Journal of Environmental Management 187 (2017) 24–30

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Agronomic assessment of pyrolysed food waste digestate for sandy soil management

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ARTICLE INFO

Article history:
Received 24 March 2016
Received in revised form
13 November 2016
Accepted 14 November 2016
Available online 18 November 2016

Keywords:
Agronomy
Pyrolysis
Relative enrichment
Thermogravimetric
Germination and nutrient sorption

ABSTRACT

The digestate (DFW) of an industrial food waste treatment plant was pyrolysed for production of biochar for its direct application as bio-fertilizer or soil enhancer. Nutrient dynamics and agronomic viability of the pyrolysed food waste digestate (PyD) produced at different temperatures were evaluated using germination index (GI), water retention/availability and mineral sorption as indicators when applied on arid soil. The pyrolysis was found to enrich P, K and other micronutrients in the biochar at an average enrichment factor of 0.87. All PyD produced at different temperatures indicated significantly low phytotoxicity with GI range of 106–168% and an average water retention capacity of 40.2%. Differential thermogravimetric (DTG) thermographs delineated the stability of the food waste digestate pyrolysed at 500 °C (PyD500) against the degradation of the digestate food waste despite the latter poor nutrient sorption potential. Plant available water in soil is 40% when treated with 100 g of digestate per kg soil, whereas PyD500 treated soil indicated minimal effect on plant available water, even with high application rates. However, the positive effects of PyD on GI and the observed enrichment in plant macro and micronutrients suggest potential agronomic benefits for PyD use, in addition to the benefits from energy production from DFW during the pyrolysis process.

1. Introduction

Pyrolysis of waste biomass to biochar (a carbon rich material resembling charcoal) and its subsequent application to soil as a mechanism to enhance water and nutrient retention is becoming a widely accepted practice (Hossain et al., 2011; Sohi et al., 2010; Kan et al., 2016). The 30–50% organic carbon loss in soil due to intensive tillage (Khalifa and Yousef, 2015; Lee et al., 2013) may be ameliorated through organic rich digestate or organic oriented biochars. Generally, reduction in soil aggregate capacity, lack of water and nutrient retention properties lead to soil erosion and fertility losses (Novak and Busscher, 2013) and consequently low crop production. Biochar application to soil appears to offer ancillary environmental benefits. For example, biochar produced from cattle manure was reported to lower CO_2 emission and stabilized N_2O gas emissions when compared to raw cattle manure and anaerobically treated digestate (Schouten et al., 2012). The potential of carbonaceous bio-solid sludge for the remediation of acidic or alkaline soil was reported with delinquent tendency of heavy metal bio-accumulation and bioavailability (Hossain et al., 2011). Successful cases of soil improvement and other prospective use of biogas from the digestate process were also reported. The food waste digestate was proposed as feedstock for fuels and the production of other materials such as biochar and fertilizers have been reported (Sheets et al., 2015). The practice of using biochar or digestate for soil improvement is particularly vital to agricultural Mediterranean soils and other arid regions known to exhibit a progressive depletion in soil organic matter due to warm climate that cause high rates of mineralization (Montemurro et al., 2010). However, the use of digestate as a fertilizer could be problematic if not monitored or produced properly. This is because digestates may contain substantial concentrations of heavy metals and organic pollutants (Brändli et al., 2007; Wu et al., 2016), physical impurities, pathogens (Al Seadi and Lukehurst, 2012), viscosity and odour (Arthurson, 2009), and impact quality management (Alburquerque et al., 2012). Thus, further treatment may be essential for its utilization.

Characteristics and use of different biomass oriented chars are reported in a number of studies (Alburquerque et al., 2012;

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http://dx.doi.org/10.1016/j.jenvman.2016.11.030

Keiluweit et al., 2010; Opatokun et al., 2016) however, feedstock availability, seasonal or regional peculiarity and cost benefit analysis have limited the commercial realization of these findings. Targeting food wastes for biochar production may become a sustainable pathway to solving environmental impacts related to its disposal while recycling soil nutrients and minerals. Global food wastes are currently estimated at 1.3 billion tonnes per year and are also expected to increase by 53% by 2025 (Adhikari et al., 2006; FAO., 2011). The rate of generation and investment implication of food waste was extensively reported in (Girotto et al., 2015). Anaerobic digestion of food or organic wastes for energy and digestate are established measures to alleviate loads on landfills while simultaneously producing soil fertilizer. There is also an option to pyrolyse digestates produced from anaerobic digestion for biogas and biochar with the objective of maximizing the recovery of energy and the potential use of biochar in agriculture (Monlau et al., 2016; Yuan et al., 2016).

The objective of this work is to study the properties of biochars produced at different temperatures from food waste digestate, and assess their suitability for agronomic applications. Elemental enrichment, water holding capacity and the seed germination index effect of biochars produced from food waste digestate at different charring temperatures (300, 400, 500 and 700 °C) were evaluated. The phosphate sorption capacity and plant available water in sandy soil treated with biochar produced at 500 °C (PyD500) was further evaluated.

2. Material and methods

2.1. Materials (soil, food waste digestate and biochar production)

Pelleted food waste digestate (9.8% dry matter) after an industrial mesophilic anaerobic treatment process was collected from EarthPower Pty Ltd located in Sydney. The sample was oven dried (60–70 °C) and converted to biochar using a fixed bed horizontal tubular reactor with $10^{\circ}\mathrm{C\,min}^{-1}$ heating rate considering four peak temperatures of 300, 400, 500 and 700 °C at holding time of 4 h. Production details of the chars have been reported earlier (Opatokun et al., 2016). The chars were washed using distilled water to reduce the dust accrue during production, subsequently milled and sieved through 0.45 mm sieve before oven dried and kept in sealed container for use. The produced samples are subsequently referred to as PyD with suffix number representing the production temperature.

Sandy textured soil was collected from a farm located in Al-Rahba in Abu Dhabi (United Arab Emirates). The properties of the soil are shown in Table 1 and were determined as described in Khalifa and Yousef (2015). Subsequently, the biochar was added to soil at application rates of 10, 50, 100 and 150 g biochar per kg of oven-dried soil. The manually mixed to homogeneous consistency, oven-dried at 70 °C for 24 hr to remove any residual moisture and stored in sealed glass mason jars at room temperature until further analysis.

Table 1
Properties of the sandy soil used.

Texture	Sand (%)	Silt (%)	Clay (%)	pH	EC (μS/cm)	TOC (%)
Sandy	96.12	3	0.88	7.9	752	1.12

2.2. Biochar characterization and analysis

Elemental and physicochemical analyses of the biochars were obtained using Australian Standard (AS) 1038.3, 1038.6 and USEPA 6010/6020A ICP. The relative enrichment (RE) of the chars were determined as reported (Hossain et al., 2011) to express the substrate elemental and nutrients diversity and equally show the degree of volatility expressed by these elements. Larger relative enrichment (RE) is expressed by RE factor greater than 1 while elements depletion is exhibited for RE lower than 1. RE factors are calculated according to equation (1):

$$\text{Relative enrichment (RE)} = \frac{\textit{Elemental Concentration in Biochar}}{\textit{Elemental Concentration in Substrate}} \times \frac{\textit{Char}}{100} \tag{1}$$

The pH and EC were measured from a soil to water ratio (1:1 wt/v) slurry. The water holding capacity (WHC) of biochar was determined by saturating about 8 g of dried sample (contained in hilgard cup) with water. The latter was allowed to drain in humid enclosure after which the differences in mass were calculated. The phytotoxicity was evaluated based on germination index (Thipkhunthod et al., 2006) on water-soluble extracts from the biochars using tomato seed (*Lycopersicum esculantum*). One gram (dry wt.) of each substrate was mixed with 10 ml of distilled water through an electric rotator at 125 rpm for 1 h. The extracts were then filtered while the filtrate obtained was centrifuged at 9000 rpm for 15 min. For the germination test, 2 ml of the supernatant was diluted with 1 ml of distilled (DI) water and sprayed over a petri dish with double layered filter papers. Ten seeds of tomato were placed in each petri plate at room temperature in the dark for a period of five days. Control treatment was maintained with equivalent amount of distilled water only. The number of germinated seeds (G) and root length (L) were recorded while the seed germination index was calculated as described in equation (2)–4 (Tiquia, 2003).

$$\text{Relative seed germination (\%)} = \frac{\textit{Number of germination seeds in extract}}{\textit{Number of tested seeds in control}} \times 100 \tag{2}$$

$$\text{Relative root growth (\%)} = \frac{\textit{Mean Root Length in Extract}}{\textit{Mean Root Length in Control}} \times 100 \tag{3}$$

$$\text{Germination Index (\%)} = \frac{(\%\,\textit{Seed Germination}) \times (\%\,\textit{Root Growth})}{100} \tag{4}$$

The differential thermogravimetric (DTG) analysis of DFW and PyD500 were determined using Mettler Toledo thermogravimetric analyser (TGA/DSC 1 STARe system) interfaced on STARe software. 30 mg of each sample was used in each measurement. A heating rate of 5 °C/min with nitrogen flowing at 20 ml/min as a carrier gas was used to evaluate the substrate stability and thermal