical properties, heavy metals and microbial parameters. This study could benefit the application of biochar and contribute to understand the adverse effects of biochar on the function of indigenous microbes.

2. Materials and methods

2.1. Biochar and river sediment

Biochar was produced by rice straw biomass at 600 °C for 3 h using a reported method (Guo and Chen, 2014). Produced biochar was mixed evenly, ground to pass through 0.154-mm sieve and characterized for specific surface area, production yield, pH, and pore width, which were followed by the protocol of Chintala et al. (2014). Selected properties were shown in Table 1.

River sediment was collected from the surface layer of the Xiangjiang River, Changsha, Hunan province by a clam sampler. After removing gravels and plant residues, sediment was put into a sterilized plastic bag and then taken to the laboratory within 1 h (Huang et al., 2015). In order to make sediment and biochar completely incorporated, sediment was slightly air-dried in the dark, then crushed, mixed evenly and sieved through a 0.154-mm sieve. After pretreatment, the sediment was stored at 4 °C in a refrigerator (Lou et al., 2011). Selected sediment properties were determined according to the procedure described by Hu et al. (2014b) and main properties were presented in Table 1.

2.2. Experimental design

The rice straw biochar was used to amend the heavy metal-polluted sediment. Meanwhile, physicochemical properties, heavy metals and microbial parameters were determined. The percentages of rice straw biochar in the sediment were 0% (C_0), 1% (C_1) and 5% (C_2) (w/w). Experiments were designed with three replicates. 300 g (dry weight) of prepared sediment was weighed into 2 L beakers and then 1500 mL of sterile water was added to simulate sediment environment. After incubated for 7 days to acclimatization, biochar was respectively added to sediment and mixed evenly at three different concentration levels. All beakers were covered with apertured plastic wrap and incubated in an incubator at 20 °C. Subsamples were respectively collected from each beaker on day 2, 7, 15, 30, 45, 60 and 90. Then subsamples were vacuumly filtered to obtain the uniform moisture content and stored at −20 °C for subsequent determination.

2.3. Chemical analyses

The pH, organic matter content, total Zn and Cd were measured according to the procedure described by Hu et al. (2014b). Toxicity characteristic leaching procedure (TCLP) was performed to quantify the leachability of heavy metals following the protocol described by

Table 1
The physicochemical properties of experimental sediment and biochar. Data represent the mean ± SE.

	Properties	Value
Sediment	pH	6.65 ± 0.32
	Temperature (°C)	20
	Water content (%)	69.3 ± 0.4
	Organic matter content (%)	6.3 ± 0.3
	Total nitrogen (g kg^{-1})	0.5 ± 0.09
	Total Cu (mg kg^{-1})	69.35 ± 1.6
	Total Zn (mg kg^{-1})	225 ± 15
	Total Pb (mg kg^{-1})	167.1 ± 1.3
	Total Cd (mg kg^{-1})	25.5 ± 0.4
Biochar	pH	10.45 ± 0.5
	Yield (%)	29
	Surface area (m^2 g^{-1})	285.33
	Average pore width (nm)	40
	Pore volume (mL g^{-1})	0.040