Ecological Engineering 104 (2017) 141–149

Contents lists available at ScienceDirect

Ecological Engineering

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

Seasonal dynamics of soil microbial activity after biochar addition in a dryland maize field in North-Western China

Li-xia Zhu[a,b], Qian Xiao[a,c], Hong-yan Cheng[a,b], Bing-jie Shi[a,b], Yu-fang Shen[a,*], Shi-qing Li[a,*]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, 712100, China
[b] College of Natural Resources and Environment, Northwest A&F University, Yangling, 712100, China
[c] College of Forestry, Northwest A&F University, Yangling, 712100, China

ARTICLE INFO

Article history:
Received 16 November 2016
Received in revised form 15 March 2017
Accepted 9 April 2017
Available online 21 April 2017

Keywords:
Biochar rates
Microbial dynamics
Soil water content
Urease
Alkaline phosphatase

ABSTRACT

Soil microbes are of great importance in assessing key ecosystem functions due to their high sensitivity and capacity of providing ecologically relevant information. Benefits of biochar have been demonstrated, including enhancing carbon (C) sequestration and improving soil fertility. Considerable attention has been taken to effects of biochar on soil properties; however, information regarding effects of biochar on seasonal changes of soil microbial activities in field experiments in dryland soil was not well known. Based on a 2-year spring maize (*Zea mays* L.) field experiment, we examined changes in soil microbial biomass carbon (MBC), nitrogen (MBN), phosphorus (MBP), urease and alkaline phosphatase activities with three biochar application rates (0, 10, and 30 t ha^{-1}) at 0–10 cm and 10–20 cm soil layers in year 2013 and 2014 in silty loam soils on the Loess Plateau in North-Western China. Our results indicated that biochar increased MBC except at silking stage (R1) in 2013, whereas it tended to decrease MBC except at 6-leaf stage (V6) in 2014. MBN in the shallower (0–10 cm) soil layer in 2013 and MBP in 2014 generally increased with biochar rates. Significant positive correlations between microbial biomass and soil water content (SWC) were observed. Results also showed that there were considerable fluctuations in enzymes activities across the growth periods and depths. Biochar significantly increased alkaline phosphatase activities in 2014, and resulted in small but detectable shifts in soil urease activities in both years. These results provided evidence that biochar addition could be an effective management practice for soil microbial activities throughout crop growing season in a dry agricultural system, although soil factors from different climates might lead to some shifts of effects of biochar.

1. Introduction

Biochar, produced by crop residues or any other organic waste through process of pyrolysis, has been an important topic in soil science, and many study groups are studying effects of biochar on agroecosystems. Currently, biochar has been taken as a soil amendment to improve soil fertility and sequester carbon (Lehmann and Joseph, 2009; Sohi et al., 2010) by its resistance to degradation in soil (Mašek et al., 2013); effects of biochar on soil physical and chemical properties, such as increasing soil water content retention (Glaser et al., 2002) and soil pH (Yuan et al., 2011), affecting soil structure (Zhang et al., 2011), reducing greenhouse emissions (Karhu et al., 2011) and promoting available soil nutrients (dissolved organic matter, P, K) (Liang et al., 2006) have also been studied. However, the extent of change is mainly dependent upon the size and activity of the microbes and enzymes, which are more sensitive to fluctuations of soil quality and environment.

The special porous structure of biochar (Downie et al., 2009) would trap carbon substrates, especially water-extractable organic carbon (Lin et al., 2012), and mineral nutrients, which will in turn affect soil microbial structure and activity (Anderson et al., 2011; Kolb et al., 2009; Lehmann et al., 2011; Liang et al., 2010; O'Neill et al., 2009) due to a relatively satisfactory micro-environment for microbes. To date, responses of soil microbial biomass to biochar amendment varied mainly due to different biochar types, soil textures and other ecosystem attributes. In multiple experimental cases, there is growing evidence that biochar may increase microbial biomass (Bruun et al., 2011; Smith et al., 2010; Steinbeiss

* Corresponding author at: State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, 712100, China.
E-mail addresses: justin2118@163.com (L.-x. Zhu), shenyufang@nwsuaf.edu.cn (Y.-f. Shen), sqli@ms.iswc.ac.cn (S.-q. Li).

http://dx.doi.org/10.1016/j.ecoleng.2017.04.026
0925-8574/

et al., 2009; Zimmerman et al., 2011) as a result of the presence of labile carbon fractions and residual organic material. Luo et al. (2013) conducted an incubation experiment with biochars prepared at 350 °C (BC350) and 700 °C (BC700); BC350 significantly increased MBC, while BC700 showed low biological activities 90 days later. In response to application of biochar from eucalyptus to a coarse-textured soil, Dempster et al. (2011) found a decrease in MBC and soil organic carbon (SOC) decomposition. However, these effects might be undervalued or overestimated under controlled conditions; field conditions are complex and dynamic and many soil processes might be affected by biochar years after the initial application. Some studies showed no or little effect of biochar on microbial biomass, because recalcitrance (Kuzyakov et al., 2009) and toxicity effect (Dempster et al., 2011) may reduce microbial biomass. In the long term, however, influences within agricultural soils appear less certain; both positive and negative effects of biochar on soil microbial biomass have been observed (Keith et al., 2011; Zimmerman et al., 2011). Difference in pyrolysis temperature, organic materials, soil structure and properties, as well as rates and manners of biochar addition make it difficult to synthesize disparate responses. Thus, there is a need to further understand effects of biochar on soil microbial biomass, especially when seasonal changes might alter microbial mediated nutrient dynamics and affect nutrient availability for crops.

Microorganisms are largely responsible for decomposition of soil organic matter via a variety of enzymes, whose activities are also sensitive indicators of soil environments. Few studies have been undertaken to examine effects of biochar on soil enzyme activities. Jin (2010) found that activities of soil alkaline phosphatases increased with biochar rates, while β-D-glucosidase activities decreased. It has also been found that biochar amendment could suppress enzyme activities related to soil carbon mineralization, while promoting activities of enzymes relevant to N, P translation and utilization (Awad et al., 2012; Bailey et al., 2011). However, different soil conditions throughout crop growing season and variable climates could result in changes of soil physico-chemical factors, which would in turn lead to changes in effects of biochar on soil microbes. Thus, long-term studies on field trials are required to further understand effects of different rates and types of biochar on key ecosystem functions.

In the present study, a field experiment with three rates of biochar addition was performed over two consecutive growing seasons. This study aimed to compare the seasonal variations of soil microbial biomass and enzyme activities in calcareous soils from different soil layers in a dryland maize field on the Loess Plateau. We hypothesized that (1) biochar would affect soil microbial biomass and enzyme activities, (2) effects of biochar on soil microbial biomass and enzyme activities would show seasonal fluctuations which might be caused by shifts in SWC. The results would be useful in explaining details of soil microbes and related ecological processes in this study area.

2. Materials and methods

2.1. Site description and biochar characteristics

The experiments were performed at the Changwu Agricultural and Ecological Experimental Station on the Loess Plateau in China (35.28°N, 107.88°E, 1200 m above sea level). Dryland farming is dominated by monoculture cropping systems that are mainly comprised of spring maize (*Zea mays* L.), which is produced by rain-fed agriculture across the region. The average annual precipitation was 580 mm, with about 73% falling during the growing season of spring maize (from May to September) and the annual evaporation was 1565 mm. The precipitations of the experimental station in year 2013 and 2014 are listed in Table 1. The annual average air temperature is 9.1 °C, with a mean air temperature of 19.7 °C between May and September. The soils at this site are Cumuli-Ustic Isohumosols (Gong et al., 2007) with a loam texture of 13% sand, 72% silt, and 15% clay. In April 2013, prior to the start of the experiment, the main properties of soil in top 20 cm layer were as follows: bulk density 1.3 g cm^{-3}, pH 7.9, organic matter 15.1 g kg^{-1}, total N 0.99 g kg^{-1}, Olsen-P 6.6 mg kg^{-1}, NH_4OAc-K 127.1 mg kg^{-1}, and mineral N 9.96 mg kg^{-1} (NO_3^--N and NH_4^+-N).

Table 1
Annual and monthly rainfall (mm) during the growth period of maize in year 2013–2014 and the 20-year average at the experiment site.

Years	Months						
	April	May	June	July	August	September	Annual
2013	22	66	42	237	38	117	579
2014	83	29	56	21	135	35	412
20-year	36	46	71	94	106	84	548

The biochar used in this experiment was made from maize straw by low pyrolysis and thermal decomposition at 450 °C. The biochar had a carbon concentration of 591.60 g kg^{-1} and a N concentration of 9.77 g kg^{-1}. The initial values of the density and pH were 0.4 g cm^{-3} and 9.8, respectively.

2.2. Experimental design and field management

In this study, the biochar application rates were set at 0, 10 and 30 t ha^{-1} and designated as BC0, BC10 and BC30, respectively. The biochar was applied evenly to the soil surface only in April 2012 before maize sowing, and was then incorporated to a depth of 20 cm. Each treatment had an area of 56 m^2 and measured 7 m × 8 m arranged in a completely randomized block design with three replicates. All treatments had alternating wide (60 cm) and narrow (40 cm) row spacing. In each treatment the same fertilizer was applied. The chemical fertilizers were broadcast over the soil at rates of 90 kg N ha^{-1} in the form of urea (N 46%), 40 kg P ha^{-1} in the form of calcium super phosphate (P_2O_5 12%), and 80 kg K ha^{-1} in the form of potassium sulphate (K_2O 45%) as the base fertilizer on each treatment; the soil was then ploughed to mix the fertilizer into the subsurface. In each treatment, the maize (*Zea mays* L.) was planted 5 cm deep at a density of 65,000 plants ha^{-1} at the end of April in each experiment year. An additional 67.5 kg N ha^{-1} (urea, N 46%) was applied using a hole-sowing machine in the furrows at the jointing and tasselling stages. The maize was harvested gradually, when ripe, at the end of September each year.

2.3. Soil sample collection and preparation

Soils were sampled during maize growing season from April to September in 2013 and 2014, which can be divided into five stages: (i) before sowing (PT), (ii) the 6-leaf stage (V6), (iii) the silking stage (R1), (iv) the dent stage (R5) and (v) the physiological maturity stage (R6). At each treatment, soil cores were drilled randomly using a 4 cm diameter auger with three replications and then mixed into one composite sample for each soil depth (0–10 cm and 10–20 cm). Each soil sample was sieved at 2 mm to remove visible plant residues and aggregates. The fresh soil samples were transported in a low temperature to the laboratory and divided into three parts. One part was used to determine the SWC, one part was air-dried for the determination of SOC and the other part was stored at 4 °C before microbial analyses within one week.