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Responses of microbial performance and community to corn biochar in calcareous sandy and clayey soils

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ABSTRACT

Biochar can be used as an organic amendment to improve soil physical and chemical attributes, with a potentially significant influence on soil microbial performance. However, this effect of biochar is poorly understood for arid soils with low organic matter content. The main objective of this study was to quantify the response of microbial attributes to corn biochar in two calcareous soils with different texture. Three slow pyrolysis biochars were prepared at 200, 400 and 600 °C from corn feedstocks. The biochars were added to sandy and clayey soils at 0.5 and 1% (w/w) and the mixtures were incubated for 90 days under standard laboratory conditions (25 ± 1 °C and 70% of soil field capacity). Soils amended with raw (uncharred) feedstock and unamended (without biochar and raw residue) as the control were also considered in the experiment. The soil properties measured included microbial respiration during 60 days, microbial biomass carbon (C), substrate-induced respiration (SIR), fungal (FR) and (BR) bacterial respiration at the end of the incubation. Compared with the unamended control, the addition of corn raw feedstock or its biochar significantly increased cumulative microbial respiration (62–462%), MBC (66–169%), SIR (50–216%), BR (129–308%) and FR (42–200%), but tended to decrease FR/BR ratio (5–90%), depending largely upon its production temperature and application rate as well as soil texture. The positive effects of biochar addition on increasing microbial properties were more pronounced at 1% than 0.5% application rates for all the attributes and in sandy than clayey soils for MBC, SIR and FR attributes. Overall, the measured microbial attributes were all greater in uncharred than charred feedstock treatments and tended to decline with increasing pyrolysis temperature. The relative abundance of soil bacteria increased with biochar addition and pyrolysis temperature, while that of soil fungi decreased. Biochar addition increased microbial performance potentially due to an increase in soil C content while increasing pyrolysis temperature altered biochar chemistry and properties which may have contributed to the decreased microbial performance. It is concluded that although biochar application may improve microbial processes and attributes in calcareous soils with low organic matter content, its effects on microbiological properties are mainly meditated by soil texture, pyrolysis temperature for biochar production and application rate. The greatest response by the microbial indicators can occur when corn biochars produced at low temperatures were added to less fertile sandy soils at 1% addition rate. The study provided clear evidence that application of low temperature corn biochars at 45–50 t ha^{-1} to calcareous soils may have a great potential for improvements in the microbial indicators of soil quality.

1. Introduction

Biochar is the product of biomass feedstocks pyrolized at different temperatures in an oxygen-limited environment. It is commonly used to improve soil fertility and quality, increase plant growth and sequester carbon (C) in soil for mitigating climate change (Lehmann et al., 2009; Spokas, 2010). Biochar as an amendment can increase soil fertility and quality by affecting different soil processes and properties (Demisie et al., 2014; Paz-Ferreiro et al., 2014; Obia et al., 2016), and subsequently enhancing plant growth and C sequestration rate (Spokas, 2010; Wu et al., 2013; Windeatt et al., 2014). The important and beneficial effects of biochar application on soil fertility and quality are positive changes in soil physical and chemical properties (Masto et al., 2013a; Wu et al., 2013; Demisie et al., 2014; Xu et al., 2016) with a potentially

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significant impact on soil microbial functions (Masto et al., 2013a, b; Demisie et al., 2014; Ippolito et al., 2014; Gul et al., 2015).

Understanding the direct and indirect effect of biochar on soil microbial properties is an important aspect of biochar studies because these soil properties are often considered powerful and sensitive indicators of soil functioning and quality (Bastida et al., 2008; Paz-Ferreiro and Fu, 2016). However, the long- and short-term effects of biochar addition on microbial attributes are somewhat inconclusive and cannot be generalized for its practical application at a large scale in different soil types (Lehmann et al., 2011; Paz-Ferreiro et al., 2012; Masto et al., 2013a; Gul et al., 2015). This is particularly true in calcareous soils of arid regions with low soil organic matter (SOM) content and water availability (Ippolito et al., 2014; Elzobair et al., 2016).

The enhanced soil microbial properties have been attributed to an improvement in soil physical and chemical properties, the abundance of microbial population and the creation of a favorable microhabitat for soil microbes (Pietikäinen et al., 2000; Luo et al., 2013; Gul et al., 2015; Abujabhah et al., 2016). Specifically, the positive impacts of biochar on soil microbial properties could be primarily due to improved soil structure and aeration, increased soil specific surface area, improved soil water holding capacity or the presence of different labile C compounds for microbial utilization in the biochar (Smith et al., 2010; Lehmann et al., 2011; Demisie et al., 2014). Application of biochar may also change the soil microbial community composition and functional groups due to supply of labile C fractions and changes in soil pH and salinity (Rousk et al., 2013; Abujabhah et al., 2016; Xu et al., 2016). Yet, biochar addition to the soil can have no (Masto et al., 2013a; Lu et al., 2014; Rutigliano et al., 2014; Elzobair et al., 2016) or in some instances even negative (Paz-Ferreiro et al., 2012; Mukherjee et al., 2016) impacts on soil microbiological properties, depending on specific soil attributes considered. Though the underlying mechanisms behind positive or negative effects are poorly understood and unclear, it is probably due to changes in the soil pH and salinity (Paz-Ferreiro et al., 2012, 2014; Ameloot et al., 2013; Masto et al., 2013a) or changes in biochar chemistry and properties such as its aromaticity, hydrophobicity and toxicity after pyrolysis (Cantrell et al., 2012; Al-Wabel et al., 2013). The inconsistencies in the direction and magnitude of biochar effects on soil microbial and biochemical attributes are also due to differences in soil type, biochar source and particle size, production conditions (pyrolysis temperature and duration), application rate and occasionally the length of experiment (Zimmerman et al., 2011; Demisie et al., 2014; Paz-Ferreiro et al., 2014; Gul et al., 2015). For instance, biochar application increased soil respiration in the Ultisol with low organic matter but not in the Mollisol with high organic matter (Purakayastha et al., 2016). Kolb et al. (2009) studied the effect of charcoals produced at 500 °C from a feedstock mixture on two Entisols with different texture and C contents; and found that charcoal addition increased microbial biomass and activity in loamy sand soils more than in finer-textured soils. Spokas and Reicosky (2009) quantified the effects of 16 different biochars produced from different biomass feedstock on net CO_2 efflux from agriculture soils and observed that some biochars (5) increased, a few (3) reduced and the rest had no influence on soil respiration. However, these effects of biochar addition on microbial properties are particularly limited and poorly known for less fertile arid and semi-arid soils containing very low organic matter content (Smith et al., 2010; Ippolito et al., 2014, 2016b; El-Mahrouky et al., 2015; Elzobair et al., 2016). More importantly, very few information is available about how pyrolysis temperature and biochar application rate would affect these soil properties.

Application of different soil amendments such as biochar may help to increase or at least maintain SOM level and biological activities and subsequently soil fertility and quality in arid and semi-arid lands (Ippolito et al., 2014, 2016a; El-Mahrouky et al., 2015). Thus, the objectives of this short-term study were to quantify the effects of corn biochar produced at different pyrolysis temperatures on soil microbial attributes, compare soil microbial attributes between the soils amended with corn biochar and uncharred corn feedstock (un-carbonized materials) and establish whether corn biochar effects would vary with pyrolysis temperature, application rate and soil texture in arid soils with low SOM content. We tested the hypotheses that biochar addition to soil would stimulate microbial biomass and respiration, and the stimulating effects of corn biochar would vary with pyrolysis temperature and application rate. Specifically, it is also hypothesized that sandy soils with low C content would more likely benefit from biochar application than clayey soils with high C content.

2. Materials and methods

2.1. Soil sampling and analysis

Sandy and clayey soils samples were obtained from the 0–30 cm depth in arable fields located in Alborz province, northwest Iran. The mean long-term annual rainfall at the sampling site is 256 mm and average yearly temperature is 14.2 °C. The study site was not under cultivation prior to soil sampling. The soils were classified as Typic Haplocalcid derived from calcareous sediments. Twenty individual samples from 100 m × 100 m plots were collected and mixed thoroughly to obtain a composite sample (>10 kg) for each soil type. Soil samples were air-dried and passed through a 2-mm mesh. Visible stones and crop fragments were removed. Initially, soil texture (Gee and Bauder, 1986) and some chemical properties were determined. The selected characteristics of the study soils are presented in Table 1.

2.2. Biochar production and characterization

The raw feedstock for biochar production was collected from a corn field at Soil and Water Research Institute, Meshkin Dasht, Karaj, Iran. The raw corn stalks were initially air-dried and ground to pass a 2-mm sieve. Corn biochars were then produced using slow pyrolysis procedure by heating to 200, 400 and 600 °C temperatures for 2 h in a laboratory thermal furnace (Shimaz 2.5L, Shimaz-Co). A stainless steel cylinder (30 cm height, 10 cm diameter, 0.5 cm thickness) with two small holes (1 mm diameter) was used to create an oxygen-limited environment and protect raw materials from the free oxygen. First, the raw feedstocks were wrapped in aluminum foil to further minimize free oxygen before thermal combustion. Next, the wrapped feedstocks were placed in the cylinder. Finally, the cylinder was placed into the muffle furnace and heated gradually to the target temperatures. Biochar subsamples were obtained for the analysis of physical and chemical characteristics using the procedures described previously (Cantrell et al., 2012; Enders et al., 2012; Al-Wabel et al., 2013). The measured chemical characterization and properties of raw biomass and its biochars are reported in Table 1.

2.3. Experimental design, and soil incubation and analysis

We used a 2 × 4 × 2 full-factorial experiment organized in a completely randomized design with four replicates of each treatment combination including the following factors: (1) soil texture (sandy and clayey), (2) biochar produced at 0, 200, 400 and 600 °C, and biochar application rate (0.5 and 1% w/w), resulting in total number of 64 experimental units. The equivalent field rates of these amendments for the 0–30 cm depth was nearly 26 and 52 t ha^{-1} of corn residue or biochar for sandy soil, and 23 and