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Effects of acidic and neutral biochars on properties and cadmium retention of soils

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HIGHLIGHTS

- The C rich acidic biochar did not work for nutrients supply or Cd retention but helped in storing C.
- The neutral mineral rich biochar enhanced nutrient and sorption for some soils.
- Neutral mineral rich biochar hardly increased soil C after 11 months.

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ABSTRACT

In this study, an acidic biochar and a neutral biochar were applied at 5 wt% into two soils for an 11-month incubation experiment. One Ferrosol soil (Ba) was slightly acidic with low organic matter and the other Dermosol soil (Mt) was slightly alkaline with high organic matter. The acidic (pH = 3.25) wood shaving (WS) biochar had no marked impact on nutrient levels, cation exchange capacity (CEC), pH and acid neutralization capacity (ANC) of either soil. By contrast, the neutral (pH = 7.00) chicken litter (CL) biochar significantly increased major soluble nutrients, pH, ANC of soil Ba. In terms of C storage, 87.9% and 69.5% WS biochar-C can be sequestrated as TOC by soil Ba and Mt, respectively, whereas only 24.0% of CL biochar-C stored in soil Ba and negligible amount in Mt as TOC. Biochars did not have significant effects on soil sorption capacity and sorption reversibility except that CL biochar increased sorption of soil Ba by around 25.4% and decreased desorption by around 50.0%. Overall, the studied acidic C rich WS biochar held little agricultural or remedial values but was favourable for C sequestration. The neutral mineral rich CL biochar may provide short-term agricultural benefit and certain sorption capacities of lower sorption capacity soils, but may be unlikely to result in heightened C sequestration in soils. This is the first study comprehensively examining functions of acidic and neutral biochars for their benefits as a soil amendment and suggests the importance of pre-testing biochars for target purposes prior to their large scale production.

1. Introduction

Biochars are carbon-rich products produced through thermochemical processing of biomass under an oxygen-deficient environment (Cao and Harris, 2010; Venegas et al., 2015). It has been a hot topic of research in recent years due to its versatile role in soil

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Abbreviations

ANC	Acid neutralization capacity
Ba	Soil from Mt Bygalore (Ferrosol, acidic)
CEC	Cation exchange capacity
CL biochar	Chicken litter biochar
EC	Electrical conductivity
Mt	Soil from Mt Shank (Dermosol, alkaline)
PyC	Pyrogenic carbon
TOC	Total organic carbon
WS biochar	Wood shaving biochar
Ba11, Ba11WS, Ba11CL	Soil Ba, WS biochar amended soil Ba, and CL biochar amended soil Ba after 11-month incubation, respectively
Mt11, Mt11WS, Mt11CL	Soil Mt, WS biochar amended soil Mt, and CL biochar amended soil Mt after 11-month incubation, respectively

biogeochemical processes. The most important environmental functions of biochar include acting as a long-term carbon sink for climate change mitigation (Lehmann, 2007b; McBeath and Smernik, 2009; Bird et al., 2017), a soil conditioner that increases soil nutrient retention, cation exchange capacity (CEC), soil fertility and crop yield (Liang et al., 2006; Downie et al., 2011; Qu et al., 2016), and an in situ immobilizer for soil heavy metal contaminants (Cao et al., 2009; Uchimiya et al., 2011a; Qian et al., 2013; Lu et al., 2017). Biochars perform in these processes by increasing soil organic carbon and reducing greenhouse gas emission (Lehmann, 2007b), increasing soil pH, acid neutralization capacity (ANC) and CEC (Glaser et al., 2002; Cheng et al., 2006; Yuan and Xu, 2011; Venegas et al., 2015) as well as increasing soil intrinsic binding sites for soil contaminants (Cao and Harris, 2010; Beesley et al., 2011; Uchimiya et al., 2011c).

Biochars are commonly alkaline (Jiang et al., 2012a) which contribute to their liming effects and enhanced sorption of soils for cationic contaminants. However, biochar pH values can range from acidic to alkaline (Chan and Xu, 2009) and lower pH biochars are normally neglected. Biochar pH increases with increasing pyrolysis temperature as more acidic functional groups can be removed at higher temperatures (Ippolito et al., 2016). Biochars produced under low pyrolysis temperatures can be acidic (Novak et al., 2009; Hagner et al., 2016; Zhang et al., 2017). For example, birch (*Betula* spp.) biochar produced at 300 °C and 375 °C were shown to be acidic (pH = 5.1 and 5.2, respectively) (Hagner et al., 2016). Pecan shell (350 °C) and switchgrass (250 °C) biochar had a pH of 5.9 and 5.4, respectively (Novak et al., 2009). In limited studies about lower pH biochars, low-temperature (250 and 350 °C) acidic switchgrass biochars were found to lower pH and initially increase plant-available nutrients in aridic calcareous soils (Ippolito et al., 2012, 2016). Similarly, neutral biochars may also behave differently from normally available alkaline biochars in environmental processes after being added into soils. From this sense, a more comprehensive examination of potential benefits of acidic and neutral biochar on soil nutrient leaching, C storage and contamination remediation is essential.

Cadmium is one of the most hazardous metals and is readily absorbed from soil to plant with a relatively high transfer coefficient and subsequently to animals and human through fodder and food products (Park et al., 2011; Zhao et al., 2015a). In this study, Cd was selected as a model metal to study contaminant retention capacity of soils given its wide presence in agricultural soils due to Cd-rich phosphate fertilizers applications (Naidu et al., 1994; Ali et al., 2013; Muehe et al., 2013). The objectives of this work were to (i) study effects of acidic and neutral biochars on soil properties especially surface charge properties; (ii) examine the C sequestration capacity of acidic and neutral biochars by evaluating soil total organic carbon (TOC) and stable organic carbon (pyrogenic carbon, PyC) content; (iii) explore sorption behaviours and mechanisms of biochar amended soils for Cd.

2. Methods

2.1. Incubation of biochar-amended soils

Two typical Australian soils (0–10 cm) were sampled for this study. One Ferrosol soil from Mt Bygalore (Ba) of New South Wales (S33°39.88′, E146°49.07″) of Australia that is lower in organic matter content and slightly acidic (pH = 6.14, TOC = 16.3 mg/g). The other Dermosol soil was sampled from Mt Shank (Mt) of South Australia (S37°56.78′, E140°44.59′) that is slightly alkaline higher in organic matter soil (pH = 7.87, TOC = 78.9 mg/g). One biochar made from chicken litter (CL, 550 °C) and one from wood shavings (WS, 650 °C) were obtained from commercial producers. The biochars were made by 16-min slow pyrolysis (8 min in the drier, 8 min in the pyrolysis chamber) in a Continuous Flow Pyrolyzer. Biochar products were water mist quenched immediately after pyrolysis, then additional water was hosed onto the bulk product. Before use, both biochars were air dried and sieved to pass through a 2-mm stainless steel sieve to represent their typical use as a soil amendment. Biochars were mixed with soils at the ratios 5 wt% on a dry weight base. Soils with/without biochar amendment were incubated at 25 ± 2 °C for 11 months in 2L glass jars with holes on the lids. The jars were maintained at 60% water holding capacity (WHC) and weighed for water replenishment every week within the first 3 months and every fortnight thereafter. Incubation of all samples were in duplicates. At the end of the 11 months, the soil samples were dried and sieved (<2 mm or <150 μm) for further chemical analysis and the sorption experiment. These soil samples after 11 months incubation were used for following analysis and sorption experiment. Following the way "soil name + months of incubation + biochar types", the samples were recorded as Ba11, Ba11WS, Ba11CL, Mt11, Mt11WS, Mt11CL, respectively.

2.2. Soil and biochar characterization before and after treatment

Soil and biochar pH, electrical conductivity (EC) were determined using 1:5 and 1:10 sample to water ratio, respectively. Soil TOC were determined by combusting oven dried and ground soil samples (<150 μm) at 1100 °C in a CHN Elemental Analyzer (Euro EA 3000 Elemental Analyzer, Eurovector SPA, Milano, Italy) that uses infrared technology to quantify CO_2. Soil pyrogenic carbon (PyC), was measured by a chemo-thermal oxidation (CTO-375) method. Both TOC and PyC analysis were collaborated with a lab in Switzerland where same analytical procedure as Agarwal and Bucheli (2011) were applied. Soil and biochar total metals was extracted by microwave digestion in aqua regia following USEPA 3051 40 method before detecting metals by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7900, USA). Soil texture was determined by the hydrometer method (Gee et al., 1986). Amorphous Al, Mn and Fe (Al_{oxa}, Mn_{oxa}, Fe_{oxa}) was extracted by 0.2 M ammonium oxalate/oxalic acid following Rayment and Higginson (1992). The contents (wt%) of carbon (C), hydrogen (H), nitrogen (N), sulphur (S) of biochars were measured by a CHNS analyzer (Vario Micro cube, Elementar, Germany). Ash content (%) was measured by heating samples under 800 °C for 4 h in muffle furnace. The weight percent of oxygen was determined by mass difference (Chen et al., 2008; Cheng et al., 2013; Luo et al., 2016).