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Bamboo- and pig-derived biochars reduce leaching losses of dibutyl phthalate, cadmium, and lead from co-contaminated soils

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HIGHLIGHTS

- Pig biochar reduced leaching of DBP, Cd, and Pb in the low organic carbon (LOC) soil.
- Contaminant leaching was higher in the LOC soil than in the high organic carbon soil.
- Existence of Cd and Pb enhanced mobility of DBP in the pig biochar-treated LOC soil.
- Alkalinity and phosphate in biochar controlled the leaching loss of Cd and Pb.
- Impact of pig biochar on leaching of DBP, Cd, and Pb is stronger than bamboo biochar.

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ABSTRACT

Biochar effect on the potential mobility of dibutyl phthalate (DBP), cadmium (Cd), and lead (Pb) in co-contaminated soils is not well investigated. A laboratory leaching study was conducted to evaluate the effect of biochars derived from bamboo (BB) and pig (PB) on the leachability of DBP, Cd, and Pb through soil columns packed with two soils with low or high organic carbon content (LOC; 0.35% C: HOC; 2.24% C) and spiked with DBP, Cd, and Pb. Application of PB to the LOC soil significantly ($P < 0.05$) reduced the leaching loss by up to 88% for DBP, 38% for Cd, and 71% for Pb, whereas its impact was insignificant in the HOC soil. The higher efficacy of PB in reducing the leaching of DBP, Cd, and Pb in the LOC soil than that of BB might be related to PB's higher specific surface area, surface alkalinity, pH, and mineral contents compared to those of BB. Co-contamination of Cd and Pb enhanced leaching of DBP in the LOC soil treated with PB, possibly by competition for the sorption sites. Leaching of DBP, Cd, and Pb were

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significantly ($P < 0.05$) higher in the LOC soil than in the HOC soil. This study revealed that the effectiveness of biochars was dependent on the soil organic carbon content. Application of PB to the LOC soil was effective in reducing the leaching risk of DBP, Cd, and Pb.

1. Introduction

The fast development and expansion of China's economy have been accompanied by uncontrolled disposal of wastes derived from various industries. In addition, the wide uses of waste materials and plastic products such as mulching film and roofing material for greenhouses in agriculture have contributed to complex contamination of soils with potentially toxic elements (PTEs) and emerging organic pollutants such as phthalic acid esters (PAEs) (He et al., 2015; Wu and Sun, 2016; Zhao et al., 2018). The co-occurrence of PTEs and emerging organic pollutants in soils is an issue of great concern affecting human health and ecosystems (Antoniadis et al., 2017). Nearly 20% of the agricultural soils in China are reported to be contaminated with PTEs, which is leading to a crop loss of more than 12 million tons each year (Li et al., 2014). Fan et al. (2017) found that cadmium (Cd) and lead (Pb) concentrations were relatively high in agricultural soils in Northern China. Cadmium and lead are nonessential elements for plant growth, can be taken up by crops, and are highly toxic to humans and thus, are important PTEs (Antoniadis et al., 2017).

Approximately 36 million hectares of soils are contaminated by organic pollutants such as PAEs (Yang et al., 2013; Zhao et al., 2018) in China. Phthalic acid esters are a group of synthetic compounds widely used as plasticizers in the manufacturing of plastics, with an annual production larger than 8 million tons, including dibutyl phthalate (DBP), di-(2-ethylhexyl) phthalate (DEHP), and diethyl phthalate (DEP) (Abdel-Daiem et al., 2012; Wang et al., 2016). Dibutyl phthalate is one of the most common plastic additives and dominates the environmental PAE contamination (Zhang et al., 2015). In recent years, the extensive use of plastic films has resulted in widespread PAE pollution of agricultural soils, because PAEs are not covalently bonded to the polymeric matrix of plastics, and thus, they are readily released into the environment (Keresztes et al., 2013). Phthalic acid esters are classified as potential endocrine-disruptors, and have a high bio-accumulation potential (Bauer and Herrmann, 1997; Zhang et al., 2015). Moreover, PAEs are ranked top priority pollutants in risk assessment (He et al., 2015; Zhao et al., 2018). Many studies have focused on the fate of PTEs and PAEs in soils due to their accumulation in soils (Beiyuan et al., 2017; Keresztes et al., 2013), which increases the risk of PTEs and PAEs entering the human food chain (Antoniadis et al., 2017). In addition, the mobile fraction of PTEs and PAEs is at risk for being leached through soils potentially contaminating groundwater and surface water resources. For instance, Europe confronts serious groundwater pollution problems with agriculture being the biggest polluter due to leaching of PTEs and pesticides from agricultural soils (Sneddon et al., 2006). In order to minimize the bioavailable amounts of PTEs and PAEs in soils, it is important to find an effective soil amendment for the immobilization of PTEs and PAEs.

Biochar is carbon-rich material made by pyrolysis of residual biomass (Zhang et al., 2013). Biochar has been applied to amend degraded soils because it typically has a high carbon content and a high porosity (Wu et al., 2012; Yang et al., 2017a), and can be used to improve soil structure and thereby, increase fertilizer use efficiency and plant growth (Dong et al., 2015; Xu et al., 2015). In addition, it enhances soil carbon sequestration (Wang et al., 2014; Wu et al., 2015) and reduces greenhouse gas emission (Deng et al., 2017; Dong et al., 2013; Li et al., 2018). Previous studies have indicated that biochar application is an effective method to (im)mobilize PTEs and organic pollutants in soils by modifying soil physico-chemical properties (El-Naggar et al., 2018; Lu et al., 2014, 2017; He et al., 2018), which is mainly explained by its high alkalinity, oxygenic functional groups and hydrophobic nature (He et al., 2016; Jiang et al., 2012; Zhang et al., 2014). It has been shown that the sorption of PTEs and organic pollutants by biochar amended soil primarily affects the leachability of contaminants in soils (Beiyuan et al., 2017; Qi et al., 2017). The possible sorption mechanisms of PTEs and PAEs, demonstrated in many studies, include electrostatic interaction between metal cations and negatively charged functional group, ion exchange via proton exchange, and pore-filling on the surface of biochar (He et al., 2015; Niazi et al., 2018a,b; Yang and Xing, 2009; Zhang et al., 2016). Some biochars applied to contaminated soils enhanced the immobilization of Cd and Pb and decreased their bioavailability and movement to groundwater due to the precipitation of Cd-carbonates and Pb-phosphates (Niazi et al., 2018a,b; Wu et al., 2017). Several studies have also demonstrated that the reduction of the mobility and bioavailability of PAEs were due to pore diffusion, partitioning and sorption via electrostatic interaction in biochar amended soils (Zhang et al., 2016). Further, the competitive sorption mechanisms between PTEs and organic pollutants in biochar-amended soils affect the leachability of these contaminants in soils (Lee and Park, 2013; Schaffer et al., 2012; Zama et al., 2017). Some studies (e.g., Sun et al., 2012) investigated the effect of biochar application on the mobility of single contaminants. However, information on the impact of biochar on the leachability of PTEs and PAEs in co-contaminated soils is limited.

Therefore, the aims of this study were 1) to investigate the effect of bamboo and pig biochars on the leaching of DBP, Cd, and Pb in two different soils, and 2) to assess the effects of soil organic carbon contents on biochar-, Cd-, and Pb-induced mobility of DBP. The results are important for understanding the potential risk of groundwater contamination from co-contaminated soils.

2. Materials and methods

2.1. Reagents

All chemicals used were of analytical reagent grade except acetonitrile. Dibutyl phthalate, the chemicals acetone, methanol, n-hexane and petroleum ether (≥99.5%) were purchased from Shanghai Lingfeng Chemical Reagent Co., Ltd. (Shanghai, China). Cadmium nitrate terahydrate and lead nitrate (≥99%) were purchased from Aladdin Industrial Co., Ltd. (Shanghai, China). The high performance liquid chromatography (HPLC)-grade acetonitrile (≥99.9%) was obtained from Tedia Co., Ltd. (Fairfield, Ohio, USA).

2.2. Collection and characterization of the studied soils and biochars

Two soils (Ferric Acrisols in the Food and Agricultural Organization (FAO) system of classification) were selected for this study