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ORIGINAL ARTICLE

Conocarpus biochar as a soil amendment for reducing heavy metal availability and uptake by maize plants

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Abstract The objective of this study was to assess the use of *Concarpus* biochar as a soil amendment for reducing heavy metal accessibility and uptake by maize plants (*Zea mays* L.). The impacts of biochar rates (0.0, 1.0, 3.0, and 5.0% w/w) and two soil moisture levels (75% and 100% of field capacity, FC) on immobilization and availability of Fe, Mn, Zn, Cd, Cu and Pb to maize plants as well as its application effects on soil pH, EC, bulk density, and moisture content were evaluated using heavy metal-contaminated soil collected from mining area. The biochar addition significantly decreased the bulk density and increased moisture content of soil. Applying biochar significantly reduced NH_4OAc- or AB-DTPA-extractable heavy metal concentrations of soils, indicating metal immobilization. *Conocarpus* biochar increased shoot dry biomass of maize plants by 54.5–102% at 75% FC and 133–266% at 100% FC. Moreover, applying biochar significantly reduced shoot heavy metal concentrations in maize plants (except for Fe at 75% FC) in response to increasing application rates, with a highest decrease of 51.3% and 60.5% for Mn, 28% and 21.2% for Zn, 60% and 29.5% for Cu, 53.2% and 47.2% for Cd at soil moisture levels of 75% FC and 100%

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FC, respectively. The results suggest that biochar may be effectively used as a soil amendment for heavy metal immobilization and in reducing its phytotoxicity.

1. Introduction

During the last decades, the concern for heavy metal contaminated soils has increased due to their stream seriously threatening the ecosystem (Friesl et al., 2003; Moon et al., 2013). The soils can be polluted with heavy metals by various human activities (Al-Farraj et al., 2013; Moon et al., 2013). Mining activity is one of the most important sources for heavy metals introduced into soils (Ok et al., 2011a,b; Reglero et al., 2008; Al-Farraj et al., 2013). Heavy metals are regarded as non-degradable or non-destroyable inorganic contaminants, changing their solubility and chemical forms and subsequently their availability to plants. The total contents of heavy metals in soils might not mirror their phytotoxicity and accessibility to plants. Phytoavailability refers to the readily available form of a heavy metal, which is uptaken by plants. Thus, it is very important to decrease heavy metal accessibility and availability to plants in contaminated soils.

Soil remediation from hazard contaminants is urgent to rehabilitate polluted soils for safe food production. The rehabilitation of heavy metal contaminated soils is usually dependent on in situ and ex-situ remediation techniques (Vangronsveld and Cunningham, 1998; Lim et al., 2013; Moon et al., 2013). The immobilization and phytoremediation techniques are currently considered as effective method to remediate heavy metal contaminated soils (Moon et al., 2013; Lim et al., 2013; Illera et al., 2004; Ok et al., 2010, 2011b; Usman et al., 2006). The soil amendments have to possess a high binding capacity as well as to be safe for the environment, and not to have adverse effects on soil structure, soil fertility, or the ecosystem. Recently, it has been reported that biochar produced from carbonization of organic wastes can be considered as an alternative additive, which may not only affect C sequestration of soil, but also change its physico-chemical and biological properties (Ibrahim et al., 2013; Lehmann et al., 2003; Chan et al., 2007; Glaser et al., 2002; Tryon, 1948). Additionally, due to its functional and sorptive characteristics, biochar has been suggested to be an effective sorbent for various hazardous inorganic and organic contaminants (Vithanage et al., 2014; Cao et al., 2009). It has been reported that the additions of biochars increased the soil capacity to retain and adsorb plant nutrients and decrease the nutrient losses by leaching (Uzoma et al., 2011; Chan et al., 2008, 2007; Lehmann et al., 2003; Glaser et al., 2002). Biochars have been also shown to decrease heavy metal mobility and bioavailability (Méndez et al., 2012). The addition of biochar to soils might modify some chemical soil properties such as cation exchange capacity and soil acidity, providing circumstances that are suitable for heavy metal immobilization and subsequently reducing their availability to plants (Park et al., 2011). The surface functional groups and adsorption sites on biochar could increase the soil cation exchange capacity and consequently increase metal exchange capacity of soil through the formation of complexes with cationic heavy metal (Paz-Ferreiro et al., 2014).

The use of biochar, depending on its quality, may affect chemical and biological soil properties, thus affecting heavy-metal redistribution among solid-phase components. Specifically, the effects of biochar application depend on various factors such as the soil type, the metal type, the type of feedstocks used for charring, pyrolysis conditions and the amount of biochar applied to the soil (Park et al., 2011; Debela et al., 2012). In Saudi Arabia, *Conocarpus erectus* L. is an evergreen tree planted around parking lots and along streets and its recycling is problematic due to its huge aboveground biomass and widespreadness. *Conocarpus erectus* L. wood is hard and durable and possesses high calorific value as fuel but it is most widely used for high-grade charcoal (Morton, 1981; Al-Wabel et al., 2013). Therefore, transforming conocarpus wastes into biochar may be considered as a mean for waste recycling (Al-Wabel et al., 2013). The main objective of the present study was to evaluate the efficacy of *Concarpus* biochar as a soil immobilizing agent for reducing heavy metal availability and uptake by maize plants as well as its application effects on soil pH, EC, bulk density, and soil moisture.

2. Materials and methods

2.1. Soil sampling

The heavy metal-contaminated soil for this study was collected from the mining area of Mahad AD'Dahab, Saudi Arabia. The soil samples were collected from the surface soil layer (0–20 cm). All soil samples were mixed thoroughly and then air-dried. Then, the soil samples were sieved passing through a 2-mm screen. Some chemical and physical properties of soil were estimated according to standard procedures (Sparks, 1996). The soil texture was determined by means of the hydrometer method. Soil pH and electrical conductivity (EC) were measured with a glass electrode using a soil-to-water ratio of 1:1. The total content of Fe, Mn, Zn, Cd, Cu and Pb was determined by EPA 3051 microwave digestion method. Heavy metal concentrations were determined by ICP (Perkin Elmer Optima 4300 DV ICP-OES). The total concentrations of heavy metals in soil samples are 26,118 mg kg^{-1} for Fe, 970 mg kg^{-1} for Mn, 5453 mg kg^{-1} for Zn, 1430 mg kg^{-1} for Cu, 8.12 mg kg^{-1} for Cd and 541 mg $kg^{-1}$for Pb.

2.2. Biochar production and characteristics

The biochar applied in this study was produced by pyrolysis of conocarpus (*Conocarpus* species) trees wastes, which was collected from the campus of King Saud University, subjected to direct sunlight (moisture content was nearly 4.7%) and then cut down to small pieces (7–10 cm). After that, the pyrolysis process for conocarpus pieces was