Science of the Total Environment 613–614 (2018) 20–29

Contents lists available at ScienceDirect

Science of the Total Environment

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

Effect of biochar amendment on compost organic matter composition following aerobic composting of manure

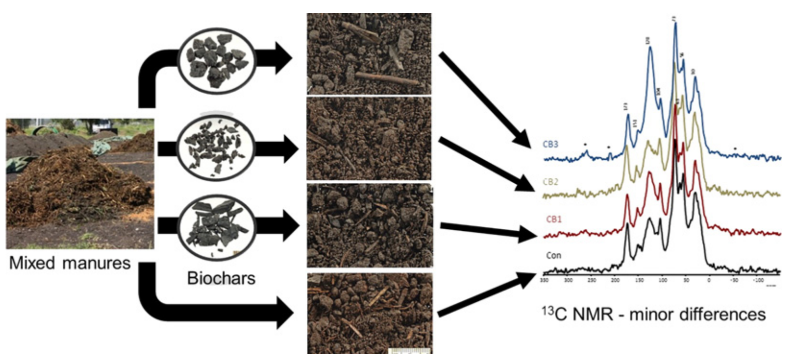
Nikolas Hagemann [a,*,1], Edisson Subdiaga [b], Silvia Orsetti [b], José María de la Rosa [c], Heike Knicker [c], Hans-Peter Schmidt [d], Andreas Kappler [a], Sebastian Behrens [e,f,**]

[a] Geomicrobiology, Center for Applied Geoscience, University of Tuebingen, Sigwartstrasse 10, 72076 Tuebingen, Germany
[b] Environmental Mineralogy and Chemistry, Center for Applied Geoscience, University of Tuebingen, Sigwartstrasse 10, 72076 Tuebingen, Germany
[c] Instituto de Recursos Naturales Agrobiología de Sevilla (IRNAS-CSIC), Av. Reina Mercedes, 10, 41012 Seville, Spain
[d] Ithaka Institute for Carbon Strategies, Ancienne Eglise 9, Arbaz 1974, Switzerland
[e] Department for Civil, Environmental, and Geo-Engineering, University of Minnesota, MN, United States
[f] BioTechnology Institute, University of Minnesota, MN, United States

HIGHLIGHTS

- Overall, biochar had minor impacts on organic matter speciation after optimized aerobic composting.
- ^{13}C NMR does not reveal biochar-induced changes in compost bulk C speciation.
- Just FT-IR suggests that compost feedstock decomposition decreased in the presence of biochar.
- Sewage sludge biochar reduced concentrations of dissolved organic carbon in compost.
- Higher total organic carbon content can be widely explained by the added biochar-C.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 March 2017
Received in revised form 15 August 2017
Accepted 15 August 2017
Available online 9 September 2017

Editor: D. Barcelo

Keywords:
Pyrogenic organic carbon
FTIR
NMR
Humic substances
Amazonian Dark Earth
Sewages sludge char

ABSTRACT

Biochar, a material defined as charred organic matter applied in agriculture, is suggested as a beneficial additive and bulking agent in composting. Biochar addition to the composting feedstock was shown to reduce greenhouse gas emissions and nutrient leaching during the composting process, and to result in a fertilizer and plant growth medium that is superior to non-amended composts. However, the impact of biochar on the quality and carbon speciation of the organic matter in bulk compost has so far not been the focus of systematic analyses, although these parameters are key to determine the long-term stability and carbon sequestration potential of biochar-amended composts in soil. In this study, we used different spectroscopic techniques to compare the organic carbon speciation of manure compost amended with three different biochars. A non-biochar-amended compost served as control. Based on Fourier-transformed infrared (FTIR) and ^{13}C nuclear magnetic resonance (NMR) spectroscopy we did not observe any differences in carbon speciation of the bulk compost independent of biochar type, despite a change in the FTIR absorbance ratio 2925 cm^{-1}/1034 cm^{-1}, that is suggested as an indicator for compost maturity. Specific UV absorbance (SUVA) and emission-excitation matrixes (EEM) revealed minor differences in the extractable carbon fractions, which only accounted for ~2–3% of total organic carbon. Increased

* Corresponding author.
** Correspondence to: S. Behrens, Department for Civil, Environmental, and Geo-Engineering, University of Minnesota, MN, United States.
E-mail addresses: nikolas.hagemann@agroscope.admin.ch (N. Hagemann), sbehrens@umn.edu (S. Behrens).
[1] Present address: Agroscope, Environmental Analytics, Reckenholzstraße 191, 8046 Zurich, Switzerland.

http://dx.doi.org/10.1016/j.scitotenv.2017.08.161

EEM
Electron exchange capacity
Farmyard manure

total organic carbon content of biochar-amended composts was only due to the addition of biochar-C and not enhanced preservation of compost feedstock-C. Our results suggest that biochars do not alter the carbon speciation in compost organic matter under conditions optimized for aerobic decomposition of compost feedstock. Considering the effects of biochar on compost nutrient retention, mitigation of greenhouse gas emissions and carbon sequestration, biochar addition during aerobic composting of manure might be an attractive strategy to produce a sustainable, slow release fertilizer.

1. Introduction

Biochar is defined as charred organic matter produced by pyrolysis that has multiple uses in agriculture and is eventually applied as a soil amendment (EBC, 2012; Lehmann and Joseph, 2009). Its use as a soil amendment is motivated by the global historic use of charcoal that led to the formation of anthropogenic soils including the Amazonian Dark Earths in the Amazon basin ("Terra Preta do Indio", Glaser, 2007). Amazonian Dark Earths and similar soils worldwide have a higher agronomic value and a higher content of organic matter than their adjacent, non-anthropogenic soils that have not received an anthropogenic input of pyrogenic carbon (Lehmann et al., 2003; Wiedner and Glaser, 2015). However, the addition of pure biochar to soil combined with conventional agricultural practices, especially the application of inorganic fertilizers, does not necessarily increase soil quality and crop yields (Crane-Droesch et al., 2013; Hagemann et al., 2017a; Jeffery et al., 2015). The combination of biochar with organic amendments, such as compost, has recently received increasing attention due to promising results in both pot and field experiments (Kammann et al., 2016; Schmidt et al., 2015; Schulz et al., 2013).

Biochar amendment was further shown to have desired effects on the composting process, including the reduction of N_2O emissions (C. Wang et al., 2013) and the reduction of nitrogen leaching (Steiner et al., 2010). Increases in crop yield by biochar-amended composts have been explained by the slow nutrient release from co-composted biochar and its improved properties as organic fertilizer (Kammann et al., 2015b). Biochar pieces that were manually picked from compost following a co-composting process have been shown to have an increased cation exchange capacity and a higher number of oxidized carbon functional groups on their surface than the original (Khan et al., 2016; Wiedner et al., 2015).

In practice, co-composted biochar is not applied to soil after separation from the compost, but as a biochar-amended compost. Thus, there is the need to also understand the composition of this complex organic material mix as a whole. This includes the impact of biochar on the quality of non-pyrogenic organic matter of the mature biochar-amended compost, which has so far only been the subject of a few studies. Jindo et al. (2012) found an increased stability of biochar-amended manure + organic waste compost assessed by thermogravimetric analysis. In this study the authors did not observe any considerable changes in ^{13}C nuclear magnetic resonance (NMR) spectra of the bulk compost beyond a general increase in aromatic carbon structures. Since this increase in aromatic carbon is a direct consequence of the biochar addition (Jindo et al., 2012), the authors argued for the need of a selective analysis of the non-biochar organic matter of biochar-amended compost, i.e. to separate biochar and compost for analysis. Other studies have focused only on the humic substances instead of the bulk compost (Jindo et al., 2016; Wang et al., 2014) or focused on biochar-amended sewage sludge compost (Zhang et al., 2014).

In the present study, we conducted a farmyard manure composting experiment at a sub-industrial scale. Mixed manure was composted as a non-amended control as well as after addition of three different biochars at 4.3% (w/w). After maturation, we analyzed and compared the organic matter of the four different biochar compost treatments using elemental analysis, extractions with 0.1 M KCl, and spectroscopic techniques applied to bulk compost. Prior spectroscopy on the bulk compost samples, we manually removed biochar particles to focus our data analyses on the non-biochar fraction of the composts.

2. Materials and methods

2.1. Biochars and aerobic composting of manure

Aerobic co-composting of biochar was conducted from August to October 2014 on an outdoor composting facility at the Ithaka Institute in St. Léonard, VS, Switzerland. The composting feedstock comprised mixed manures (farmyard manure) and green plant materials. The feedstock was mixed and split into four windrows of 20 m^3 each. Three windrows were amended with different biochars (B1, B2, B3) at a rate of 4.3% (dry matter w/w) resulting in biochar-amended composts CB1, CB2, CB3. One windrow was composted without amendment as a control (Con).

Mixed woody waste biochar: B1 (700 °C, Pyreg® process, Sehn et al., 2010), sewage sludge char: B2 (650 °C, Pyreg® process) and wood waste/pruning residue biochar: B3 quenched with water (700 °C, flame curtain pyrolysis in a Kon-Tiki, cf. Cornelissen et al., 2016; Schmidt and Taylor, 2014) were analyzed according to the requirements of European Biochar Certificate (EBC, 2012) by Eurofins Umwelt Ost GmbH, Halsbrücke-Tuttendorf, Germany. The physical and chemical properties of the three biochars are listed in Table 1. While B1 and B3 fulfill the "basic" criteria of the European Biochar Certificate, sewage sludge char B2 had elevated concentrations of Cu and Zn and a carbon content below 50%. Therefore, B2 would not be considered a biochar according to EBC (2012). However, to facilitate reading this text, we will also refer to B2 as a biochar.

Compost windrows were mechanically turned for aeration every day during the first three weeks of composting and every third day thereafter, for 6 weeks. Between turning events, windrows were covered with a felt to reduce evaporation and heat loss. These procedures promote an aerobic process of decomposition and allow the development of elevated ("thermophilic") decomposition temperatures (Kammann et al., 2016). Temperatures reached 60 °C and remained at about 60 °C for the first two to three weeks. Thereafter, temperatures decreased gradually to ambient outdoor temperatures (18–25 °C) in the following seven weeks. When the ammonium concentration in the four compost windrows reached < 10 mg NH_4^+-N kg^{-1} the composts were considered mature and were packed in open plastic bags and stored frost-protected.

2.2. Elemental analysis of composts

Samples of mature control compost and biochar-amended composts CB1, CB2 and CB3 were freeze-dried and powdered in an agate mortar. Total organic carbon (TOC) was measured in a CN elemental analyzer (Vario EL, Elementar, Hanau, Germany). For inductively coupled plasma optical emission spectrometry (ICP-OES; DV 5300, Perkin Elmer, Waltham MA, USA), a modified aqua regia (nitrohydrochloric acid) microwave extraction/digestion protocol was used as suggested by the manufacturer (Start 1500, MLS, Leutkirch, Germany).

Exchangeable ions, including nutrients, were extracted from moist compost with a calcium-acetate-lactate extraction ("CAL" extraction, Kießling et al., 2008) and quantified by ICP-OES (DV 5300, Perkin