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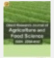

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Biochar and poultry manure application effects on selected soil chemical properties and bioaccumulation of heavy metals in maize plant cultivated on degraded soils

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ABSTRACT

With the rapid development of industrialization and overpopulation, a significant number of heavy metals have been produced and entered the soil through anthropogenic (illegal mining) interference, and has become an issue of global focus. Soil samples for this study were collected in degraded farmland in Amagu, Abakaliki, Nigeria. The study evaluated the effect of composted poultry manure and biochar on heavy metals (Lead, Copper, and Zinc) in degraded soil and its bioaccumulation in maize plants. Biochar from three feedstocks were pyrolyzed at 42^0C*, while poultry manure from battery cage system was composted for 90 days before application. The study was a 4 × 2 factorial experiment in a completely randomized design. The soil's physical and chemical properties were analysed before treatment. The application of Composted poultry manure (CPM) and biochar sources reduced the acidity of the soil and recorded a significant increase in the organic carbon content. After harvest, Pb still exceeded the Food and Agricultural Organization (FAO) permissible limit of 100 mg/kg in Agricultural soils, but reduced significantly in the root region. CPM showed a significant (*$P \leq 0.05$*) increase by 33 % of the amount of Pb in the shoot after harvesting. Significant increases were recorded in the level of copper in the shoot across the biochar treatments. About 140 % reduction of Zinc in the soil was recorded after composted poultry manure was applied. The application of the organic treatments varied in their effects on different elements and plant bioaccumulation mechanisms. The amount of Pb in the root and shoot reduced after the application of biochar and poultry manure.*

Keywords: *Biochar, composted poultry manure, heavy metals, maize, root, shoot*

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INTRODUCTION

Agricultural ecosystems are important in providing essential products and supply services to humans (Li *et al*., 2023). However, environmental contaminants harmful to plants and human health often emanate from anthropogenic activities, contributing to pollution in soil, air, and water. The heightened level of industrialization vis -a- vis sustainable development and utilization of land resources has become a hot-button issue globally. This is especially in agricultural areas where indiscriminate human activities such as excessive use of fertilizers, irrational irrigation, and use of pesticides occur (Wang *et al*., 2018; Yan *et al*., 2018; Woodford, 2019), which have deleterious impact on the quality of the soil used for agriculture (Fierer *et al*., 2020, Zhang *et al*., 2023).

This has posed a potential risk to public health, ecosystems and challenges for the attainment of Global Sustainable Development Goals (Chai *et al*., 2023, Liu *et al*., 2023). Heavy metal accumulation in agricultural soils has become an issue of global concern because of its impacts on human health due to bioaccumulation in food chains (Wang *et al*. 2018; Yang *et al*., 2020); growth and yield of the crops (Angon *et al*., 2024), and long-term impacts on soil fertility (Song *et al*., 2017; Xu *et al*., 2019) especially when it is naturally deposited in shale parent material. However, the application of carbonaceous materials (biochar) as an innovative approach to reduce the mobility and bioavailability of heavy metals in contaminated soils and plants is an environmentally friendly, easily prepared, effective and economical technique (Nie *et al*., 2018; Xu *et al*., 2018). Biochar, a product of the slow and incomplete combustion of organic materials, can enhance the physical, chemical and biological properties of soil when used in agriculture (Prendergast-Miller *et al*., 2014; Hossain *et al*., 2020). The high capacity of biochar to adsorb potential heavy metals in soil can be attributed to electrostatic attraction, ion exchange, precipitation, and complexation (Egene *et al*. 2018; Jatav *et al*., 2021).

The prospect of biochar as a soil amendment in agricultural research has recently been recognized as a promising yet underutilized technology (Jemal and Yakob, 2021). The stability of biochar allows for long-term carbon storage, soil amelioration and reduced soil acidity, leading to improved crop production (Brtnicky *et al*., 2021; Cheng *et al*., 2020; He *et al*., 2019). Biochar is known to reduce the hazards of heavy metals and organic pollutants (Peng *et al*., 2017), improve soil nutrients (Prasad *et al*., 2021), increase soil water content (Razzaghi *et al*., 2020), alter soil structure, stimulate microbial activity (Amoakwah *et al*., 2022) and consequently promotes crop growth. The efficacy of biochar is usually optimized by controlling pyrolysis temperature and feedstock type, and production of biochar with dynamic characteristics (Das *et al*., 2021; Lataf *et al*., 2022; Tomczyk *et al.,* 2020). Composted organic manure, especially from poultry wastes has been reported to improve the mineral composition in tissues of vegetables (Jonathan *et al.,* 2012), and source of nutrients in the soil for plant uptake (Okoro *et al.,* 2022). Poultry manure enhances soil organic matter content and forms simple and chelated complexes with toxic elements. This process affects the bioavailability of toxic heavy metals in the soil, subsequently influencing plant physiological and metabolic processes. (*Okoro et al*., 2022). Organic soil amendments are commonly used to bind heavy metals by transforming them from highly bioavailable forms to less bioavailable fractions, which are associated with organic matter (OM), metal oxides, or carbonates (Walker et al., 2004). These amendments are particularly effective due to their humic acid content, which binds a wide range of metal (loids), including Cd, Cu, and Pb (Alvarenga *et al*., 2009). The presence of heavy metals in soil, plants and their bioavailability are pertinent because of the multiple adverse effects on human health when crops grown in such soils are consumed (Okoro *et al.,* 2022). Therefore, the objectives of this study are to evaluate the effects of composted poultry manure and biochar sources on selected soil chemical properties and to determine the uptake of heavy metals by maize plants

MATERIALS AND METHODS

Description of soil sampling location

The soil samples were collected from farmlands around mining sites in Amagu, Enyigba in Abakaliki local government area of Ebonyi State. The area (Amagu) is located between latitude 06^0 10’ - 06^0 13’ N and longitude 08^0 05’ - 08^0 10’ E in the derived savanna vegetation of the southeast ecological zone (Figure 1). The area experiences bimodal patterns of rainfall (April – July) and (September – November). The total mean annual rainfall ranges between 1700 – 2000 mm. The minimum and maximum temperatures lie within 27 ^{0}C – 31 ^{0}C respectively. The soil belongs to the order Ultisol, with shale as the predominant parent material (Nwaogu and Ebeniro, 2009). Mining of minerals, stone quarrying, palm wine tapping, and farming constitutes the major economic activities of the people in the study area.

Figure 1: One of the mining sites at Amagu Enyigba.

Description of the location of the screen house experiment

The study was conducted in the screen house of the Department of Soil Science and Land Resources Management (Michael Okpara University of Agriculture, Umudike). It is located between latitude 05º2’ North and longitude 07º33’ East, with an elevation of 112 m above sea level. The climate of the area is essentially humid with an average rainfall distribution of 2117 mm which is distributed over 10 months in a bimodal rainfall pattern. It has a relative humidity ranging from 75- 76% and temperature range of 19-35ºC (NRCRI, 2019).

Soil sample collection

The soil samples used for the analysis were randomly collected at 0 – 20 cm depth using a soil auger and spade from cultivated farmlands around the mining site. Random soil samples were collected at five different points (70m apart) which were bulked together, air-dried at room temperature (27.0^{0}C) and sieved with a 2 mm and 4 mm sieve for laboratory analysis, and greenhouse experiment respectively.

Biochar production and collection of research materials

The different feedstocks for biochar production were pyrolyzed at 420 ^{0}C in a double-barrel metallic drum (height 67 inches × diameter 22.5 inches). The combustion lasted 45 minutes, while the temperature was determined using an infrared meter. The biochar produced was allowed to cool, finely ground using an automated grinding machine, and passed through a 0.25 mm mesh sieve size. Oba super II maize seeds were sourced from the Research and Training Unit of Michael Okpara University of Agriculture, Umudike.

Composted poultry manure (CPM) production

Poultry manure collected fresh from the battery cage system (Lodu in Umuahia) was composted in a perforated plastic drum composter. The poultry manure collected was composted for 90 days with regular stirring at two-week intervals to increase aeration and decomposition. This setup was situated in a greenhouse to avoid direct contact with sunlight. At the expiration of 90 days, the composted manure was air-dried, ground, and sieved with a 1mm sieve and stored. Chemical compositions of the CPM were also analyzed.

Experimental procedures and test crop

Ten kilograms of collected soil samples were placed in a 12-litre container. Biochar was applied to the soil at a uniform rate of 10 t/ha (equivalent to 44.4 g/10 kg of soil) and allowed for two weeks before planting. The experiment was a 4 × 2 factorial experiment in a completely randomized design. The factors consist of four sources of biochar (control, empty oil palm bunch, maize cob, wood shavings) and two rates of poultry manure (0, 10 t/ha), with three replications**.** In each pot, three seeds were planted and then thinned down to two seedlings after 10 days of germination. Hand-picking of weeds was done as they emerged during the experiments.

Laboratory analysis

Soil physical and chemical analysis conducted included: particle size analysis using Bouyoucos hydrometer method as described by Kettler *et al.,* (2001). Soil pH was determined in a 1:2.5 ratio, soil to water suspension using an electrode pH meter (Mclean, 1965). Organic carbon was determined using the Wet dichromate oxidation method as described by Walkey and Black (1934) and modified by Nelson and Sommers (1996). Available phosphorus was determined using Bray 2 method of Bray and Kurtz (1945) as described by Kuo (1996). Total nitrogen was determined using the micro kjeldhal method as described by Bremner (1996). Total heavy metal levels in both soil and plant samples were determined using the Aqua Regia method (3:1 ratio of HCl: HNO_3), a method described by Ehi-Eromosele *et al*., (2012). All plant samples were carefully harvested at 7 weeks after planting and oven-dried at a temperature of 70 ^{0}C for 72 hours and constant weight were recorded.

Statistical analysis

The data generated were subjected to mean descriptive analysis and analysis of variance (ANOVA) using the GENSTAT package (12th Edition).

RESULTS AND DISCUSSION

The physical, chemical, and microbial properties of soil samples used for the study

The physical, chemical, and microbial properties of the soil samples used for the experiment are presented in (Table 1). Particle size distribution differed significantly between the farmland close to mining areas when compared to farmlands far from the mining areas. Based on the results shown, the soil was observed to belong to the textural class of Sandy clay loam (SCL). Available phosphorus was observed to be higher in the farmland around the mining site with a value of 8.47 mg/kg than the control (7.03 mg/kg). The extremely high amount of heavy metals observed in the farmlands around Amagu mining area was similar to that reported by Aremu, *et al*., (2010); Ayodele and Modupe (2008). The artisanal mining activities expose the geological materials (the shale and the ores), which are the natural sources of these heavy metals to intensive surface weathering.

When these geological materials are broken down either by chemical, biological or mechanical weathering, the composite metals are released into the soil either as aqueous species or in dispersed forms of the constituting mineral or as precipitates of new minerals. Once heavy metals especially lead have been deposited in the soil, it moves very slowly down the profile and can persist for a long time at the surface (Mahida *et al*., 2023).

Table 1: The physicochemical and microbial properties of soil samples used in the study.

Soil parameters	Mining site	Control site	T-test value
Sand (g/kg)	670.0	710.0	0.008
Silt (g/kg)	240.0	200.0	0.008
Clay (g/kg)	90.0	90.0	n.s
Textural class	SCL	SCL	
pH	4.83	4.94	n.s
Organic carbon (%)	0.98	1.04	0.035
Total nitrogen (%)	0.04	0.05	0.035
C/N ratio	24:1	20:1	---
Available phosphorus	8.47	7.03	n.s
Lead (mg/kg)	3042	2305	--
Copper (mg/kg)	48.5	40.5	--
Zinc (mg/kg)	709	431	--

Note: SCL = sandy clay loam, C/N: Carbon/Nitrogen

Table 2: Chemical characteristics of organic amendments used for the study.

PROPERTIES	EMCB	EOPBB	WSB	CPM
Moisture content (%)	4.61	14.74	5.18	NDD
pH	8.11	8.50	6.45	8.01
Electrical conductivity (us/cm)	0.80	0.36	1.15	NDD
Total nitrogen (%)	2.72	1.85	0.92	1.92
Available phosphorus (ppm)	0.15	0.34	0.21	0.99
Total organic carbon	40.1	52.2	56.3	38.7
C/N ratio	15:1	29:1	60:1	20:1
Exchangeable bases (cmol/kg)				
Calcium	6.2	7.9	4.8	5.61
Magnesium	2.8	3.1	2.4	1.82
Potassium	12.7	19.3	14.6	0.43
Sodium	1.8	2.0	1.3	0.042
Heavy metals (mg/kg)				
Lead (Pb)	0.66	0.54	0.45	0.03
Zinc (Zn)	0.92	1.23	0.10	0.13
Copper (Cu)	0.04	0.28	0.14	0.06

ND = Not detected, NDD = Not determined, EMCB = Empty maize cob biochar; EOPBB = Empty oil palm bunch biochar; WSB = Wood shavings biochar; CPM = Composted poultry manure

The high heavy metals concentration in the soils of the study sites portends a great risk to human health and the environment, as soil is a veritable channel of heavy metal entry into the food chain. The hazardous effects of high concentrations of these heavy metals due to artisanal mining activities on human population might be further aggravated by the fact that major staple food crops were planted as close as 50 meters from the mines.

The physical and chemical composition of organic amendments used for study

The selected physical and chemical properties of the different sources of biochar produced at about 420 ° C are shown in (Table 2). Empty oil palm bunch biochar (EOPBB) contained the highest amount of moisture (14.74%) compared to other sources; while empty maize cob biochar (EMCB) recorded the least moisture content (4.61 %). The pH of the biochar showed variation across the different sources of biochar. EOPBB and EMCB had a pH of 8.5 and 8.11 respectively. However, wood shavings biochar (WSB) had the lowest pH value of 6.45.

The electrical conductivity (EC) of the different sources of biochar also showed variations. The WSB had the highest EC value of 1.5 us/cm while EOPBB and EMCB had 0.36 and 0.80 respectively. Total nitrogen across the different biochar sources ranged between 0.92 and 2.27 %. EMCB had the highest value of total nitrogen (2.72 %), while available phosphorus was lowest at EMCB (0.15 %) and highest at EOPBB (0.34 %). The total organic carbon value was also observed to be highest in WSB (56.3 %), while EMCB and EOPBB recorded total organic carbon content of 40.12 and 52.2 %, respectively. Exchangeable cations (Ca, Mg, Na, and K) were also presented in Table 6. Exchangeable potassium was highest across the different cations, ranging from 12.7 to 19.3 cmol/kg. Comparing the different sources of biochar showed that exchangeable cations in EOPBB were observed to be highest; while exchangeable cations in EOPBB and WSB varied randomly. Eight heavy metals were analyzed to ascertain their levels in biochar sources. The highest level of lead (Pb) was found in EMCB with the value of 0.66 mg/kg > EOPBB (0.54) > WSB (0.45) > CPM (0.03).

Table 3: Main effects and interaction of biochar and CPM on selected soil chemical properties after harvest.

Treatments		**pH**	**Avail. P**	**Org. C**	**TN**
			(mg/kg)	(%)	(%)
Biochar	Control	4.5	9.1	0.94	0.05
	EMCB	5.2	11.4	1.48	0.09
	EOPBB	5.0	11.9	1.61	0.12
	WSB	5.0	9.4	1.62	0.08
	LSD$_{0.05}$	0.41	2.04	0.49	0.04
CPM	0t/ha	4.7	9.7	1.07	0.07
	10t/ha	5.1	11.2	1.76	0.10
	LSD$_{0.05}$	0.29	1.44	0.35	0.03
Biochar × CPM LSD$_{0.05}$		0.59	n.s	1.83	n.s
Interaction					
CPM 0 × CONTROL		4.4	8.2	0.9	0.04
CPM 0 × EMCB		4.7	10.5	1.5	0.08
CPM 0 × EOPBB		4.6	9.6	0.8	0.09
CPM 0 × WSB		5.2	10.5	1.1	0.06
CPM 10 × CONTROL		4.6	10.1	1.0	0.05
CPM 10 × EMCB		5.6	12.3	1.4	0.11
CPM 10 × EOPBB		5.4	14.2	2.4	0.16
CPM 10 × WSB		4.8	8.2	2.2	0.10

Note: EMCB = Empty maize cob biochar; EOPBB = Empty oil palm bunch biochar; WSB = Wood shavings biochar; CPM = Composted poultry manure; T.N = Total nitrogen.

The amount of Pb can be attributed to the source of feedstock used in feed production for the poultry birds.

Effect of CPM and biochar on selected soil chemical properties

The main effects and interaction of biochar and CPM on selected soil chemical properties after harvest are shown in (Table 3). Soil samples applied with empty maize cob biochar (EMCB), empty oil palm bunch biochar (EOPBB) and wood shaving biochar (WSB) recorded similar pH values (5.2, 5.0 and 5.0 respectively) but were significantly ($p \leq 0.05$) higher values than the control (4.5). Soils samples treated with EMCB reduced soil acidity by 13.5 %, while EOPBB and WSB reduced significantly the soil acidity by 10 %, when compared with the control. The addition of composted poultry manure (CPM) to the soil also significantly ($P \leq 0.05$) increased the soil pH by 7.8 %, thereby reducing the soil acidity. There was significant ($P \leq 0.05$) interaction between biochar and CPM in reducing acidity in the soil. This interaction reveals that the combined application of CPM/EMCB to the soil gave the highest significant change in pH value (5.6) than other treatments. This is consistent with the findings of numerous researchers (Sayyadian *et al*., 2019; Almaroai and Eissa, 2020) who inferred that the soil pH is greatly influenced by biochar application due to the alkaline pH value of the charred feedstock. The increase in soil pH value after the application of the biochar treatments is attributed to the high ash and dissolution of carbonates and hydroxides present in biochar (da Silva *et al*., 2017; Jatav *et al*., 2021; Qasim *et al*., 2021).

Biochar recorded a significant effect on the degraded soil, as also recorded by Das *et al*., 2023. According to Dai *et al*., (2021), the negatively charged functional groups such as oxides, hydroxides and carbonates of alkaline metals, organic anions (e.g. oxalate and malate), inorganic anions such as sulfate (SO_4^{2-}), phosphate (PO_4^{3-}), silicate (SiO_4^{4-}), and iron hydroxides ($FeOH_2$) (Li *et al*., 2023) in the biochar may have been responsible for the increase in soil pH. This was possible by binding the H^+ ions from soil solution, thereby reducing the activity of H^+ and Al^{3+} ions and other acid-forming ions through neutralization and association reactions (Chintala *et al*., 2014).

A significant interaction was recorded between biochar and CPM (Table 3), the least value (4.4) was recorded in absolute control; however, the value was comparable to that obtained in sole EMCB (4.7), EOPBB (4.6), CPM (4.6) and CPM/WSB (4.8). Soil samples treated with EOPBB had the highest (11.2 mg/kg) available phosphorus content, while the control had the least (9.1 mg/kg). The result of this study showed that soil treated with EOPBB (11.9 mg/kg) had significantly ($P \leq 0.05$) increased available phosphorus level than WSB (9.4 mg/kg) and control (9.1 mg/kg). Incorporation of EMCB and EOPBB into the soil significantly increased the available phosphorus content by 20.2 and 23.5 %, respectively when compared with the control. Similarly, the use of CPM in the soil significantly increased available phosphorus content by 13.4 %. The observed increase in available phosphorus due to the application of biochar could be due to the presence of phosphorous (P) in the biochar treatment and the increase in the availability of P with time was because of microbially mediated mineralization of soil organic P to form inorganic P (Opala *et al*., 2012). The direct release of P from different biochar treatments may have been through ligand exchange, desorption or dissolution (Chathurika *et al*., 2016); P adsorption against leaching (Madiba *et al*., 2016), and mineralization of organic P through enhanced microbial growth (Dume *et al*., 2017. In acid soils, P binds to Al or Fe oxides/hydroxides which on biochar addition gets solubilized and is made available to the crops (Borno *et al*., 2018.). The effect of biochar additions on P availability of the soil depends on soil texture. Zhang *et al*. (2016) reported a 25% higher P availability in heavy textured soils than coarse-textured sandy soils on biochar addition. Similar findings were also recorded by Glaser and Lehr, (2019); Tesfaye *et al*., 2021; Alotaibi *et al*., 2021.The soil samples amended with EMCB, EOPBB and WSB had similar values of organic carbon, but were significantly (P≤0.05) higher than the control. Soil samples treated with EMCB increased organic carbon content by 36.5 %, while EOPBB and WSB increased the organic carbon content by 41.6 and 42 %, respectively. The incorporation of CPM to the soil significantly (P≤0.05) increased the soil organic carbon by 39.2. %. The result shows that the combined application of CPM/EOPBB to the soil gave the highest significant organic carbon value (2.4) than other treatments, although the value was comparable to CPM/WSB (2.2). This is because biochar applications are more effective in degraded soils (low nutrient status) than in fertile soil (Hailegnaw *et al*., 2019). The least organic carbon value (0.8) was observed in EOPBB; however, the value was not significantly different from that obtained in absolute control (0.9), WSB (1.1), CPM (1.0) and CPM/EMCBM (1.4) treatment. Organic carbon is a crucial indicator for assessing soil quality, and its concentration and dispersion have a direct and indirect impact on the functioning of soil ecosystems (Maurya *et al*., 2020). The increase in organic carbon content may be attributed to the retention of nutrients and the formation of stable soil organic matter complexes (Lehmann, 2011). These changes in soil biochemical properties can contribute to the increase in OC content in tropical soils. However, the effect of biochar on the OC content of tropical soils can also depend on various factors such as biochar properties (*e.g.*, feedstock, production temperature, and duration), application rate, soil type, and environmental conditions (*e.g.*, temperature, moisture, and vegetation) (Lehmann, 2011). For instance, the presence of higher lignin content from WSB biochar which is more recalcitrant and stable leading to higher OC sequestration potential than that of EMCB and EOPBB was recorded. The application rate of biochar at 10t/ha could also have influenced the organic C content, as higher application rates may lead to greater inputs of biochar-derived OC into the soil, thus resulting in higher OC buildup (Adekiya *et al*., 2020). Similarly, the increase in soil organic matter after application of biochar was recorded by Yang *et al*. (2020), Agegnehu *et al*. (2017), and Okoro *et al*. (2022). Soil samples treated with EOPBB showed a significant (P≤0.05) increase in total nitrogen (0.12 %) than other treatments. Similarly, the application of CPM to the soil indicated a significant (P≤0.05) increase in TN content by 30 %. Application of EOPBB biochar to the soil may have stimulated the process of nitrification (Edwards *et al*., 2018), especially in tropical soils. Many studies have reported that biochar incorporation increased the soil N availability, N uptake and nitrogen use efficiency by the crops (Jones *et al*., 2012; Abbruzzini *et al*., 2019).

Effect of CPM and biochar on heavy metals (Pb, Cu, Zn) accumulation in the soil and maize plant at 6 weeks after planting

The main effects and interaction of CPM and biochar on the level of some selected heavy metals (Pb, Cu, and Zn) bioaccumulation in the soil, root, and shoot of maize plant after harvest show that the application of biochar generally increased the amount of lead in the soil (Table 4). The soil treated with EOPBB had significantly higher 64.9% Pb (4890 mg/kg) than the control (2964 mg/kg). The increase in the amount of Pb followed an increasing sequence at EMCB > WSB > EOPBB by 27.9, 44.5 and 64.9 % respectively when compared with the control. The application of CPM in the soil also significantly (P≤0.05) increased the amount of lead in the soil by 35.4 %. A significant (P≤0.05) interaction between CPM and biochar on Pb level in the maize root was observed. The interaction reveals that the combined application of CPM/EOPBB gave the highest significant Pb increase value (5430 mg/kg) than other treatments. The application of biochar resulted to a significant reduction of lead in the root system. The highest increase in Pb level in maize root was recorded at control (251.2 mg/kg) than other treatments. There was a significant interaction between biochar and CPM in reduction of Pb in the root of the maize plant. This could be due to the release of chemical messengers by plants such as ethylene and jasmonic acid when grown in soil containing high levels of heavy metals (HMs) that reduce HM toxicity in plants (Thao *et al*, 2015).The soil samples treated with EOPBB had significantly higher copper (Cu) (69.1 mg/kg) than EMCB and WSB which were less than the level of Cu in the control (6.32 mg/kg). Soil treated with EMCB had significant (P≤0.05) reduction by 58.4% in Cu than other treatments, especially control. The variations in values from the different biochar sources could be attributed to the antagonistic or synergistic interactions between HM elements during absorption or translocation in plants. (Zhao *et al*., 2023).The sole application of CPM to soil also had significant (P≤0.05) reduction in the Cu level in the maize root by 55.2 %. The application of biochar to the soil generally reduced the amount of Cu in the root of maize plant although not significant.

Table 4: Effect of CPM and biochar on heavy metal (mg/kg) accumulation in soil, and maize plant after harvest.

		Lead (Pb)			Copper (Cu)			Zinc (Zn)		
Treatments		**Soil**	**Root**	**Shoot**	**Soil**	**Root**	**Shoot**	**Soil**	**Root**	**Shoot**
	Control	2964	251.2	6.32	46.1	8.17	4.2	714	32.2	43.8
	EMCB	3791	216.1	8.91	31.9	12.7	10.0	297	59.7	36.6
Biochar	EOPBB	4890	190.6	11.4	69.1	13.3	4.3	488	58.7	29.1
	WSB	4283	209.3	14.8	29.8	11.3	5.4	621	48.5	37.5
	LSD$_{0.05}$	1181	29.2	4.9	26.6	n.s	2.7	257	19.5	9.9
CPM	0t/ha	3142	215.4	8.3	37.5	15.7	7.2	718	54.0	33.1
	10t/ha	4867	218.2	12.4	50.9	7.1	4.7	322	45.5	36.8
	LSD$_{0.05}$	835	n.s	3.5	n.s	3.8	1.9	182	n.s	n.s
Biochar × CPM LSD$_{0.05}$		n.s	41.3	n.s	n.s	n.s	2.8	n.s	n.s	14.0
Interaction										
CPM 0 × CONTROL		1657	232.3	5.6	57.0	9.7	4.4	1088	52.5	50.5
CPM 0 × EMCB		2789	206.8	5.3	32.3	17.3	6.7	465	44.0	41.5
CPM 0 × EOPBB		4530	215.7	10.7	42.7	19.2	3.7	646	55.8	14.5
CPM 0 × WSB		3594	206.8	11.5	18.2	16.5	4.6	673	63.8	26.0
CPM 10 × CONTROL		4271	270.2	7.1	35.2	6.7	4.4	341	12.0	37.2
CPM 10 × EMCB		4794	225.3	12.5	31.5	8.0	3.3	129	75.3	31.7
CPM 10 × EOPBB		5430	165.5	12.0	95.5	7.5	4.9	249	61.5	43.6
CPM 10 × WSB		4972	211.8	18.1	41.5	6.2	6.2	568	33.2	49.0

Note: EMCB = Empty maize cob biochar; EOPBB= Empty oil palm bunch biochar; WSB= Wood shavings biochar; CPM= Composted poultry manure.

The application of EMCB to the soil had a significant increase on the amount of Cu in the shoot, it increased by 138.1 % when compared with the control. In contrast, the use of CPM in the soil significantly reduced the amount of Cu in the shoot by 34.7%. The significant ($P \leq 0.05$) interaction of biochar and CPM on Cu level in the shoot reveals that the combined application of CPM/EMCB gave the highest Cu reduction value (3.3 mg/kg) than other treatment combinations. The application of biochar to the soil recorded a significant reduction of Zinc in the soil, with EMCB having 140% reduction when compared with the control. A similar reduction in Zn amount in the soil was also recorded after the application of CPM. This could also be attributed to the specific functional groups (carboxyl, hydroxyl, phenol, alcohol, carbonyl or enol) on the biochar surface, which was able to chelate metals and lead to complexation of heavy metals onto the surface and inner pores of biochar (Inyang *et al.*, 2016; Nejad and Jung, 2017; Yang *et al.*, 2018). The amount of Zn in the soil decreased after biochar application (Table 4), appearing to be a possible reason for decreasing heavy metal content across the biochar sources. The decrease in heavy metal uptake by plants grown under biochar application can also be related to the combined effect of increased plant growth, heavy metal immobilization in soil and stable metal-organic complexes formation (Beesley *et al.*, 2013; Xu *et al.*, 2016). Other authors also attributed this reduction to the ability of biochar to increase the soil pH (Zhu *et al.*, 2018; Eissa, 2019). The reductions in the uptake of heavy metals with the application of biochar are however in contrast with the copper amount in the root and similar findings of Antonangelo and Zhang, 2019, Medynska- Juraszek *et al.*, 2020.

Sole application of EMCB to the soil gave a significant increase in the amount of Zn in the root of maize by 45.1 %. The result showed that the application of the different biochar sources resulted to the accumulation of Zn at the root region. This can be attributed to the fact that plants absorb HMs by their roots from soil solutions in the form of ions and transport them to various subcellular compartments through a diverse set of ion channels and transporter proteins such as HM ATPase, ATP binding cassette transporter, and cation diffusion facilitator (Yu *et al.*, 2019).The application of biochar to the soil also decreased the amount of Zn in the shoot of maize crop. Soil applied with EOPBB had higher significant ($P \leq 0.05$) reduction value (29.1 mg/kg) of Zn in the shoot of maize than control (43.8 mg/kg). A significant ($P \leq 0.05$) interaction between biochar and CPM on Zn level in the shoot was observed. This reduction in the shoot could be attributed to the rhizosphere effects on HM–plant interactions. For instance, by the roots secretions, organic molecules such as amino acids (e.g., methionine, lysine, and histidine) and organic acids (e.g., oxalic acid, citric acid, malic acid, tartaric acid, and succinic acid) secreted can bind with HMs and convert them to non-toxic and unavailable forms (Yu *et al*., 2019). The root-secreted organic molecules also provide nutrient resources to rhizosphere microbial populations to generate metabolites that can bind with the HMs and prevent them from root absorption (Caracciolo and Terenzi, 2021). A wide range of beneficial as well as pathogenic bacterial and fungal populations produce organic acids such as gluconic acid, oxalic acid, acetic acid, and malic acid as natural chelating agents for HM detoxification (Gajewska *et al*., 2022). In acidic soil, heavy metals can remain in free cationic forms in the soil solution and be biologically available for plant uptake (Prokkola *et al*., 2020).

Conclusion

The study showed that the soil was acidic and had a low nutrient status which may have affected the migration of lead and zinc in the plant. The levels of heavy metals (lead, zinc, and copper) observed were greater than the FAO permissible limits for agricultural soils. The effects of the application of the different biochar sources varied across the different types of heavy metal and also across the different segments of the maize plant. However, application of the different biochar sources reduced Pb in the root region and Zn in the shoot region while, CPM reduced Cu in the root, shoot region, and Zinc in the soil and root region respectively. From the study, the sole application of EOPBB reduced bioaccumulation of Pb in the root of the maize plant.

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