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Short Communication

Comparative analysis biochar and compost-induced degradation of di-(2-ethylhexyl) phthalate in soils

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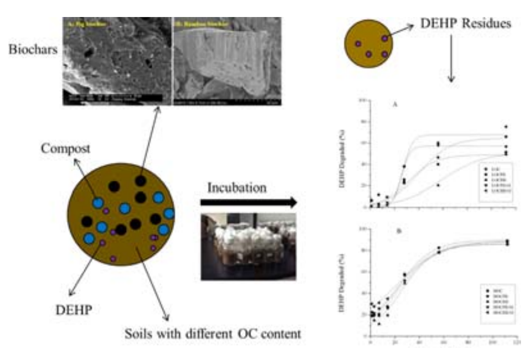
HIGHLIGHTS

- Di-(2-ethylhexyl) phthalate (DEHP) degraded faster in high organic matter soil.
- DEHP half-life declined in low organic matter soil amended with biochar and compost.
- Biochar had no effect on DEHP half-life in high organic matter soil.
- DEHP degradation accelerated after 2 weeks incubation.

GRAPHICAL ABSTRACT



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ABSTRACT

In recent years, biochar has been extensively studied as a sorbent for immobilizing contaminants and minimizing their bioavailability in soils. Few studies have been conducted to evaluate the interactions between biochar and compost in soils and their impact on degradation of organic contaminants. In the present study, soils with high

Abbreviations: DEHP, di-(2-ethylhexyl) phthalate; EDS, X-ray energy dispersive spectroscopy; PB, biochar derived from pig; BB, biochar derived from bamboo; LOC, low organic carbon content soil without organic amendments; LOCPB, LOC amended with 0.5% pig biochar (w/w); LOCBB, LOC amended with 0.5% bamboo biochar (w/w); LOCPB-M, LOC amended with 0.5% pig biochar and 0.5% compost (w/w); LOCBB-M, LOC amended with 0.5% bamboo biochar and 0.5% compost (w/w); HOC, high organic carbon content soil without amendments; HOCPB, HOC amended with 0.5% pig biochar (w/w); HOCBB, HOC amended with 0.5% bamboo biochar (w/w); HOCPB-M, HOC amended with 0.5% pig biochar and 0.5% compost (w/w); HOCBB-M, HOC amended with 0.5% bamboo biochar and 0.5% compost (w/w).

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organic carbon content (HOC) and low organic carbon content (LOC) were spiked with 100 mg·kg^{-1} di-(2-ethylhexyl) phthalate (DEHP) amended with biochar derived from dead pigs, bamboo, and composted sheep manure. The soils were thereafter incubated for 112 days at 25 °C and periodically sampled for monitoring DEHP concentrations. Degradation of DEHP was described by a logistic model. Results showed that the initial degradation rates were slow, but accelerated after 14 days of incubation. The DEHP degradation rates were higher in the HOC soils than in the LOC soils over the incubation period. The half-lives of DEHP were shorter in the LOC soils treated with pig biochar, and bamboo/pig biochar plus compost than in the untreated soil. However, there was no significant difference in the half-lives of DEHP in the HOC control and treated soils. The differential effects of soil amendments on DEHP degradation between LOC and HOC soils could be explained by the properties of the organic amendments, soil pH and the organic carbon contents of the soils.

1. Introduction

Agricultural materials such as mulching films, biosolids, manures, pesticides and fertilizers may increase the economic returns of agricultural production but some of these can also lead to widespread phthalic acid esters accumulation in soils (Xue et al., 2015; Sun et al., 2016a; Zhang et al., 2016). These phthalic acid esters compounds are a class of refractory organic plasticizers, of which di-(2-ethylhexyl) phthalate (DEHP) is most commonly used in plastic products, including polyethylene, polystyrene, polyethylene terephthalate, and polyvinyl chloride. The DEHP disrupts endocrine functions in humans (Keith and Telliard, 1979). The low water solubility and degradation rate of DEHP contribute to its accumulation and persistence in soils (Ejlertsson et al., 1997; Katayama et al., 2010). In most regions of China, the DEHP concentrations in soils exceed the soil cleanup guidelines recommended (0.44 mg·kg^{-1}) by the United States Environmental Protection Agency (US EPA) (He et al., 2015; Sun et al., 2016b). It is essential to better understand the effects of soil properties and organic amendments on the degradation of DEHP in order to reduce its potential hazards and environmental risks.

Microbial degradation is regarded as the primary pathway for phthalic acid ester degradation in aquatic and soil environments (Meng et al., 2015). A number of studies have been conducted to investigate the biodegradation of phthalic acid esters in soils, sediments or waters (e.g., Wang et al., 1995; Yuan et al., 2002; Zhang et al., 2016). Biochar is typically a porous material which can be used to increase microbial biomass (Wang et al., 2016; Igalavithana et al., 2017), promote humic substance synthesis (Wang et al., 2014), improve crop growth and yield (Dong et al., 2015; C. Y. Xu et al., 2015), reduce greenhouse gas emissions (Dong et al., 2013; Deng et al., 2017; Li et al., 2018), and reduce the bioavailability of trace elements (Rinklebe et al., 2016; Yang et al., 2016; Ahmad et al., 2017; Lu et al., 2017; Wu et al., 2017b) and organic contaminants (Wang et al., 2010; Ahmad et al., 2012; Zhang et al., 2013; Zhang et al., 2014). The effect of biochar on the degradation of organic pollutants showed mixed results in previous studies. Some research indicated that biochar can accelerate the degradation rate of organic pollutants (Yang et al., 2010), but other studies showed the opposite (Loganathan et al., 2009; Jones et al., 2011). However, the information on the effect of biochar on DEHP degradation in soils is limited.

Along with the development of livestock industry in China, 600 million pigs are produced each year (B. Xu et al., 2015), which would result in at least 20 million dead pigs (3–5% natural mortality rate) annually. The conventional methods such as anaerobic digestion are no longer sufficient for coping with the increasing number of dead pigs safely and effectively. Pyrolysis of the whole pigs is a clean and effective method to treat dead pig, and the pig biochar product is rich in nutrients and can potentially be used as a soil amendment (Yang et al., 2017). The pig biochar (PB) has characteristics different from biochars derived from plant feedstock. The bamboo biochar (BB), a typical biochar commonly produced and used in South China, was used to compare with the pig biochar for their effects on DEHP degradation in soils.

Compost is characterized by high organic matter contents (Gallardo-Lara and Nogales, 1987), and amending soils with compost can facilitate the degradation of organic contaminants because compost can improve the physical properties of soils, and increase the soil carbon contents (Chang et al., 2009). Compost applications also provide additional nutrients and energy, thus stimulate microbial activities and increase the degradation rate of organic contaminants (Semple et al., 2001; Namkoong et al., 2002).

Previous studies indicated that application of compost to a soil can typically enhance nutrient and energy supply to microorganisms (Wu et al., 2017a). Application of a mixture of biochar and compost can reduce the pore water concentrations (i.e., soil solution concentration) of contaminants including heavy metals and organic compounds, and increase organic carbon bioavailable to microbes (Zeng et al., 2015; Liang et al., 2017). Yet, the potential effect of compost mixed with biochar on the degradation of DEHP in soils remains uncertain in the existing literature. The present study was conducted to determine the degradation rates of DEHP in soils containing low/high organic carbon contents in the presence of biochar and compost to evaluate the role of soil properties and organic amendments in the degradation of DEHP.

2. Materials and methods

2.1. Soils

Soil properties are important factors to influence the degradation of organic contaminants, thus two bulk topsoil samples (0–20 cm) were collected with a spade from two adjacent fields with different cultivation history but the same soil type in Lin'an, Hangzhou, Zhejiang Province, China. Both soils are Ferrisols (Gong, 2003). The sampling locations in each field were chosen randomly, and the five sub-samples collected per field were bulked. One of the field sites has been used for growing vegetables with frequent inputs of chemical fertilizers and manure, while the second site had not been cultivated and the vegetation at this site was sparse natural vegetation. The soil samples were air-dried and passed through a 2-mm sieve prior to the analysis of soil properties using standard methods. The ratio of water to soil was 5:1 (w/v) for pH and conductivity measurements with a pH meter (Mettler-Toledo FE20K, Switzerland) and a conductivity meter (DS307, China), respectively. The organic carbon (OC) content, the total nitrogen (N) content and the cation exchange capacity (CEC) were determined using the ammonium exchange, potassium dichromate and Macro Kjeldahl method, respectively (Lu, 2000). The sand, silt and clay contents of the two soils were determined using the pipette method (Rayment and Higginson, 1992). The two soils have similar properties with the exception of their organic carbon contents (Table 1). The soil from the vegetable field had a relatively high OC content of 3.8% (HOC) due to long time cultivation, while the second soil never received fertilizers or manure, and had a lower organic carbon (LOC) content of 0.6%. The background concentrations of DEHP in the LOC and HOC soils were 7.25 mg·kg^{-1} and 8.36 mg·kg^{-1}, respectively. The soil samples were spiked with DEHP at 100 mg·kg^{-1} following the protocol by