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The effect of biochar and compost from urban organic waste on plant biomass and properties of an artificially copper polluted soil

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ABSTRACT

Soil contamination with copper is a global issue, in particular in soils with a history of fertilizers, fungicides or municipal waste amendment. Several remediation techniques have been investigated to reduce the environmental impact of Cu-contaminated soil, including the use of organic amendments such as composts and biochars, which can bound part of the soluble fraction of the metal. The objective of this work is to study the effect of biochar and biochar plus compost addition on copper mobility, soil microbial biomass and growth of different plant species following remediation of a soil spiked with copper (1000 mg Cu kg^{-1}). The contaminated soil was treated with 10 wt% of biochar or biochar plus compost. Different plant species (mustard, cress and ryegrass) were grown in the soil during 4 weeks. A significant reduction on the mobile form of Cu was observed in soils treated with biochar and biochar plus compost. The highest microbial biomass values were obtained in samples treated with biochar plus compost. After cress growth, the microbial biomass of soil treated with biochar plus compost was similar to that of non-polluted soil. The germination test showed increased root length in the amended soils compared to the contaminated soils. With respect to biomass growth of vegetable species in copper polluted soil, only ryegrass presented a satisfactory growth in the contaminated soil without the biochar treatment. For mustard and cress, biomass growth was only observed following biochar addition.

1. Introduction

Soil contamination is a global issue, constituting a threat to ecosystems, farming production and human wellbeing. When soil contamination is produced by heavy metals, impacts are significant, as they are non-biodegradable compounds. Important consequences of heavy metal contamination comprise variations on pH, high electrical conductivity or microbial properties alteration (Vacca et al., 2012; Yang et al., 2012). Keeping in mind that metals distribution may vary along time and with soil conditions (Lu et al., 2005), undesirable effects such as incorporation to higher level of the food chain, water contamination and human health affectations are granted. Agricultural use of copper fungicides has led to a high level of copper in many soils around the world which persists and further accumulates in the topsoil under current management practices. Increasing copper concentrations in soils has negative effects, including reducing plant biomass (Kolbas et al., 2015; Mc Bridge et al., 1981) and affecting soil biodiversity. As an example of the latter, Cu contamination can reduce the abundance and biodiversity of soil organisms, thus inhibiting the activity of hydrocarbon-degrading microorganisms and leading to an impairment of the C and N cycles (Mackie et al., 2014).

Coupled to this, urban organic waste is increasingly produced as a consequence of urbanization and urban sprawl. Most urban wastes are disposed in landfills, creating a series of problems which include the emission of greenhouse gases, soil contamination, leaching of pollutants to groundwater and the production of obnoxious odors. Urban organic wastes could be composted, but composts are not harmless and could pose several risks to human. This includes exposure associated to atmospheric dispersion and the presence of pathogens in the compost (Déportes et al., 1995). Moreover, compost addition to soil in Spain has resulted in the accumulation of total and available heavy metals (Ramos, 2006) and thus, better valorization alternatives need to be explored. The use of compost in agriculture can lead not only to increased metal concentrations in the crops or in the groundwater but also to

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building up soil salt content (Hargreaves et al., 2008).

Several remediation techniques have been investigated to reduce the environmental impact of metal contaminated soils (Bolan et al., 2014). Stabilization/solidification method is a remediation technology defined as the process of using non-toxic substances (organic and inorganic) for minimizing the solubility of heavy metal contaminants in soils and thus reducing its leachability to the groundwater and the environment. Several soil amendments have been used successfully for immobilization of metals, including lime or phosphate (Cao et al., 2008) and organic materials from different origins, including compost (Vaca-Paulin et al., 2006; Karami et al., 2011; Venegas et al., 2015). More recently, biochar, the carbonaceous product obtained by biomass thermal treatment (pyrolysis) in absence or with a limited amount of oxygen (<1%) (Lehmann et al., 2011), has been studied as amendment for the remediation of heavy metal contaminated soils (Karami et al., 2011; Paz-Ferreiro et al., 2014).

According to Zhang et al. (2013) biochar has several impacts in the mobility of heavy metals. Studies performed in a nicked polluted soil demonstrated that the addition of biochar reduces the quantity of mobile, leached and also bioavailable nickel (Méndez et al., 2014). Lu et al. (2014) proposed that biochar effect on the metal mobility is partially due to superficial adsorption combined with the interchange of ions between the metals and calcium, magnesium, sodium and potassium ions. Carbonates phosphates and sulphur also contribute to the stabilization of the soil pollutant (Park et al., 2013).

Paz-Ferreiro et al. (2014) concluded that biochar as amendment can improve plants growth with some additional effects such as (i) improve biological activity of soil and at the same time that decrease the toxicity of the soil, (ii) biochar acts like a slow release fertilizer and increases microbial biomass, (iii) regulate soil pH. Furthermore, other benefits, including carbon sequestration, binding of nutrients and improved soil water retention capacity (Liang et al., 2014; Méndez et al., 2012; Paz-Ferreiro et al., 2012) have also been reported frequently in the literature.

A diverse number of feedstocks have been used to prepare biochars suitable for the remediation of heavy metals in soils (Gascó et al., 2016a; Méndez et al., 2014; Paz-Ferreiro et al., 2014). However, to our knowledge, there is a lack of studies using urban waste biochar for the remediation of polluted soils.

Thus, our literature review has identified the prospect to transform urban organic wastes into biochar, in order to divert the amount of residues disposed in landfills and remediate heavy metal polluted soils. The main objective of the present work is to determine the efficiency of biochar and biochar plus compost addition in the remediation of a copper-spiked soil. The soil was grown with different plants species in order to determine the prospects for revegetation and study the risk of metal transfer to the plants.

2. Materials and methods

2.1. Raw materials

The selected soil (C) was sampled in El Fresno town (Ávila, Spain, latitude: 40° 37′ N, longitude: 4° 44′ W, altitude: 1073 m) and it is classified as Typic Xerofluvent according to Soil Taxonomy (Soil Survey Staff, 2014).

Organic waste (R) was produced in a solid waste treatment plant located in the North of Spain. After its reception, solid wastes were pretreated with different mechanical equipment, such as trommels in order to separate the organic matter of other materials. Biochar (B) was obtained by thermal treatment of R in an inert atmosphere in a Heron 12-PR/300 series 8B muffle, at a heating rate 10 °C min^{-1} until reaching 500 °C. This temperature was maintained for 1 h.

2.2. Raw materials characterization

Soil (S), compost of urban organic waste (R) and corresponding biochar (B) were air-dried, crushed and sieved through a 2 mm mesh prior to analyses. Raw materials were characterized, with the following properties being measured:

Soil texture was determined following the methodology of Bouyoucos (1962). pH and electrical conductivity (EC) were determined with a soil:water ratio of 1:2.5 using a Crison micro-pH 2000 and a Crison 222 conductivimeter (Alella, Spain) respectively. Cation exchange capacity (CEC) was determined in $NH_4OAc/HOAc$ at pH 7.0 (Sumner and Miller, 1996). Organic carbon (C_{oxi}) oxidized with dichromate was determined by the Walkley–Black method (Nelson and Sommers, 1996) and soluble organic carbon ($C_{oxi\ soluble}$) was determined after sampling the extract in a ratio sample:water 1:10 (m/v) following 1 h agitation. After that, $C_{oxi\ soluble}$ was determined according to the Walkley-Black method.

Kjeldahl nitrogen content ($N_{Kjeldahl}$) was done by Kjeldahl's method (Bremner et al., 1996) and phosphorous (P) was analyzed with Shimadzu UV-1203 UV spectrophotometer at 430 nm using Olsen's method (Watanabe and Olsen, 1965).

Thermal analyses (TG, dTG and DTA) of samples R and B were performed in a thermobalance Labsys Setaram. Samples (40–50 mg) were heated until 850 °C in an air atmosphere with a 40 mL min^{-1} flux using a heating rate of 15 °C per minute (Méndez et al., 2014). Proximate analysis was determined by thermogravimetry using a Labsys Setaram equipment (Caluire, France). The sample was heated to 600 °C under N_2 with a 30 °C min^{-1} heating rate. Moisture content was calculated as the weight loss from the initial temperature to 150 °C. Volatile matter (VM) was determined as the weight loss from 150 to 600 °C under N_2 atmosphere. At this temperature, air was introduced and fixed carbon (FC) was calculated as the weight produced when the final sample was burnt. The ash was determined as the final weight of the samples.

All experiments were performed in triplicate.

2.3. Preparation of polluted soil and treatments

The sampled soil was contaminated with copper at a concentration of 1000 mg Cu^{2+} kg^{-1} of soil and uncontaminated soil (C) and contaminated soil were incubated during 3 weeks at 20 °C. The copper source was copper sulphate ($CuSO_4.5H_2O$). The period of incubation was chosen as it is common in studies on heavy metal mobility (Oorts et al., 2008) or soil biological properties (Creamer et al., 2014).

After the incubation period, contaminated soil (Cont) was treated with a 10% of biochar (Cont + B) and with 10% of biochar and 5% of compost (Cont + B + R).

2.4. Germination test

Bioassay of seed germination and early stage seedling growth is a simple and commonly used ecotoxicological text that is starting to be used to study the biochar effect in soils (Méndez et al., 2015) and, although several species have traditionally been used to evaluate phytotoxicity, there are no standardized plant species in use for this kind of assay (Gascó et al., 2016b). The phytotoxicity test was made following the procedure described by Zucconi et al. (1985) with 9 species in order to have a better understanding of biochar effects: Cress (*Lepidium sativum*), white mustard (*Sinapsis alba*), lentil (*Lens culinaris*), lettuce (*Lactuca sativa*), tomato (*Lycopersicon esculentum*), *basil* (*Ocymum basilicum*), English ryegrass (*Lolium perenne*), wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) (Table 1).

The test was carried out on filter paper in Petri dishes. Five

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