Agriculture, Ecosystems and Environment 225 (2016) 150–159

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Response of different soil organic matter pools to biochar and organic fertilizers

César Plaza[a,*], Beatrice Giannetta[b], José M. Fernández[a], Esther G. López-de-Sá[a], Alfredo Polo[a], Gabriel Gascó[c], Ana Méndez[d], Claudio Zaccone[b]

[a] Instituto de Ciencias Agrarias, Consejo Superior de Investigaciones Científicas, Serrano 115 bis, 28006 Madrid, Spain
[b] Department of the Sciences of Agriculture, Food and Environment, University of Foggia, via Napoli 25, 71121 Foggia, Italy
[c] Departamento de Producción Agraria, ETSI Agrónomos, Universidad Politécnica de Madrid, Ciudad Universitaria, 28040 Madrid, Spain
[d] Departamento de Ingeniería Geológica y Minera, ETSI Minas y Energía, Universidad Politécnica de Madrid, Ríos Rosas 21, 28003 Madrid, Spain

ARTICLE INFO

Article history:
Received 19 October 2015
Received in revised form 15 April 2016
Accepted 20 April 2016
Available online 27 April 2016

Keywords:
Biochar
Microbial biomass C
Municipal solid waste compost
Physical fractionation
Sewage sludge
Soil respiration
Stable isotopes

ABSTRACT

A full understanding of the agronomic and environmental potential of biochar, and especially its potential as a C sequestration strategy, requires a full comprehension of its effects on native soil organic matter (SOM), as well as of its interactions with other organic amendments co-applied to the soil. In a field experiment, we investigated changes in quantity and quality of SOM pools characterized by different protection mechanisms as affected by 20 t ha^{-1} of biochar added alone or combined with two different organic fertilizers (i.e., municipal solid waste compost and sewage sludge) 8 months after application. In particular, free, intra-macroaggregate, intra-microaggregate, and mineral-associated SOM fractions were separated and analyzed for organic C, total N, and stable isotopic ratios; further, diffuse reflectance infrared Fourier transform spectroscopy was used to examine functional group composition. Soil biomass C content, basal respiration, and metabolic quotient were also determined. Biochar and organic fertilizer application increased significantly SOM content. Biochar accumulated mainly in the free SOM pool, not protected by the soil mineral matrix. Especially noteworthy was the significant interaction effect found between the biochar and organic fertilizer factors on mineral-associated organic C content. This suggested a promoting action of biochar on C stabilization in organically-fertilized soils through the formation of organo-mineral complexes. Organically-fertilized soils had higher microbial C than unfertilized soils. Basal respiration and metabolic quotient, however, were not affected by any of the treatments. As a whole, our results support the potential of biochar application as a strategy to sequester C in soils.

1. Introduction

Biochar is a C-rich product made by the pyrolysis of biomass (e.g., plant-derived biomass), with the intention of climate change mitigation and soil quality enhancement (e.g., Lehmann and Joseph, 2015). In particular, C in biochar is believed to form very stable structures, which can be stored in soils for much longer than the biomass C from which it originates, thus helping to fight global warming. Other benefits of soil application of biochar have been reported to include increased water and nutrient retention, increased cation-exchange capacity, correction of soil acidity, habitat for soil microbes, and control of plant pathogens, among others (e.g., Lehmann, 2007; Masiello et al., 2013; Lehmann and Joseph, 2015).

In spite of potential environmental and agricultural benefits of biochar application, there are still many open questions about its potential deleterious effects (Cernansky, 2015). In particular, some studies have found that biochar may increase mineralization rates of native soil organic matter (SOM). For example, Wardle et al. (2008) found that applying biochar stimulated soil microbial activity and loss of boreal forest humus over a 10-year period. Similarly, Luo et al. (2011) and Singh and Cowie (2014) reported positive priming effects of biochar on native SOM in incubation experiments. On the other hand, there are also studies in the literature showing no effects or even negative priming effects (Liang et al., 2010; Cross and Sohi, 2011; Jones et al., 2011; Lu et al., 2014; Weng et al., 2015). According to Zimmerman et al. (2011), differences in the magnitude and sign of the priming effect hinges

* Corresponding author.
E-mail address: cesar.plaza@csic.es (C. Plaza).

http://dx.doi.org/10.1016/j.agee.2016.04.014
0167-8809/

on soil and biochar type, such that SOM mineralization tends to be stimulated in soils with low C content treated with biochars produced at low temperatures from grasses instead of woods.

For given climatic and environmental conditions, the interacting mechanisms that protect organic matter in the soil from mineralization conceptually include (a) selective preservation and synthesis of recalcitrant structures, (b) physical disconnection from decomposers, microbial enzymes, and O_2 by inclusion within macro and microaggregates, and (c) inaccessibility by chemical association with mineral surfaces (e.g., Piccolo, 2001; Six et al., 2002a; Von Lützow et al., 2006; Schnitzer and Monreal, 2011; Courtier-Murias et al., 2013; Plaza et al., 2013). Despite much effort over the past years, the processes and mechanisms contributing to organic matter stabilization and destabilization in soils treated with biochar remain largely unknown. Particularly little attention has been devoted to the interaction of biochar with other products used in agriculture to ameliorate soil fertility. Biochar is a recalcitrant material potentially suited to enhance C sequestration in soils, with much slower rates of decomposition than other organic amendments (e.g., Bolan et al., 2012), but not a significant source of plant nutrients. Thus, biochar application in combination with organic fertilizers is believed to be a promising strategy to improve its benefits on soil quality and crop yields (Ngo et al., 2013, 2014).

The objectives of this work were to (a) investigate the effects of biochar on SOM pools linked to conceptual stabilization mechanisms and (b) examine whether biochar interferes with the stabilization of organic C provided with two different organic fertilizers (i.e., municipal solid waste compost and sewage sludge) co-applied to the soil. Our hypothesis was that biochar would affect the quality and quantity of native SOM and the stabilization mechanisms of organic matter in fertilized soils, mainly through changes in soil microbial growth and activity.

2. Materials and methods

2.1. Experimental site, soil, biochar, and organic fertilizers

The site selected for this research was located in the experimental farm "La Poveda" (Spanish National Research Council, CSIC), Arganda del Rey, Madrid, Spain (40°19′ N, 3°29′ W, 534 m above sea level). The site was characterized by a Mediterranean climate, with an average annual rainfall of 436 mm and average annual temperature of 14 °C. The soil showed a clay loam texture and was classified as a Xerofluvent (Soil Survey Staff, 2014). The biochar used in this study was produced in a pyrolysis plant from holm oak (*Quercus ilex* L.) chips through a slow pyrolysis process at 600 °C. The municipal solid waste compost was produced using a conventional windrow composting system at a waste treatment plant. The sewage sludge consists of the granular end-product obtained by heat drying urban wastewater solids at about 75 °C at a wastewater treatment facility. The main properties of the top soil (0–15 cm), biochar, and conventional amendments were reported in Fernández et al. (2014a) and are summarized here in Table 1.

2.2. Field experiment and soil sampling

The experiment was set up as a randomized complete block design with two factors, namely biochar and organic fertilizer, with four replicates. In particular, a control treatment (no biochar) and a biochar application at a rate of 20 t ha^{-1} were combined with no organic fertilization, municipal solid waste compost at a rate equivalent to 75 kg potentially available N (PAN) ha^{-1}, and sewage sludge at a rate equivalent to 75 kg PAN ha^{-1}. All plots ($5 \times 3\ m^2$) were planted with winter barley (*Hordeum Vulgare* L.) in mid-November 2012. Biochar and organic fertilizers were hand broadcast in late October 2012 and immediately incorporated into the upper 15 cm of soil with a rotary tiller. The rate of biochar used in this study can be considered medium (Jeffery et al., 2011), whereas the rate of organic fertilizer was selected to meet the annual N needs of the crop.

Barley was harvested in late June 2013. A two-way analysis of variance (ANOVA) revealed a significant effect of organic fertilization on aboveground biomass ($p < 0.05$), such that yields were significantly higher by 27 and 8% on the soils treated with sewage sludge and municipal solid waste compost than on the unfertilized soils. There were no main or interaction effects of biochar on aboveground biomass. Main and interaction effects of biochar and organic fertilization on grain yield were not significant (Moreno-Jiménez et al., 2016).

Just after barley harvest, soil samples representative of the plow layer (0–15-cm depth) were collected randomly from each plot. As common in the study area, soils were dry at the time of sampling. The soil samples were gently crushed and passed through a 2-mm sieve for physical fractionation and microbiological analysis. An aliquot of each sieved sample was ground with a ball mill for organic C and total N analyses.

2.3. Physical fractionation of soil organic matter

Free, intra-macroaggregate, intra-microaggregate, and mineral-associated SOM were separated using the method described by Plaza et al. (2012) with modifications detailed by Plaza et al. (2013). This method is based on the densimetric procedure of Golchin et al. (1994) and Sohi et al. (2001) for the fractionation of free and occluded SOM and the method of Six et al. (2000, 2002b) for the breakup of macroaggregates preserving microaggregates. In brief,

Table 1
Chemical properties (mean ± standard error of three laboratory replicates) of the soil, biochar, municipal solid waste compost, and sewage sludge used in this work (data from).

Property	Soil	Biochar	Compost	Sewage sludge
pH	8.80 ± 0.03	10.06 ± 0.01	6.79 ± 0.01	7.30 ± 0.03
EC (dS m^{-1})	0.11 ± 0.00	2.4 ± 0.0	10.8 ± 1.0	2.2 ± 0.2
Total organic C (g kg^{-1})	10.0 ± 0.1	597 ± 31	295 ± 3	277 ± 4
Inorganic C (g kg^{-1})	5.9 ± 0.1	14.7 ± 1.6	9.4 ± 3.8	9.3 ± 4.0
Total N (g kg^{-1})	1.2 ± 0.0	4.1 ± 0.6	16.0 ± 0.2	43.9 ± 0.5
C/N	8.3 ± 0.1	151 ± 18	18.45 ± 0.02	6.31 ± 0.09
P (g kg^{-1})	0.006 ± 0.001[a]	2.0 ± 0.2	3.1 ± 0.2	19.2 ± 0.8
K (g kg^{-1})	0.21 ± 0.02[a]	9.1 ± 0.7	6.9 ± 0.2	3.6 ± 0.1
Ca (g kg^{-1})	2.93 ± 0.14[a]	52.4 ± 4.0	38.2 ± 1.6	30.3 ± 0.8
Mg (g kg^{-1})	0.25 ± 0.02[a]	3.5 ± 0.3	3.5 ± 0.2	6.2 ± 0.1
Na (g kg^{-1})	0.069 ± 0.006[a]	0.3 ± 0.0	4.5 ± 0.2	0.7 ± 0.0

EC, electrical conductivity.
[a] Available content.