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Contrasting effects of biochar, compost and farm manure on alleviation of nickel toxicity in maize (*Zea mays* L.) in relation to plant growth, photosynthesis and metal uptake

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ABSTRACT

Nickel (Ni) toxicity in agricultural crops is a widespread problem while little is known about the role of biochar (BC) and other organic amendments like farm manure (FM) from cattle farm and compost (Cmp) on its alleviation. A greenhouse experiment was conducted to evaluate the effects of BC, Cmp and FM on physiological and biochemical characteristics of maize (*Zea mays* L.) under Ni stress. Maize was grown in Ni spiked soil without and with two rates of the amendments (equivalent to 1% and 2% organic carbon, OC) applied separately to the soil. After harvest, plant height, root length, dry weight, chlorophyll contents, gas exchange characteristics and trace elements in plants were determined. In addition, post-harvest soil characteristics like pH_s, EC_e and bioavailable Ni were also determined. Compared to the control, all of the amendments increased plant height, root length, shoot and root dry weight with the maximum increase in all parameters by FM (2% OC) treatment. Similarly, total chlorophyll contents and gas exchange characteristics significantly increased with the application of amendments being maximum with FM (2% OC) application. Amendments significantly increased copper, zinc, manganese and iron concentrations and decreased Ni concentrations in the plants. The highest reduction in shoot Ni concentration was recorded with FM (2% OC) followed by BC (2% OC) being 73.2% and 61.1% lower compared to the control, respectively. The maximum increase in soil pH and decrease in AB-DTPA extractable Ni was recorded with BC (2% OC) followed by FM (2% OC). It is concluded that FM (2% OC) was the most effective in reducing Ni toxicity to plants by reducing Ni uptake while BC (2% OC) was the most effective in decreasing bioavailable Ni in the soil through increasing soil pH. However, long-term field studies are needed to evaluate the effects of these amendments in reducing Ni toxicity in plants.

1. Introduction

Heavy metals accumulate in the agricultural soils mainly through natural sources such as weathering and volcanic eruptions and anthropogenic activities such as mining, waste disposal, and intensive use of fertilizers and pesticides (Marwa et al., 2012; Adrees et al., 2015a; Khan et al., 2016). Contamination of soils with heavy metals may reduce quality of agricultural land as well as crop yield and quality (Rehman et al., 2015; Rizwan et al., 2012, 2016a, 2016b). On the other hand, contamination of agricultural soils with heavy metals caused serious environmental and health problems (Zafar et al., 2015; Khan et al., 2016).

Like most of other heavy metals, nickel (Ni) is an essential micronutrient and is required for normal growth and development of plants. However, Ni toxicity leads to a variety of physiological disorders in plants (Guo et al., 2010; Kamran et al., 2016). Nickel could enter accumulate in the human body through food crops grown onto Ni contaminated soils (Zafar et al., 2015; Khan et al., 2016). Previous studies have shown significantly higher concentrations of Ni in different plant parts of maize (Guo et al., 2010; Marwa et al., 2012), Indian mustard (Ansari et al., 2015), rice (Nazir

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et al., 2016), wheat (Wang et al., 2015), *Eruca sativa* (Kamran et al., 2016) and cotton (Khaliq et al., 2016) when grown with Ni supply. Guo et al. (2010) reported that excess Ni accumulation decreased dry weight and grain yield of maize grown in Ni contaminated soil. Nickel toxicity linearly decreased seed germination, shoot and root lengths and biomass in Indian mustard but the response varied among the studied genotypes (Ansari et al., 2015). Similarly, Ni toxicity decreased plant height, rice yield and nitrogen (N), phosphorus (P) and potassium (K) concentrations in rice (Nazir et al., 2016) and biomass production and chlorophyll contents in *Eruca sativa* (family: Brassicaceaea) (Kamran et al., 2016). Therefore, it is imperative to decrease Ni uptake and toxicity to ensure safe food production from the soils receiving Ni contaminated water for irrigation.

Different management strategies such as the use of organic and inorganic amendments have been employed for the reduction of heavy metal toxicity in plants (Adrees et al., 2015b; Putwattana et al., 2015; Rizwan et al., 2016c; Sun et al., 2016). The application of organic amendments has benefits over most of the inorganic amendments owing to their higher biodegradability, improvement in soil properties, and cost-effectiveness (Rizwan et al., 2016c). Recently, different easily available organic amendments have been used for the phytoremediation of metal contaminated soils such as biochar (BC), farm manure (FM), compost (Cmp) and press mud (PM) (Ahmad et al., 2015; Yousaf et al., 2016). It has been reported that BC application increased maize growth, biomass production and decreased accumulation of toxic metals (Al-Wabel et al., 2015). In another study, BC and Cmp mixtures decreased bioavailable fractions of Pb, Zn, and Cd in the soil (Karer et al., 2015). More recently, BC and Cmp application increased the Cu immobilization in the soil and decreased its uptake by sunflower (Jones et al., 2016). Similarly, cow manure and rice straw decreased Cd and Zn concentrations in maize shoots, roots and grains (Putwattana et al., 2015). These studies showed organic amendments could decrease the metal concentrations in plants through different mechanisms such as metal immobilization in the soil and improvement in soil fertility status. Thus, application of organic amendments might be a suitable option for cultivation of contaminated soils. However, little information is available on the effect of BC, FM and Cmp for immobilization of Ni in soil and its toxicity to plants (Mosa et al., 2016; Shen et al., 2016). Therefore, there is a dire need to evaluate the role of these organic amendments on reducing Ni toxicity to plants.

The major food requirement of the world is fulfilled mainly through cereal crops such as maize, wheat and rice. At world level, maize is among the most cultivated crops with production of 883 metric tons (MT) in 2011 followed by rice (723 MT) and wheat (704 MT) (FAOSTAT, 2014). Several studies reported that Ni toxicity decreased maize growth and yield (Chen et al., 2009; Ahmad and Ashraf, 2012; Sreekanth et al., 2013). In addition, little information is available regarding the effect of BC, Cmp and FM on reducing Ni toxicity in maize. Therefore, it was hypothesized that BC, Cmp and FM may decrease Ni toxicity by reducing Ni uptake and enhancing the micronutrient uptake by maize. Thus, the present study was conducted to evaluate the effects of BC, Cmp and FM on growth, photosynthesis and Ni and mineral nutrient uptake by maize in Ni contaminated soil. Furthermore, the effects of amendments on bioavailable Ni in soil and soil properties including soil pH and EC were also studied.

2. Material and methods

2.1. Soil collection and characterization

Surface soil (0–20 cm) was collected from an agricultural field from University of Agriculture Faisalabad (UAF), air dried under cover and passed through a 2 mm sieve. The soil was analyzed for basic physical and chemical properties (Table 1) including textural class (Bouyoucos, 1962), pH of soil saturated paste (pH_s), and electrical conductivity of saturated paste extract (EC_e) (Richards, 1954), organic carbon (Jackson, 1962), and plant available (ammonium bicarbonate-diethylene triamine pentaacetic acid extractable, AB-DTPA) metals (Soltanpour, 1985). The pH was measured with the help of pH meter (model HM-12P). The EC_e was measured by using the conductivity meter (Lovibond® Model Sensodirect Con 200) after calibrating it with 0.01 *N* KCl solution. Bioavailable heavy metals were determined by extracting the soil with AB-DTPA solution. The AB-DTPA solution was prepared by using 0.005 *M* DTPA +1.0 *M* NH_4HCO_3 at pH 7.6 and 10 g of soil was extracted with 20 mL of AB-DTPA solution by horizontally shaking for 120 min, and then extracted samples were centrifuged and filtrated. The metal concentrations in the soil extract were determined using atomic absorption spectrometer (Solar S-100, Thermo Electron, USA).

Table 1
Properties of soil used in the pot experiment.

Texture	Clay loam
Sand (%)	63.6
Silt (%)	12.0
Clay (%)	24.4
pHs	6.9
ECe (dS m^{-1})	7.3
Cation exchange capacity (CEC) ($cmol_c$ kg^{-1})	15.7
Soluble CO_3^{2-}(mmol L^{-1})	0.82
Soluble HCO^{3-}(mmol L^{-1})	4.64
Soluble Cl^-(mmol L^{-1})	6.52
Soluble $Ca^{2+}+Mg^{2+}$ (mmol L^{-1})	15.13
Organic matter (%)	0.54
Available Ni (mg kg^{-1})	0.21
Available Cu (mg kg^{-1})	0.41
Available Zn (mg kg^{-1})	0.79

2.2. Soil amendments

Three organic amendments viz biochar (BC), compost (Cmp) and farm manure (FM) from cattle farm were used for the study. Biochar was prepared from *Eucalyptus saligna* wood at 450 °C under limited supply of oxygen in Isotemp muffle furnace (550 series, Fisher Scientific, Pittsburgh, PA). Compost was obtained from Soil Microbiology and Fertility Laboratory, Institute of Soil and Environmental Sciences (ISES), UAF, Faisalabad while FM was collected from the dairy farm of the University. Compost and FM were air-dried and passed through a 2 mm sieve. The EC and pH of the amendments were measured in 1:1 ratio of solid to water suspension while the organic carbon contents were determined following the method described by Jackson (1962). The typical properties of FM, BC and Cmp were EC 7.8, 8.23 and 7.49 dS m^{-1} and pH 7.49, 7.97 and 6.98 respectively. Background levels of organic carbon (OC) contents in FM, BC and Cmp were 31.97%, 33.43% and 27.42%, respectively.

2.3. Pot experiment

A pot experiment was conducted in the wire house under ambient air and temperature conditions in ISES, UAF, Pakistan. Soil was treated with 160 mg Ni kg^{-1} of the soil by using nickel chloride and was kept to equilibrate for 100 days at about 40% of the field water holding capacity. After this, FM, BC and Cmp were applied at three rates equivalent to 0, 1% and 2% of organic carbon and the amendments were thoroughly mixed in the soil. Each pot