Chemosphere 142 (2016) 14–23

Contents lists available at ScienceDirect

Chemosphere

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

Physical and chemical properties of biochars co-composted with biowastes and incubated with a chicken litter compost

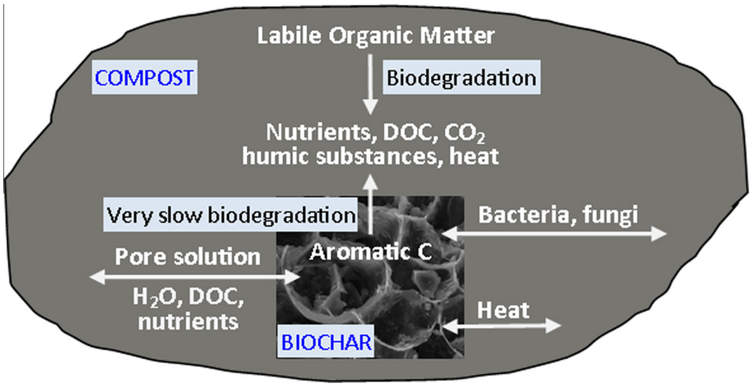
Naser Khan [a,b,c,*], Ian Clark [c], Miguel A. Sánchez-Monedero [d], Syd Shea [e], Sebastian Meier [f], Fangjie Qi [a,b], Rai S. Kookana [g], Nanthi Bolan [a,b,h]

[a] Centre for Environmental Risk Assessment and Remediation (CERAR), Building X, University Blvd., University of South Australia, Mawson Lakes, SA 5095, Australia
[b] Cooperative Research Centre for Contaminants Assessment and Remediation of the Environment (CRC CARE), Building X, University Blvd., University of South Australia, Mawson Lakes, SA 5095, Australia
[c] School of Natural and Built Environments, University of South Australia, Building P, Materials Lane, Mawson Lakes, SA 5095, Australia
[d] Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC), Department of Soil Conservation and Waste Management, Campus Universitario de Espinardo, 30100 Murcia, Spain
[e] Environmental and Natural Resource Management Consultants Pty Ltd, 59 Solomon St., Fremantle, WA 6160, Australia
[f] Scientific and Technological Bio-recourse Nucleus, BIOREN-UFRO, Universidad de la Frontera, P.O. 54-D, Temuco, Chile
[g] CSIRO, Land and Water Flagship, PMB 2, Glen Osmond, SA 5064, Australia
[h] Global Centre for Environmental Risk Assessment and Remediation, University of Newcastle, Callaghan, NSW 2308, Australia

HIGHLIGHTS

- Generally, amended biochar gained elements when compost had higher level of elements than biochar.
- Some biochars showed strong affinity for B, C, N and S.
- Biochars sorbed N during co-composting and incubation with compost.
- Biochar C showed recalcitrance during co-composting and incubation with compost.
- The cation exchange capacity of co-composted biochars increased, but not of incubated biochars.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 31 December 2014
Received in revised form 10 May 2015
Accepted 19 May 2015
Available online 1 June 2015

Keywords:
Biochar
Carbon
Compost
Nutrient
Trace element
Sorption

ABSTRACT

Two experiments were conducted where three biochars, made from macadamia nutshell (MS), hardwood shaving (WS) and chicken litter (CL), were co-composted with chicken manure and sawdust, and also incubated with a chicken litter based commercial compost. Biochars were added at the rates of 5% and 10% in the co-composting and 10% and 20% in the incubation experiment. The rates of biochar had no consistent effect on the change in element contents of composted- or incubated-biochars. The biochar C demonstrated recalcitrance in both composting and incubation systems. Composting increased the CEC of biochars probably due to thermophilic oxidation. The increases in CEC of WS and CL were 6.5 and 2.2 times, respectively, for composting. Translocation of elements, between biochar and compost medium, occurred in both directions. In most cases, biochars gained elements under the influence of positive difference of concentrations (i.e., when compost medium had higher concentration of elements than biochar), while in some cases they lost elements despite a positive difference. Biochar lost some elements (WS: B; CL: B, Mg and S) under the influence of negative difference of concentrations. Some biochars

---

* Corresponding author at: Centre for Environmental Risk Assessment and Remediation (CERAR), Building X, University Blvd., University of South Australia, Mawson Lakes, SA 5095, Australia. Tel.: +61 8 8302 3756; fax: +61 8 8302 3057.
E-mail address: naser.khan@mymail.unisa.edu.au (N. Khan).

http://dx.doi.org/10.1016/j.chemosphere.2015.05.065
0045-6535/

showed strong affinity for B, C, N and S: the concentration of these elements gained by biochars surpassed the concentration in the respective composting medium. The material difference in the biochars did not have influence on N retention: all three netbag-biochars increased their N content. The cost of production of biochar-compost will be lower in co-composting than incubation, which involves two separate processes, i.e., composting and subsequent incubation.

1. Introduction

Biochar based compost, termed as 'biochar-compost', may be used to remediate soils contaminated with metals, while also improving its health. There are three approaches for production and co-application of the biochar-compost: (i) mix biochar and compost followed by its application to soil instantly i.e., without incubation (Blackwell et al., 2009), (ii) prepare co-compost from biochar and other raw feedstocks prior to its application to soil, and (iii) incubate biochar and fresh compost for a specified period prior to its application to soil. Biochar-compost produced according to Approaches (ii) or (iii) is identified as co-compost or incubated-compost, respectively. Most of the literature (Steiner et al., 2007, 2008; Karami et al., 2011) shows that, where biochar was mixed with compost, the mixture was applied to soil without any prior incubation as in Approach (i) listed above. There are, however, some reports in the literature where biochar was co-composted as in Approach (ii) (Yoshizawa et al., 2005; Hua et al., 2009; Dias et al., 2010; Borchard et al., 2012; Jindo et al., 2012; Theeba et al., 2012; Prost et al., 2013), but there was no comparative study of co-composting (Approach (ii)) and incubation (Approach (iii)) in regard to biochar interactions with compost. Steiner et al. (2004) reported examples of 'cultural practices' (i.e., non-experimental) from Amazonian basin, where biochar was incubated as in Approach (iii). No experimental data was found in the literature where biochar was incubated with compost.

A composting pile undergoes various bio-physico-chemical changes over the composting period. The temperature in a pile rises and falls (Khan et al., 2014) reflecting the underlying changes in available C and N substrates, and microbial population or activity. The changes in pile include decomposition of easily degradable organic matter, mineralization of slowly degradable organic matter, and humification of ligno-cellulosic compounds (Insam and De Bertoldi, 2007), and a large loss of C and N (Larney et al., 2008). There would be changes in EC (Khan et al., 2014), CEC (Prost et al., 2013) and dissolution of organic and inorganic chemicals from their solid phases to compost pore solution.

The mobility of elements in the composting pile depends on a number of factors e.g., temperature, pH, CEC, composting stage (Larney et al., 2014), mass flow of elements compost pore solution, concentration gradient (that drives diffusion) of elements in compost pore solution (Seymour and Bourdon, 2003), and binding with organic matter that is in solid or solution phase (Leita and De Nobili, 1991; Larney et al., 2014). Moisture (40–60%) is added to feedstocks to mainly favor the growth of microbial population. This results in a compost pore solution that can transport the chemicals. Dissolved elements move from high concentration to low concentration by diffusion process, while, dissolved elements can move to any direction by mass flow (Barber, 1962; Singer and Munns, 2006).

Biochars have a recalcitrant carbonaceous structure (Glaser et al., 2002) that may possess a micro-porous as well as reactive surface (Brennan et al., 2001). Biochar contains trace metals and major nutrients (Chan and Xu, 2009; Singh et al., 2010) that are derived from its feedstock biomass. The presence of a wide range of functional groups on its surface (Amonette and Joseph, 2009) allows it to adsorb dissolved ions (Boehm, 2001); while the micropores allow absorption of a common solvents (Rouquerol et al., 1999) including moisture (Thies and Rillig, 2009). Both the biochar (Mohan et al., 2014) and compost (Bolan et al., 2011b) are known to sorb trace metals. Bamboo biochar was found to reduce mobility of Cu and Zn and emission of N while being co-composted with sewage sludge (Hua et al., 2009). It has been shown that, its sorption affinity for Cu might increase when co-composted with feedstocks like manure and straw (Borchard et al., 2012). Biochar can adsorb dissolved organic carbon (Pignatello et al., 2006).

Biochar contains elements derived from its organic feedstocks. However, it may have higher capacity for elements than its initial contents. In such a case, it may sorb elements from a composting or incubating medium, where there is abundance of mobile elements.

Because there is no thermophilic stage in the incubation system, the compost product is substantially different from that derived from a co-composting system. Therefore, it may be expected that the influence of incubation system on incorporated biochar may be different to that of co-composting system. The overall objective of the two experiments presented in this paper was to compare the performance of element retention of BCs during their co-composting with organic feedstocks and also incubation with commercial compost. We assumed that the sorption of elements by biochar in co-composting and incubation system would depend on (i) the rate of application of biochar, (ii) the type (or properties) of biochar, (iii) the method i.e., co-composting or incubation, and (iv) the initial element concentration difference existing between compost medium and biochar, where the elements would move from compost medium (higher concentration) to biochar (lower concentration).

2. Methods

2.1. Co-composting experiment

Seven co-composts were prepared from chicken manure (CM), pine softwood sawdust (SD) and three types of biochars (BC) made from macadamia nutshell (MS), hardwood shavings (WS), and chicken litter (CL). The MS, WS and CL were collected from three different suppliers or producers in Australia. The piles (~125 L) were composted for 133 days in spherical plastic bins (~153 L) that were placed in an automated greenhouse that maintained temperature between 20 °C and 50 °C. The temperature, dissolved organic carbon (DOC), plant germination index, C/N in composts were used to determine the maturity of the compost. Each bin was aerated at a rate of 0.028 L min^{-1} kg^{-1} DM to accelerate the composting process. The piles were turned by rolling the bin on floor to further improve air supply. Compost samples were collected only after rolling. One of the composts (control co-compost) contained no BC, while the rest six (biochar co-compost) contained BCs. Each type of BC was added at the rate of 5% or 10% wet weight. Accordingly, the composting piles were labeled as coCNT, coMS5, coMS10, coWS5, coWS10, coCL5 and coCL10. The compost feedstock ratios and properties of BCs are presented in Tables 1 and 2, respectively. Additional descriptions