Geoderma 282 (2016) 120–128

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Biochar addition reduced net N mineralization of a coastal wetland soil in the Yellow River Delta, China

Xianxiang Luo [a,b], Lei Chen [a], Hao Zheng [a,b,*], Jingjing Chang [a], Hefang Wang [a], Zhenyu Wang [a,b], Baoshan Xing [c,**]

[a] Institute of Costal Environmental Pollution Control, and Ministry of Education Key Laboratory of Marine Environment and Ecology, Ocean University of China, Qingdao 266100, China
[b] Laboratory of Marine Ecology and Environmental Science, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266071, China
[c] Stockbridge School of Agriculture, University of Massachusetts, Amherst, MA 01003, USA

ARTICLE INFO

Article history:
Received 1 April 2016
Received in revised form 19 June 2016
Accepted 11 July 2016
Available online 22 July 2016

Keywords:
Biochar
Soil degradation
N mineralization
C:N ratio
Urease activity

ABSTRACT

Soil degradation has seriously threatened global soil and food security. Biochar application is a promising management option to remediate the degraded soils. However, extensive application of biochar is limited by lack of understanding the effects of biochar on nitrogen (N) mineralization in the degraded coastal wetland soils. Therefore, the individual or combined effects of biochar, reed stem and urea fertilizer application on N mineralization in a coastal wetland soil were investigated using a 150-days incubation experiment, and the underlying mechanisms were discussed. Biochar addition reduced net N mineralization, but no significant effect was observed between the treatments with different addition rates. The combined addition of the biochar and reed stem had little effect on net N mineralization because of the higher C:N ratio (45.5–49.3). However, biochar addition in combination with the urea fertilizer initially decreased net N mineralization, but slightly increased it later on. The biochar-induced reduction of net N mineralization was mainly ascribed to the increased C:N ratio and decreased urease activity. Therefore, adding N fertilizer to the biochar to enhance the delivery of N prior to its incorporation into soil, which may avoid N immobilization due to N deficiency, could be an effective strategy for remediating the degraded coastal wetland soils.

1. Introduction

The dominant soils with nutrients deficiency and high-salt stress in the wetlands of Yellow River Delta, China (Wu et al., 2014), have degraded severely, thus threatening soil health and productivity (Koch et al., 2012). The low primary productivity of the coastal wetland soils is the main ecological problem in the Yellow River Delta. Although several technologies (e.g., amendments from straw residues, addition of freshwater, phytoremediation) have been used to remediate these wetland soils, they all have drawbacks (e.g., high costs, short lasting of ameliorating effects) (Wu et al., 2014). Moreover, the remediated soils are still facing severe stress due to anthropogenic disturbances such as oil exploitation, sea salt extraction and tourist industry in this region (Higgins et al., 2013). Therefore, a cost-effective and sustainable soil amendment with multiple benefits for improving soil quality, restoring primary productivity and conserving ecological functions is urgently required. The promotion of biochar technology has been proposed as one of such solutions (Lehmann and Joseph, 2015).

Biochar is a carbon-rich material produced from heating biomass in the absence of or with limited air to above 250 °C, and is distinguished itself from other carbon (C) products (e.g., charcoal, activated carbon) in that it is intended for use as a soil amendment for soil improvement and carbon sequestration, as well as other functions for environmental management (Lehmann and Joseph, 2015). Biochar has been reported to modify soil characteristics via enhancing soil aggregate stability (Soinne et al., 2014), increasing water and nutrient retention (Abel et al., 2013), and stimulating soil enzymes activities (Oleszczuk et al., 2014), and thus promoting plant growth and augmenting crop yields (Jones et al., 2012; Reibe et al., 2015). However, biochar application into soils does not always result in positive effects (Jeffery et al., 2011; Spokas et al., 2011; Carvalho et al., 2016). Spokas et al. (2011) reported that approximately 30% of the selected studies ($n = 45$) had no significant differences on crop growth or yield compared to the controls without biochar, and even 20% observed negative results. Nitrogen (N) is a major essential nutrient for plant growth, which is mainly originated from mineralization of soil organic N (SON, accounting for 85–95% of total N (TN)), to ammonium by soil microorganisms (e.g., bacteria, actinomyces) in the coastal wetland soils of the Yellow River Delta. However, the effect of adding biochar on SON mineralization in the coastal soil has received

* Correspondence to: B. Xing, Stockbridge School of Agriculture, University of Massachusetts, Amherst, MA 01003, USA; H. Zheng, Institute of Costal Environmental Pollution Control, and Ministry of Education Key Laboratory of Marine Environment and Ecology, Ocean University of China, Qingdao 266100, China.
** Corresponding author.
E-mail addresses: zhenghao2013@ouc.edu.cn (H. Zheng), bx@umass.edu (B. Xing).

http://dx.doi.org/10.1016/j.geoderma.2016.07.015
0016-7061/

much less attention than C (Sun et al., 2014; Wu et al., 2014). Sun et al. (2014) reported that adding wheat straw biochar significantly decreased C mineralization, but the incorporation of the low-temperature biochar (300 °C) alleviated the drought stress to microbes in the coastal soil. Wu et al. (2014) found that application of furfural biochar decreased the soil pH by 0.3–0.4 due to the use of acidic biochar (pH 4.5) and increased soil organic carbon (SOC) content. Because nutrient (e.g., N, P) deficiency is one of the main reasons for the low primary productivity in these wetland soils, more attention should be paid to the interactions between biochar and nutrient cycling, especially N, which is a crucial limiting factor for vegetation restoration in the degraded coastal soils.

Biochar application can alter soil N dynamics via enhancing nitrification (Ulyett et al., 2014), decreasing denitrification (Case et al., 2015), adsorbing NH_4^+ and reducing NH_3 volatilization (Mandal et al., 2016; Zheng et al., 2013b), mitigating N_2O emission (Bass et al., 2016; Case et al., 2015), increasing microbial N cycling gene abundances (Ducey et al., 2013) and improving N bioavailability for crops (Mandal et al., 2016). Therefore, it is reasonable to hypothesize that biochar application into the coastal soils may affect SON mineralization. However, addition of biochar to soils has been shown to decrease N mineralization (Prayogo et al., 2013; Dempster et al., 2012b), increase N mineralization (Ameloot et al., 2015; Maestrini et al., 2014) or have no effect on mineralization (Dempster et al., 2012a). Maestrini et al. (2014) found that the incorporation of ryegrass-derived pyrogenic organic matter (PyOM, similar to biochar) into a forest Cambisol resulted in a higher gross N mineralization due to the mineral N derived from the pyrogenic organic matter decomposition. While Prayogo et al. (2013) showed that willow biochar suppressed N mineralization when applied at both 0.5% and 2% but the mechanisms were not clear. Moreover, Dempster et al. (2012a) concluded that biochar had very limited impact on the mineralization rate of low molecular weight dissolved organic N compounds in two contrasting agro-ecosystems. These findings indicate that the effects of biochar on SON mineralization are highly variable, depending on the types of biochars and soils, and the interactions between them. Based on the possible interactions of biochar and coastal soil, we hypothesized that addition of biochar alone into the coastal soil could reduce N mineralization due to the increased C:N ratio and decreased urease activity, but the combined addition of biochar and organic N fertilizer could enhance N mineralization due to the decreased C:N ratio and pH, and the increased urease activity. To test this hypothesis, a 150-days laboratory incubation experiment was setup to evaluate the effects of peanut shell biochar application on net N mineralization in an alkaline soil collected from the coastal wetland of the Yellow River Delta. The specific objectives of this research were to: (1) evaluate the effect of biochar addition alone with different rates on the net N mineralization; (2) investigate the combined effect of adding plant residue and biochar on the net N mineralization; and (3) study the effect of adding exogenous organic N on the net N mineralization in the biochar-amended soil.

2. Materials and methods

2.1. Preparation of soil and biochar

The soil was collected from three 100-m^2 plots in a reed (*Phragmites australis*) wetland (N 37°49′31.3″, E 118°59′47.2″) in the Yellow River Delta, China, and within each plot, seven soil samples were collected to a depth of 20 cm. The soil samples were air-dried, ground to pass through a 2-mm sieve after removal of the plant residues and rocks, and then thoroughly homogenized for further analysis. The soil properties are presented in Table 1, indicating that the selected soil was alkaline, and deficient in N.

The biochar sample was produced from peanut shell at 350 °C for 2 h using slow pyrolysis as described by Zheng et al. (2013b). Shandong province, the nation's largest producer of peanut, produced >23.3% of the total peanut shell with 4.0 million tons every year (Liu et al., 2010; Wang et al., 2010). However, the majority of the peanut shell is discarded or burned directly, resulting in serious resource loss and environmental pollution. After charring, the biochar sample was ground to pass through a 2-mm sieve, and thoroughly homogenized for further analysis. The reed stems were collected from the same wetland where the soil was sampled, and dried at 75 °C for 24 h, and then ground to pass through a 2-mm sieve. The properties of the biochar and reed stem are presented in Table 1.

2.2. Soil incubation experiment

A laboratory incubation experiment was conducted with a total of seven treatments: (1) unamended soil (CK); (2) soil + 1% (*w*/w) biochar (1%BC); (3) soil + 3% biochar (3%BC); (4) soil + 3% reed stem (3%R); (5) soil + 3% reed and 3% biochar (3%R + 3%BC); (6) soil + 0.3% urea (0.3%U); (7) soil + 0.3% urea + 1% biochar (0.3%U + 1%BC). The rates of reed stem and urea fertilizer supplied sufficient C and organic N to meet the second level of the classification criteria of soil nutrients in China (National Soil Survey Office, 2002). After mixing, a 40-g soil mixture was placed into a polypropylene cup (57 mm in diameter and 47 mm in height), and all the cups were covered with lids punctured with several holes to allow gas exchange but minimize water loss from evaporation. The experiment had a completely randomized block design with seven treatments, and each treatment had thirty replicates for destructive sampling during the incubation. The soil moisture content was kept at 80% of the maximum water holding capacity (WHC) during the whole incubation period. All the cups were incubated in a constant temperature chamber (SHP-450, Jinghong, China) at 30 °C for 150 days. The soils samples were destructively sampled from three replicate cups at 0, 6, 11, 18, 25, 34, 46, 60, 100 and 150 day for analysis of NH_4^+-N, NO_3^--N, available N (AN), TN, TC, pH, electrical conductivity (EC) and urease activity.

2.3. Sample analysis

The pH, TC, TN, and NO_3^--N and NH_4^+-N content of the biochar and reed stem samples were measured as reported by Zheng et al. (2013b). Cation exchange capacity (CEC) was determined in sodium acetate extract (pH 7.0) using a flame atomic absorption spectrophotometer (M6, Thermo Elemental, USA). EC was measured in a 1:5 soil to water slurry using a conductivity meter (Cond 3210, WTW, Germany). The NH_4^+-N and NO_3^--N contents were determined using spectrophotometric method with indophenol blue reagent and phenol disulfonic acid, respectively (Zheng et al., 2013a).

Table 1
Selected characteristics of the soil, biochar and reed samples.

Samples	pH	TC (%)	TN (%)	C:N ratio	H:C atomic ratio	CEC (cmol/kg)	EC (μS/cm) [a]	NH_4^+-N (mg/kg)	NO_3^--N (mg/kg)
Soil	8.09 ± 0.02	1.13 ± 0.15	0.033 ± 0.001	34 ± 0.37	ND	9.77 ± 0.14	1548 ± 62(1:5)	4.58 ± 0.12	1.41 ± 0.07
Biochar	8.54 ± 0.03	44.0 ± 0.5	1.01 ± 0.01	44 ± 0.69	0.31	14.9 ± 0.3	5256 ± 132(1:25)	3.17 ± 0.14	0.94 ± 0.17
Reed	4.62 ± 0.02	42.9 ± 2.1	0.41 ± 0.02	105 ± 0.93	1.59	ND [b]	ND	ND	ND

[a] EC: electrical conductivity; the EC values were measured in 1:5 and 1:2.5 soil to water slurry using a conductivity meter (Cond 3210, WTW, Germany) for the soil and biochar samples, respectively.
[b] ND: not determined.