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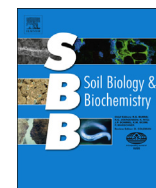

Biochar suppressed the decomposition of organic carbon in a cultivated sandy loam soil: A negative priming effect

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ABSTRACT

Conversion of plant residues to biochar is an attractive strategy for mitigation of atmospheric carbon dioxide (CO_2) emission and enhancement of carbon (C) storage in soil. However, the effect of biochar application on the decomposition of soil organic C (SOC) as well as its mechanisms is not well understood in the sandy loam soil of North China Plain. We investigated how biochar affected the decomposition of native SOC, using stable $\delta^{13}C$ isotope analyses by applying biochar produced from corn straw (a C_4 plant, $\delta^{13}C = -11.9‰$) to a sandy loam soil ($\delta^{13}C$ of SOC $= -24.5‰$) under a long-term C_3 crop rotation. The incubation experiment included four treatments: no amendment (Control), biochar amendment (BC, 0.5% of soil mass), inorganic nitrogen (N) amendment (IN, 100 mg N kg^{-1}) and combined biochar and N amendments (BN). Compared with Control, N amendment significantly ($P < 0.05$) increased total soil CO_2 emission, even when combined with biochar amendment. In contrast, biochar alone amendment did not affect total soil CO_2 emission significantly. However biochar, even when combined with N amendment, significantly ($P < 0.05$) reduced CO_2 emission from native SOC by 64.9–68.8%, indicating that biochar inhibited the decomposition of native SOC and the stimulation effect of inorganic N on native SOC degradation, a negative priming effect. N addition immediately stimulated the growth of microorganisms and altered microbial community structure by increasing Gram-positive bacteria compared to Control as measured by phospholipid fatty acid. Biochar amendment did not alter microbial biomass during the 720-h incubation period except at 168 and 720 h, but significantly ($P < 0.05$) lowered dissolved organic C (DOC) content in soil, primarily due to sorption of DOC by the biochar. Our study suggested that biochar application could effectively reduce the decomposition of native organic C and a potential effective measure for C sequestration in the test soil of the North China Plain.

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1. Introduction

Carbon (C) sequestration in agricultural soils is of significant importance, as it can mitigate atmospheric carbon dioxide (CO_2) emission and enhance soil fertility (Glaser et al., 2002; Lehmann, 2007). Biochar is produced by pyrolysis and is dominantly composed of aromatic compounds that are largely resistant to biological degradation (Baldock and Smernik, 2002). Due to its relative inertness, biochar application contributes to the soil refractory organic C pool (Glaser et al., 2001; Marris, 2006). Therefore, biochar application is a promising alternative to sequester more C compared to more traditional agricultural practices involving direct incorporation of biomass, which results in immediate and rapid mineralization, and CO_2 release (Bruun et al., 2011).

A desire to find solutions that would enhance soil C sequestration has led to studies of the effect of biochar application on soil organic carbon (SOC) decomposition (Wardle et al., 2008; Jones et al., 2011; Luo et al., 2011). However, both suppression and stimulation of native SOC decomposition by biochar have been reported by previous studies (Liang et al., 2010; Cross and Sohi, 2011; Luo et al., 2011). The inconsistent results were probably due to differences in the nature of biochar and soil, and incubation conditions used in different studies (Jones et al., 2011).

The mechanisms involved in the effect of biochar on native SOC decomposition are complicated and still not so clear. It has been reported that the abundance and community structure of soil

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microorganisms affect the rate of degradation of native SOC (Böhme et al., 2005; Billings and Ziegler, 2008). Research studies have also shown that microbial biomass in biochar-enriched soils was higher than in biochar-poor soils (O'Neill, 2007; Liang, 2008), and thus Thies and Rillig (2008) suggested that soil C sequestration after biochar amendment can not be attributed to a decrease of microbial biomass. Biochar amendment also resulted in a change in soil microbial community structure. For example, Khodadad et al. (2011) reported that biochar amendment decreased the overall microbial diversity but increased the relative abundance of specific taxa, such as actinobacteria and gemmatimonadetes. Steinbeiss et al. (2009) found that yeast-derived biochar favored fungal growth while glucose-derived biochar promoted the proliferation of Gram-negative bacteria. To date, however, few reports can be found on the relationships between SOC decomposition and microbial community structure as affected by biochar amendment. Substrate availability is one of the most important factors controlling native SOC decomposition (Uchida et al., 2012). Biochar strongly influences the availability of substrates in soils either due to the release of labile organic C from biochar (Zimmerman, 2010; Bruun et al., 2011) that supplies C source for soil microorganisms, or due to the adsorption of native SOC by biochar (Kasozi et al., 2010), which excludes microorganisms and other biota, and their extracellular enzymes from accession of native SOC (Zimmerman et al., 2011).

Nitrogen (N) fertilizer is commonly applied to increase crop yields in agricultural soils. N addition could increase soil microbial activity (Allison et al., 2008) and accelerate the decomposition of biochar (Schulz and Glaser, 2012). Therefore, it was speculated that N addition might influence the response of native SOC decomposition to biochar application. One of the most significant characteristics of soils in the North China Plain is low organic C content, which is on average only 6.4 g C kg^{-1} and is significantly lower than the national average for upland (9.60 g C kg^{-1}) and paddy (15.0 g C kg^{-1}) soils (Xie et al., 2007). It is a big challenge to find efficient practices to increase organic C in the soils of the North China Plain. The objectives of the study reported here were three-fold: (1) to measure the effect of biochar amendment on native SOC decomposition, (2) to evaluate the interaction of combination of N and biochar on native SOC decomposition and (3) to understand the mechanisms underlying the observed effects of biochar on native SOC decomposition in terms of substrate availability and microbial community in the North China Plain.

2. Materials and methods

2.1. Soil sample and biochar

Surface soil (0–20 cm) sample was collected from a field in the vicinity of Lugang town, Fengqiu county, Henan province, China (35°00′N, 114°24′E), which is located in the North China Plain. This field has been cultivated under a rotation of winter wheat (*Triticum aestivum* Linn.) and summer sweet potato (*Ipomoea batatas*), both C_3 crops, for at least 50 years. The soil, with a $\delta^{13}C$ value of $-24.5 \pm 0.3‰$ (standard error), was developed from alluvial sediments of the Yellow River and classified as aquic inceptisol (USDA, 1994).

Biochar was produced under "no-oxygen" conditions using a slow-pyrolysis process. Before pyrolysis, corn (a C_4 plant) straws were oven-dried for 12 h at 80 °C, and then transferred into the biochar reactor. The reactor was heated by a step-wise procedure. The temperature was set at 200 °C initially, and then elevated stepwise to 250, 300, 350, 400, 450 and 500 °C, respectively. At each temperature step (except for 500 °C), the process was maintained for 1.5 h. The whole process was flushed by N_2 and terminated after about 13 h when there was no visible smoke emission from the gas vent. Biochar had a $\delta^{13}C$ value of $-11.9 \pm 0.2‰$ (SE). Selected properties of soil and biochar are shown in Table 1.

2.2. Soil and biochar analyses

Moist or air-dried soil was dried at 105 °C to determine the soil moisture content. The pH of soil and biochar was determined with a glass electrode using a solid-to-water ratio of 1:5 and 1:15, respectively (Lu, 2000; Luo et al., 2011). Soil bicarbonate and carbonate were measured by the potentiometric titration (Lu, 2000). Soil NH_4^+–N and NO_3^-–N were extracted with 2 M KCl for 1 h and then analyzed on the continuous flow analyzer (Skalar San^{++}, the Netherlands). SOC concentrations were determined with the wet oxidation-redox titration method, and total N (TN) concentrations determined using the micro-Kjeldahl method (Lu, 2000). Organic C and TN concentration in biochar were analyzed by using the elemental analyzer (Vario MAX, Germany).

2.3. Laboratory decomposition incubation experiment

The experiment was carried out under laboratory incubation and included four treatments: (1) no amendment (Control), (2) biochar amendment (BC), (3) inorganic N amendment (IN) and (4) combination of biochar and N amendments (BN). The soil sample and the biochar were crushed and passed through 2 and 0.25 mm sieves, respectively. A series of 250 ml Erlenmeyer flasks with 35 g of soil sample (on an oven-dried basis) were prepared. These flasks were divided into four groups with 18 flasks for each group. Biochar was added into designated flasks at the application rate of 0.5% of soil mass (on an oven-dried basis), which is equivalent to a field application rate of 15 t ha^{-1}, and mixed well with soil. The solution of ammonium sulfate was added into designated flasks at the application rate of 100 mg N kg^{-1} while the remaining flasks were added with the same amount of deionized water as control. Soil moisture was adjusted to 80% water-filled pore space (WFPS) by adding deionized water. All flasks were covered with aluminum foils with needle-punctured holes to maintain aerobic conditions, and then incubated at 25 °C in the dark. In order to maintain soil water content, deionized water was added with mini-pipette every other day by weighing flasks during the incubation.

2.4. Measurement of soil CO_2 effluxes and DOC content

Three replicate flasks from each treatment were used to measure soil CO_2 effluxes at 0.5, 24, 72, 120, 168, 216, 264 and 720 h during incubation period. To measure CO_2 efflux and its $\delta^{13}C$, each flask was sealed using an airtight butyl rubber stopper perforated by centered

Table 1
Selected properties of soil and biochar.[a]

	pH	Organic C (g C kg^{-1})	Inorganic C (g C kg^{-1})	DOC (g C kg^{-1})	Total N (g N kg^{-1})	NH_4^+–N (mg N kg^{-1})	NO_3^-–N (mg N kg^{-1})
Soil	7.55	6.59	1.46	0.56	0.76	6.38	3.07
Biochar	10.1	639	3.51	11.2	8.87	ND	ND

DOC, dissolved organic carbon. ND, not be determined.
[a] The values denote means ($n = 4$).

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