Science of the Total Environment 569–570 (2016) 390–394

Contents lists available at ScienceDirect

Science of the Total Environment

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

Temperature and moisture responses to carbon mineralization in the biochar-amended saline soil

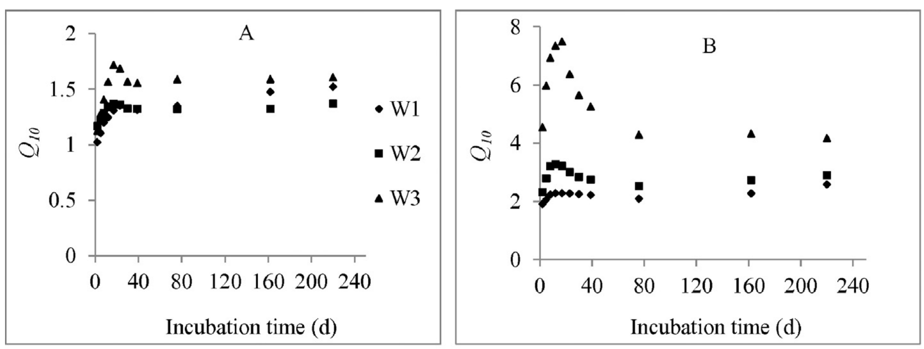
Junna Sun [a], Fuhong He [b], Zhenhua Zhang [b,*], Hongbo Shao [c,d,*], Gang Xu [d]

[a] School of Life Science, Ludong University, Yantai 264025, China
[b] Institute of Geography & Planning, Ludong University, Yantai 264025, China
[c] Institute of Agro-biotechnology, Jiangsu Academy of Agriculture Sciences, Nanjing 210014, China
[d] Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai 264003, China

HIGHLIGHTS

- Cumulative C_{min} increases with biochar added and incubation temperature.
- The temperature rise reduced the turnover time of C pools and Q_{10}.
- Cumulative C_{min} follows different trends under varying moisture conditions.
- The two-compartment model could well describe the dynamics of C_{min}.

GRAPHICAL ABSTRACT



Temperature sensitivity (Q_{10}) of carbon mineralization in saline soil under different incubation conditions (15–35°C)

ARTICLE INFO

Article history:
Received 2 May 2016
Received in revised form 12 June 2016
Accepted 13 June 2016
Available online xxxx

Keywords:
Carbon mineralization
Biochar
Temperature
Soil moisture
Saline soil

ABSTRACT

This study assessed the effects of temperature and moisture on carbon mineralization (C_{min}) in a saline soil system with biochar amendment. The dynamics of C_{min} were monitored in a biochar-amended saline soil for 220 days by incubation experiments under different conditions of temperature (15 °C, 25 °C and 35 °C) and moisture (30%, 70% and 105% of the water-holding capacity). Results showed that as the incubation temperature rose, cumulative C_{min} consistently increased in soil added with 0–4% biochar. The two-compartment model could well describe the dynamics of C_{min}. The temperature rise increased the concentration of labile C in soil, but reduced the turnover time of labile and recalcitrant C pools and the value of temperature coefficient Q_{10}. The response of C_{min} to moisture was varying in soil amended with different levels of biochar. In the control treatment (soil alone), cumulative C_{min} increased only when soil moisture was >105%. In the biochar treatments, however, 70% of water-holding capacity was optimal for C_{min}, except for 2%-biochar treatment at 35 °C. The findings highlight the necessity to consider the combined effects of soil moisture, temperature and the amount of biochar added for assessing C_{min} in biochar-amended saline soils.

* Corresponding authors at: Institute of Agro-biotechnology, Jiangsu Academy of Agriculture Sciences, Nanjing 210014, China.
E-mail addresses: zhangzh71@163.com (Z. Zhang), shaohongbochu@126.com (H. Shao).

http://dx.doi.org/10.1016/j.scitotenv.2016.06.082
0048-9697/

1. Introduction

Soil hardening, low permeability, and poor water retention–fertilizer conservation capacity are serious issues limiting soil production potential in coastal saline soils of the Yellow River Delta (Wang et al., 2010). Biochar is a solid pyrolysis product of biological matter under anoxic or hypoxic conditions at high temperatures. It typically contains 40–75% carbon (C), characterized by porous structure, large surface area, and high ion exchange capacity (Lehmann and Joseph, 2009). Application of biochar to saline soils will help to improve soil nutrient content (de la Rosa et al., 2014; Tian et al., 2016), enhance water retention–fertilizer conservation capacity (Gray et al., 2014; El-Naggar et al., 2015; Bass et al., 2016), and promote crop growth (Lashari et al., 2013; Liu et al., 2014; Agegnehu et al., 2016).

Despite its benefits mentioned above, biochar amendment may break the existing soil C balance and affect the assessment and prediction of C cycle in the soil ecosystem (Bolan et al., 2012; Bruun et al., 2011). However, decomposition of organic matter that enters the soil mainly relies on microbial activities. Microbial growth and reproduction are significantly affected by soil moisture and temperature conditions (Steiner et al., 2009).

Recent studies have examined the C mineralization (C_{min}) in biochar-amended soils (Bolan et al., 2012; Fernández et al., 2014), mostly in acid soils (Sigua et al., 2014; Zhao et al., 2015). Few studies concerning biochar amendment in saline soils have focused on the effect of temperature on C_{min} in soil. For example, Fang et al. (2014) investigated the temperature sensitivity of biochar-C in soils at 20, 40 and 60 °C in four contrasting soils including Entisol (pH = 8.77) and Vertisol (pH = 7.89). Presently, there is a limited understanding of moisture response of C_{min} in biochar-amended saline soil. Moreover, it remains unknown whether different amount of biochar applied could alter C_{min} in biochar-amended saline soil under different temperature and moisture conditions.

In this study, the dynamics of C_{min} were monitored in a biochar-amended saline soil from the Yellow River Delta by incubation experiments under different conditions of temperature and moisture. The effects of biochar amendment on C_{min} was examined in the saline soil, in order to understand the mechanisms of C cycle response to environmental changes in biochar-amended saline soil systems.

2. Material and methods

2.1. Soil and biochar

Saline soil was sampled from the 0–10 cm depth at the ecological experimental station of coastal wetland located at Dongying, Shandong Province, China (37°45′ N, 118°59′ E). The soil is a typical saline alluvial soil (Fluvisols, FAO), developed on loess material of the Quaternary period (Liu et al., 2003). The soil sample was sieved though a 2-mm sieve immediately after collection and stored at 4 °C until used. The soil had a pH (H_2O) of 8.5, a C/N ratio of 16.9, and exchanged sodium percentage of 27%.

Biochar was produced from wheat straw. After air-drying with oven, wheat straw was sieved through a 2-mm sieve and charred in a muffle oven at 300 °C for 4 h. Oxygen availability was restricted by wrapping the wood in aluminum foil during heating. The biochar contained 46.3% C and 0.6%N, respectively, with a pH (H_2O) of 6.93.

2.2. Incubation experiments

The incubation experiments included three treatments: (1) soil alone (control), (2) soil added with 2% (w/w) biochar (S + 2%C), and (3) soil added with 4% (w/w) biochar (S + 4%C). Fresh soil sample was sieved through a 2-mm sieve, and mixed with straw and biochar in a 1-L jar (total dry weight 200 g). Soil moisture was adjusted to be 30%, 70% and 105% of the water-holding capacity (WHC; W1, W2, and W3, respectively).

The jars were placed without lids at 15 °C, 25 °C and 35 °C (T1, T2, and T3, respectively) in a thermostat incubator. A rubber plug was used sealed each jar for 24 h at 2, 5, 8, 12, 17, 23, 30, 39, 76, 162, and 220 days. The rubber plug was attached to a glass tube connecting a three-way valve to facilitate gas sampling from the headspace. Gas samples were analyzed for CO_2 concentration within 24 h of collection using Agilent 7890 series gas chromatograph (Santa Clara, CA, USA). Cumulative C_{min} and C_{min} rate were calculated from the difference in CO_2 emission between 0 and 24 h. Each treatment had four replicates. Water evaporation was compensated daily by weighing the jars.

2.3. Data analysis

The rate of C_{min} was calculated as described by Sun et al. (2014). According to the trapezoidal rule, cumulative C_{min} was obtained from the sum of the area bounded by C mineralization rate. The two-compartment model was used to analyze the dependence of cumulative C_{min} on temperature and moisture. The first-order kinetic two-compartment model was fitted by Andrén and Paustian (1987) and described by Reichstein et al. (2000) in detail. It was generally thought that the labile C (C_1) and recalcitrant C (C_2) pools were equal in the same treatment. Temperature primarily affected the C_{min} rate constants (k_1 and k_2, respectively), other than the size, of C_1 and C_2 pools. However, no ideal results could be obtained from the fitting with the experimental data of C_1 and C_2 pools (data not shown). Therefore, we selected the C_1 and C_2 pools as the variables to fit the results of biochar treatments, in order to analyze the mineralization process.

The temperature coefficient (Q_{10}) of C_{min} was calculated using the formula described by Chen et al. (2000). Q_{10} has been used as a constant in most early studies of soil respiration (Xu and Qi, 2001). However, it was later found that the Q_{10} value has great variability from non-sensitive ($Q_{10} < 1$) to extremely sensitive ($Q_{10} > 20$) (Janssens and Pilegaard, 2003; Pavelka et al., 2007). This shows distinct difference from the typical temperature sensitivity ($Q_{10} \approx 2$) based on enzymatic dynamics. Analysis of variation of Q_{10} values in different types of soils has implications for accurately assessing the effect of C_{min} in the soil on CO_2 concentration in the atmosphere.

All data were analyzed using SPSS 13.0 (SPSS Inc., Chicago, IL, USA). Treatment means were separated using *t*-test and mean difference was examined by one-way ANOVA. Two-way ANOVA was applied to test the effects of moisture, temperature and biochar amendment on C_{min}. Statistical tests were considered significant at $P < 0.05$.

3. Results

3.1. Dynamics of cumulative C_{min} in biochar-amended saline soil

Table 1 shows that under different temperature conditions, cumulative C_{min} increased in different treatments with temperature rise. Taking an example S + 2%C treatment, cumulative C_{min} was 377 μg CO_2/g soil at 5 °C, which reached 651 μg CO_2/g soil (72.7% increase) at 25 °C and 1102 μg CO_2/g soil (192% increase) at 35 °C.

Under different moisture conditions, cumulative C_{min} varied in the three treatments. In the control treatment, no significant difference occurred in cumulative C_{min} between 30% WHC and 70% WHC at the indicated temperatures. A remarkable increase was observed only when soil moisture reached 105% WHC ($P < 0.05$).

In the biochar treatments, cumulative C_{min} was highest with 70% WHC, except S + 2%C at 35 °C. For instance, in the S + 4%C treatment at 25 °C, cumulative C_{min} was 668 μg CO_2/g soil with 30%WHC and 693 μg CO_2/g soil with 105% WHC, showing no substantial difference between moisture conditions. When moisture reached 70% WHC, cumulative C_{min} markedly increased to 764 μg CO_2/g soil ($P < 0.05$). However, in the S + 2%C treatment, cumulative C_{min} was highest at 35 °C, which