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Agronomic effectiveness of urban biochar aged through co-composting with food waste

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ABSTRACT

Terra preta soils have been shown to develop after considerable modification of soil through char addition and over time natural ageing has led to increase in fertility of those soils. A co-composting experiment was conducted to accelerate the artificial ageing of urban biochar (UB) with the aim of achieving similar *terra preta* effect. UB was produced through the pyrolysis of 2:1 ratio of biosolids and green waste and then composted with food waste (10% v/v) until compost maturity at around 75 days. A portion of the UB was placed in litterbags within the composting biomass in order to examine the effects of co-composting more closely. Addition of 10% UB to food waste accelerated the composting process. As measured from the litter bags, co-composting UB with foodwaste increased CEC, pH, EC and nitrogen loading of composted UB relative to the un-composted UB. However, the composting process reduced BET surface area and porosity of UB most probably due to clogging of pores by the organics released during composting. The agronomic value of UB, UB co-composted with foodwaste and foodwaste compost was evaluated in a greenhouse pot experiment with sorghum plants on a sandy acidic topsoil. Results of the pot experiment showed higher plant growth, lower emissions of N_2O and higher nitrogen use efficiency in soil amended with UB than the soil amended with compost and co-composted UB.

1. Introduction

Management of organic municipal wastes such as food waste, green waste and biosolids is becoming problematic in urban areas of many countries due to the rapid increase in population and policies restricting the landfilling of organic wastes (Chen et al., 2016; Maina et al., 2017). There is great potential to reuse these urban organic wastes to create both biochar and compost for use as soil amendments. Many studies have shown that addition of biochar to soil improves short term physical and chemical properties (Basso et al., 2013; Brockhoff et al., 2010; Van Zwieten et al., 2010). Over the long term, biochar undergoes surface oxidation (ageing) in soil (Liang et al., 2006; Spokas, 2013) and this is thought to make biochar more agronomically effective (Hagemann et al., 2017). Ageing of biochar has been simulated under laboratory condition by continuous heating at 110 °C for a periods up to eight weeks and such artificial ageing increased the cation exchange capacity (CEC) of biochar by 50% (Hale et al., 2011). However, these heating processes inhibit microbial activity and excludes the interaction with soil organic matter, both of which have been shown to be very important for the natural weathering of biochar (Cheng et al., 2006; Hale et al., 2011). On the other hand, co-composting – a process of composting of biochar with various organic substrates, provides all the precursors required for natural ageing, such as: a low temperature environment; interaction with matter and; enhanced microbial activity (Kammann et al., 2015). These bio-oxidative environments have been shown to cause an almost sixfold increase in the CEC of biochar derived from wood products (Khan et al., 2016; Prost et al., 2013). The mechanism for the increased reactivity of biochar after composting appears to be the increase of oxygen containing functional groups mainly phenolic and carboxylic groups (Wiedner et al., 2015) and sorption of organic compounds to the biochar surface (Wang et al., 2014). Other than the increase in CEC of biochar, co-composting biochar especially with manure, has been shown to increase the concentration of nutrients with concomitant reduction in the surface area of biochar possibly due to clogging of the micropores by compost derived materials (Prost et al., 2013). However, elucidating the co-composting effect on biochar is complicated owing to inability to effectively recover the material from the compost. Hand picking is the most commonly used practice (Jindo et al., 2012; Wiedner et al., 2015), however there is a distinct bias towards coarser particle sizes. More recently studies have used litterbags in biochar co-composting experiments which allows analysis of the composted

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biochar sample and is more representative of the biochar in the compost mix (Khan et al., 2014; Prost et al., 2013).

In addition to the changes in biochar, adding biochar to composting biomass also brings changes to the composting process. The properties of biochar such as high stability, high nutrient sorption, micro porosity, high water holding capacity and low bulk density makes it a value added bulking material for composting (Steiner et al., 2011). Biochar addition to poultry manure compost has been shown to reduce ammonia emissions due to its ability to adsorb ammonium during the composting process (Steiner et al., 2010). Reduction of ammonia emissions has also been observed during the first week of co-composting of biochar with sewage sludge and woodchips (Malinska et al., 2014). Furthermore, biochar aids the composting process by increasing the compost pH, speeding up the composting process, achieving a balanced C:N ratio, optimizing aeration, avoiding compaction of compost mixes and helping the compost to maintain an optimum moisture content (Sanchez-Garcia et al., 2015; Steiner et al., 2011; Vandecasteele et al., 2016). Co-composting of biochar with pig manure, has also been shown to reduce the emission of N_2O gas and this was attributed to the complete denitrification of substrate (Wang et al., 2013a). Although, biochar may reduce the emission of N_2O during the composting process, application of the co-composted biochar to soil has been shown to increase N_2O emissions by 45% as compared to non-composted biochar due to greater availability of organic compounds and nitrogen sorbed by biochar during composting process (Borchard et al., 2014; Vandecasteele et al., 2016).

In previous studies, biochar has been co-composted with various organic materials including poultry manure, cattle manure, straw, biosolids, spent mushroom and green waste (Schulz et al., 2013; Zhang and Sun, 2014). There are no studies reported on the co-composting of biochar with food waste. The composting of food waste produces high amounts of organic acids such as lactic, propionic and butyric acids which contrasts to composts produced from manures (Yu and Huang, 2009) and these organic acids may stimulate ageing of the biochar. However, the low pH of food waste (5–6) during composting also inhibits microbial activity (Yu and Huang, 2009) and this may be countered by the addition of biochar (pH of 7–9), which in turn may stimulate microbial activity. Therefore, co-composting of food waste and biochar could be complementary process, accelerating ageing of the biochar surface while increasing microbial activity.

Application of co-composted biochar to soil, (both in field and pot based studies) has resulting in mixed agronomic outcomes. In a pot study comparing un-composted and co-composted biochar without a leaching regime, improvement of plant growth of up to 305% was observed with application of co-composted biochar to a sandy loam soil due to increased availability of nutrients, mainly nitrogen (Kammann et al., 2015). A field study looking at three year vineyard growth on a sandy clay loam soil showed a non-significant effect of co-composted biochar on vine growth (Schmidt et al., 2014b). Bass et al. (2016) found a 24% reduction in papaya yield due to the application of co-composted biochar in a sandy loam soil as compared to fresh biochar. This reduction in papaya yield in the study of Bass et al. (2016) was attributed to inefficient method of application (surface broadcast) and reduced nutrient availability.

Of the nitrogen related studies looking at co-composting of biochar, the main focus has been on the changes in biochar, the composting process and plant growth after applying co-composted biochar in soil. However, these studies generally lack a whole system approach. Our study aims at investigating the whole soil – plant system by looking at major nitrogen loss and use pathways: leaching, gaseous loss, storage by soil and plant uptake with a focus on nutrient use efficiency. Our study is the first to explore the extent of ageing of biochar due to co-composting with food waste.

2. Methodology

2.1. Biochar and compost production

2.1.1. Urban biochar feedstock and production

Biosolids were sourced from Bangholme Eastern Treatment Plant, Victoria. Stabilisation of these biosolids was achieved through settling in primary sedimentation tanks, then pumping to anaerobic digesters. Digested sludge was then dried in sludge drying pans. The dried sludge was harvested during warm weather and stored for 3 years prior to pyrolysis. Moisture content of biosolids as received from treatment plant was 72 wt%. Biosolids and green waste (mainly municipal softwood garden waste chopped to 1.5 cm) were dried in a commercial dryer to a moisture content of 21 wt% and blended at a ratio of 2:1 (on a dry basis). Feedstock was pyrolysed in a commercial scale pyrolyser by Pacific Pyrolysis Pty Ltd. at the high heat treatment of 650 °C with a residence time of 40 min which are optimum conditions to produce biochar with high surface area and aromaticity (Kloss et al., 2012; Thines et al., 2017). The feeding rate was 125 kg hr^{-1} resulting in a biochar yield of 46 wt% dry basis.

2.1.2. Compost production

Food waste comprised mainly of used coffee grounds, fruit peel (citrus, watermelon, pineapple) and vegetable (lettuce, celery, carrot) scraps from the organic waste collection of commercial food premises at University of Melbourne student canteen (no meat or dairy products). The C:N ratio of food waste feedstock was 18, which is below the desirable level for composting (C:N ratio of 30). A low N content will restrict microbial activity while a high N content may overheat the compost, killing the compost microorganisms, or cause the system to become anaerobic, resulting in unpleasant odours (Kumar et al., 2010). Therefore, a commercially purchased sawdust with C:N ratio of 295 was used to adjust the C:N ratio of each compost mix to around 30:1 according to the method of Augustin and Rahman (2010). The composting mixes were prepared using the following feedstock rates on a volume basis with 3 replications:

Compost: 95% food waste, 5% sawdust
Urban biochar compost (UB compost): 85% food waste, 10% UB, 5% sawdust.

These feedstocks were composted in commercially purchased composter bins, roto twin composters (composting home, Canada) which held 70 L of compost in each compartment. The composter bins were turned once every day to ensure mixing and aeration of the compost mixture. The composter bins were kept in an automated greenhouse with day and night temperature of 24 and 18 °C respectively. The composting process was conducted for 11 weeks during which temperature and moisture were monitored to ensure a moisture range of 40–55% (the bins were free-draining, however this moisture content minimised leachate). The temperature of the compost mixes were recorded every day using iButton temperature loggers (Thermochron, DS1922T-F5) placed in the middle of the compost mix. We used a 10% biochar rate for co-composting as an earlier study (Vandecasteele et al., 2016; Zhang et al., 2014) suggested 10% on volume basis to be the most effective rate. Seed germination index, ability to reach optimum Carbon:Nitrogen ratio (C:N) and peak thermophilic stage were used as maturity indices for the composts (Khan et al., 2014). The total carbon and