Influence of biochar on bio-accumulation of heavy metals in maize crop beside lead/zinc mining sites in Ebonyi State

***Ikwuakonam G. Okoro[1], Abimbola O. Babalola[2] and Benjamin C. Maranzu[1]**
[1]Department of Soil Science and Meteorology, Michael Okpara University of Agriculture Umudike, Abia State Nigeria
[2]Department of Soil Science and Land Management, Federal University of Agriculture Abeokuta, Nigeria.
*Corresponding author's email: oignov5@gmail.com

Abstract
Mining sites are known to have deposits of mine tailings especially the surrounding farmlands. Most plants grown in such sites like Amegu-Enyigba of EbonyiState,Nigeria are always bioaccumulators of these metals. Organic soil amendment with biochar can immobilize metals and hence reduce their uptake by grown crops. The aim of the study therefore, was to ascertain the effect of biochar in immobilizing the metals in the soil and subsequent reduction in maize uptake. The study was a pot experiment with 10 kg of soil sampled from farms adjacent to mining sites and control samples collected about 5 km away from the mining sites. The treatments consisted of empty palm bunch biochar applied at 0, 1, 2, 3 t/ha equivalent to 0, 1.6, 3.2, 4.8 g/10 kg replicated three times. Data collected were subjected to analysis of variance using Genstat. Biochar applied at 3 t/ha showed significant increase in the plant shoot height at 5^{th} – 6^{th} week after planting. It also indicated that heavy metals accumulated more in the plant root than the shoot and significantly reduced (Pb 66.7%; Zn 37.5 % etc.) in the plant as the biochar rates increased. Based on the findings, 3 t/ha of biochar application to farmlands in this area reduced bioaccumulation of metals in the test crop,while further studies on increased rates of biochar to soils should be investigated.

Keywords: Biochar, maize, heavy metals, bioaccumulation, mining soils

Introduction
Heavy metals have been a source of pollution to the environment over the last century, due to the fast-growing economy and industrialization where their ores are located. Sources of these pollutants range from residential dump sites, industrial effluent/wastes, agricultural tools waste, mechanic village scraps and more recently electronic waste (Fernando *et al.,* 2012). Currently, exposure to toxic metals is an ongoing concern where certain conditions pose a danger to human and environmental health (Duffus, 2002). Also, there is the risk on people working and farming around mines as is currently the situation in Enyigba community of Ebonyi State. Heavy metals contamination in the soil has been a major concern regarding their toxicity, persistence and non-degradability in the environment (Momodu and Anyakora, 2010; Anyakora *et al.*, 2011). They accumulate overtime in soils, which act as a sink from which these toxicants are released to the groundwater and plants thus contaminating the food chain and causing various toxicological health effects such as severe vomiting, diarrhoea, bloody urine, liver, kidney failure, anaemia,inhibition of haemoglobin synthesis, dysfunction in the kidneys,

reproductive systems and cardiovascular system (Ferner, 2001). The use of alkaline organic materials (biochar) as soil amendments can increase soil pH and thereby reduce bioavailability of heavy metals (Bolan and Duraisamy, 2003). A wide range of studies have also highlighted biochar as a soil amendment that can reduce metal uptake in plants (Sui *et al*., 2018).

Biochar has been reported to bring significant changes to desirable soil properties but can also cause a negative or no response in both soil and plant material (Chan and Xu, 2009; DeLuca *et al*., 2009). Feedstock and pyrolysis condition to a large extent significantly determines the biological, physical and chemical properties of biochar (Atkinson *et al*., 2010; Quilty and Cattle, 2011). Biochar addition is recommended as an effective soil remediation technique in pervasive heavy metal contaminated sites (Kavitha *et al*., 2018; Wang *et al*., 2018).Root system responses to biochar will be affected by changes in soil properties like pH, bulk density, water holding capacity, metal and metalloid availability and changes in soil microbial activity (Jones *et al*., 2012). Rhizosphere soil is modified partly through the action of root exudates and is thus potentially a hotspot for altered mobility of heavy metals, as compared to bulk soil (Zhou *et al*., 2019). Enyigba is an agrarian community in Abakaliki Local Government Area of Ebonyi State and is richly endowed with natural deposits of solid minerals (lead, zinc, quartzite.) as well as favorable weather and fertile land for agricultural production. Surrounding farmlands, plants and water bodies within the vicinity of the mines have been contaminated by potentially toxic elements from tailings through wind and water flow and deliberate waste discharge into flowing streams. The objectives of this study are to understand how mining activities affect farmlands and to also determine the influence of biochar in translocation of heavy metals in maize crop.

Materials and methods

Description of study location and soil sample collection

Soils samples were collected from cultivated farmlands around a mining area in Amegu, Enyigba in Abakaliki Local Government Area of Ebonyi State. The study area is located between latitude 06^0 04' N and longitude 08^0 65' E in the derived savanna vegetation of the Southeast ecological zone of Nigeria. The area has about 60 m as its highest elevation, 30 m as its lowest elevation above sea level and characterized by an average rainfall of 1750-2000 mm per annum. The highlands are characterized by drought resistant grasses, along flowing stream and rivers (Nnabo, 2015). Illegal mining of minerals, stone quarry, palm wine tapping and farming constitutes the major economic activities of the people in this area. The topography of the area is undulating plain alternating with running of ridges and hills from east to west. The plains are underlain by shale and some mudstones. Amegu-Enyigba is marked by an undulating range of shale outcrops, which serve as the host for Pb-Zn mineral ore bodies.

The experiment was conducted in the screen house at Michael Okpara University of Agriculture, Umudike (latitude 05° 2' North and longitude 07° 33' East) with an elevation of 112 m above sea level (NRCRI, 2020).

Soil sample collection

The soil samples used for the analysis were randomly collected between a range of 0 – 20 cm depth using a soil auger and spade. Soil samples were collected from cultivated farmlands around the mining site, while control samples were also collected from farmlands about 5 km away from the mining site. In each of the locations (mining site and control site), random soil samples were collected at different points which were separately bulked together, air-dried at room temperature (27 ^{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

Empty oil palm bunch feed stock was pyrolysed at 320 ^{0}C in a double-barrel metallic drum (height 67 inches × diameter 22.5 inches). The pyrolysis process was carried out in 45 minutes, while the temperature was determined using an infra-red 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.Maize seed (*Oba super 6*) was sourced from the Research and Training Unit of Michael Okpara University of Agriculture, Umudike.

Experimental procedures and test crop

Ten kilograms (10 kg) of collected soil sample was placed in a 12-liter container. Biochar was applied to the soil at the rates of 0,1,2 and 3 t/ha (equivalent to 0, 1.6, 3.2 and 4.8 g/10 kg of soil), and allowed for two weeks before planting. The treatments were replicated three times in a completely randomized design. 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

The chemical composition of biochar analyzed were namely, pH, organic carbon etc. Soil physico-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 according to Wet dichromate oxidation method as described by Walkey and Black (1934) and modified by Nelson and Sommers (1996). Organic matter was determined by multiplying organic carbon values by 1.724. 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). Exchangeable acidity was determined by extracting 5 g of soil with 1N KCL and titrating with 0.5 N NaOH using phenolphthalein indicator as described by Mclean (1965). Exchangeable calcium, magnesium, sodium and potassium were extracted with NH_4OAc. Calcium and magnesium were determined using Ethylene-diamineTetra Acetic (EDTA) titration method while potassium and sodium were read using a flame photometer (Rhoades, 1982). Heavy metals in both soil and plant samples were determined using Aqua Regia method (3:1 ratio of HCl: HNO_3) a method described by Ehi-Eromoseleet *al*., (2012).

Bioaccumulation factors (BAF): **T**he Bioaccumulation factor for each plant/soil pair was calculated to obtain useful data using equation (1). BAF is the ratio of the heavy metals in the root and the shoot to the heavy metals in the soil.

$$BAF = \frac{C_{root}+C_{shout}}{C_{soil}} \quad \ldots\ldots\ldots\ldots\ldots\ldots..1$$

Croot = *Dry weight of heavy metals concentration in the root (mg/kg)*
Cshoot= *Dry weight of heavy metal concentration in the shoot (mg/kg)*
Csoil = *Dry weight of heavy metals concentration in the soil (mg/kg)*

Agronomic data

Data on plant height and stem girth were measured weekly for 6 weeks after planting. The maize plants were harvested on the 42nd day after planting, and carefully separated into shoot and roots. The plant biomass harvested was washed with flowing tap water and oven-dried at 60 ^{0}C for 72 hours in a hot air oven for onward analysis.

Statistical Analysis

Agronomic and soil data collected were subjected to analysis of variance using Genstat package. Treatment means for each parameter measured was compared at $p \leq 0.05$ using the least significant difference.

Results and discussion

Physicochemical properties of soil sampled from mining site and control

The mean values of physicochemical properties of the soil sample used for the study are presented in Table 1. The textural class of the soil collected around the mining site and control was observed to be sandy loam. The pH of the soil within the mining area and control is shown to be 6.5 and 6.0 respectively. The high pH value of these soils might be due to moderate content of carbonate minerals (Ca/Mg carbonates) in the parent material, coupled with the influence of the leached profile under annual rainfall conditions.

Available phosphorus was moderate (Enwezor *et al*., 1989) with a value of 24 mg/kg in the mining site while the control had a value of 26.3 mg/kg compared to the critical level of 15 mg/kg for Southeastern Nigeria. The total nitrogen content of the soil was low with a value of 0.12 mg/kg while that of the control was 0.11 mg/kg. This might be attributed to the high intensity of agricultural activities such as continuous cropping of fields and might have been exacerbated by insufficient organic substrates from the farming system. Organic carbon in the mining site was 1.29 % while 1.43 % was obtained at the control site which was moderate. The values of the exchangeable calcium of the soils around the mining site recorded 5.32 cmol kg $^{-1}$ and 1.12 cmol kg $^{-1}$ for the control, while exchangeable magnesium in the mining site was 2.90 cmol kg $^{-1}$ and 0.43 cmol kg $^{-1}$ for the control. Exchangeable calcium dominated the exchange site among the basic cations in the soil. This observation is in agreement with the reports of Oti (2007), who also recorded a high amount of exchangeable calcium in one of her studies in Ebonyi State. Exchangeable Sodium was observed to be very low (0.12 and 0.09 cmolkg $^{-1}$), in both polluted and control soil which may be due to low pH, because sodium is known to be low in acidic soils.

The effective cation exchange capacity (ECEC) of the soil was 8.53 cmolkg^{-1} and rated low according to Enwezor *et al*. (1981). Soils of southeastern Nigeria had earlier been reported to be low in ECEC and basic cations (Ogban and Ekerette, 2001). Lead recorded a deleterious concentration of 11,219 mg/kg within the mining site while it was 63 mg/kg in the control site. Chromium (Cr) concentration in the mining site recorded 58 mg/kg as against control (0.002 mg/kg). This trend was observed across the entire micronutrients and heavy metals analysed. From Table 1, iron (Fe) had the highest concentration within the mining site with a value of 68,241 mg/kg while 427 mg/kg was recorded in the control site.

The chemical properties of biochar obtained from empty oil palm bunch are shown in Table 2. From the table, pH of the biochar indicated alkaline (9.24) reaction with total carbon content of 53 %. Total nitrogen was low with a value of 4.2%. Among the exchangeable bases, potassium was the highest with a value of 16.5 cmol/kg. Some heavy metals indicated to be not detected (ND) are nickel and cadmium while iron and zinc had the highest concentration of 56 and 32 mg/kg, respectively. Chromium, lead and cobalt were at a very low concentration of 0.01, 0.02 and 0.001 mg/kg, respectively.

Effect of biochar on the growth of maize

The result in Table 3 shows the effect of different rates of biochar on growth of maize in soil collected from the mining area. Maize height at week 1 to week 4 were observed to increase, but not significantly different across the different rates of biochar. However, at week 5, plant height showed significant difference across the different rates of biochar applied. The highest (32.6 cm) was observed at 1 t/ha. At 6th week after planting, the highest plant height (37.3 cm) was recorded at 2 t/ha.The increasing trend in plant height at 6 weeks after planting was observed in the order of 2 >1>0> 3 t/ha.Similarly, Swagathnath *et al*. (2019) reported wide-ranging trends in shoot height after the application of biochar. High concentrations of heavy metals in soil cause adverse effects on plant growth. Thus, an enhancement of shoot height in soils contaminated with heavy metals after biochar addition could point to an improvement of soil physicochemical and microbial properties that would facilitate the recovery of the functions of these soils. The effect of biochar on the stem girth of maize in mining soil is shown in Table 3. At 2 to 6 weeks after planting, stem girth showed significant difference across the different rates of biochar applied. From the Table, the highest stem girth was observed to be at the 6th week after planting, ranging from 5.0 – 6.3 mm.

Effect of biochar on heavy metal concentration in the soil, plant shoot and root

Lead (Pb) content in the soil across the different rates of biochar application was observed to range between 80,564.3 – 91,666.7 mg/kg (Table 4). The least concentration was observed at 3 t/ha, while the highest was observed at 0 t/ha. Lead concentration was significantly reduced ($P \leq 0.05$) across the different rates of biochar application when compared with 0 t/ha and had the highest reduction rate by 12.1%. Cadmium (Cd) concentration was also significantly reduced ($P \leq 0.05$) across the different rates of biochar application with the highest concentration observed at 0 t/ha (24 mg/kg) while the least concentration was at 3 t/ha with the value of 9 mg/kg. It also indicated the highest reduction rate by 66.7%. A similar finding was reported by Namgay *and* Singh (2010),where Cd and Pb concentration decreased after biochar application. The same trend also occurred in the concentration of nickel (Ni). The reduction in concentration of chromium can be attributed to biochar, playing a role in altering the redox state of chromium, leading to the transformation of Cr^{+6} to a less mobile Cr^{+3} (Choppala *et al*., 2012).

The concentration of Zn ranged between 2125.3 – 3465.3 mg/kg which was beyond the critical limit in the soil. It showed the highest reduction rate by 37.5% at 3 tons/ha when compared with control. The alkalinity of biochar used could be responsible for the lower concentrations of available heavy metals found in mining soil. A similar finding by Antonangelo and Zhang (2019), also reported the reduction in the bioaccessibility of heavy metals after the application of biochars produced from switchgrass and poultry litter in a soil contaminated with Zn, Pb, and Cd. The utilization of biochar as amendment for the recovery of polluted soils does not eliminate the pollutants as extractive techniques, but it reinforces the immobilization of the pollutants, making them less bioavailable. Thus, a great adsorption ability of biochars is required for an effective remediation of these soils.

The concentration of lead (Pb) in the plant shoot (Table 5) was significantly reduced ($P \leq 0.05$) across the different rates of biochar applied except at 2 t/ha when compared with the 0 tons/ha. The highest lead (Pb) concentration was observed 0 t/ha with the value of 1037 mg/kg; while the lowest concentration was observed at 3 t/ha with the value of 416 mg/kg.

This scientifically confirms that the maize plant is a good hyper-accumulator for the uptake of lead (Pb). It also indicates that biochar facilitated the immobilization of lead not to be translocated to other parts of the maize plant. Cadmium (Cd) showed significant differences across the different rates of biochar application. Its concentration was observed to reduce as the rate of biochar increased. The highest concentration of cadmium was observed at 0 t/ha with a value of 7.0 mg/kg. This trend of reduction in the concentration of heavy metals as the rate of biochar increases was observed across, chromium, cobalt, iron, copper andzinc except for nickel where the increase in biochar rates resulted in a corresponding increase in its concentration. This would imply that biochar could pose no risk of increasing heavy metals in plants and hence are safe in terms of food chain transfer.

The concentration of lead (Pb) in the maize roots (Table 5) showed a significant reduction ($P \leq 0.05$) across the different rates of biochar applied, The highest lead (Pb) reduction in the maize root was observed at 3 t/ha (589.2 mg/kg), while 0 t/ha retained the least reduction (1237.5 mg/kg). The biochar used presented a higher sorption capacity for Pb, possibly as a consequence of precipitation and complexation of lead with carbonate, sulphate and phosphate present in the biochar. Cadmium (Cd) content in the maize root was also significantly reduced ($P \leq 0.05$)across the different rates of biochar applied. Its concentration was observed to decrease as the rate of biochar increased.

The highest concentration of cadmium was observed at 0 t/ha with the value of 8.1 mg/kg and the lowest of 2.7 mg/kg at 3 t/ha. Nickel (Ni) showed a significant difference ($P \leq 0.05$) across the different rates of biochar application. Its concentration ranged between 3.9 and 11.3 mg/kg. The concentration of nickel was observed to decrease as the rate of biochar increased. The highest concentration of nickel was observed at 0 t/ha (11.3 mg/kg) and the lowest value of 3.9 mg/kg at 3 t/ha. From Table 5, chromium (Cr) showed a significant difference ($P<0.05$) across the different rates of biochar application. Its concentration decreased as the rates of biochar increased. The highest concentration of chromium in the maize root was observed at 0 t/ha (4.9 mg/kg) while the lowest was observed at 3 t/ha (2.4 mg/kg). The concentrations of chromium in maize root at 1 and 2 t/ha were not significantly different from each other. This trend of decrease in the concentration of heavy metals as the rate of biochar increases was also observed across Co, Fe, Cu, and Zn. The sequence of reduced concentration of heavy metals in the maize roots could be attributed to the immobilization or chelation of heavy metals caused by biochar and AMF. While the extractable concentrations of metals in the rhizosphere give a momentary picture of metal availability to plants, the cumulative uptake of metals over the entire growth period is better reflected by the metal concentration in the plants.

This uptake is distributed between roots and shoots, and as is commonly found, roots retain a large proportion of absorbed metals and translocate limited amounts to shoots. Low translocation ratios may partly stem from root surface adsorption of metals, contributing to an extension of the extraradical immobilization observed in rhizosphere soil (Hinsinger *et al*., 2006). Reichman and Parker (2005)reported that release of phytosiderophores (PS) by roots is an important factor influencing the availability of trace elements in rhizosphere, suggesting that this mechanism may protect plants from heavy metal toxicity, reducing element transfer to plant tissues (Shenker *et al*., 2001).

Bioaccumulation of heavy metals from soil to maize plants

The bioaccumulation factors (BAF) for plants have also been provided to understand heavy metal accumulation potential (Figures 1 - 4). Bioaccumulation Factor (BAF) is used to quantify the toxic element accumulation efficiency in plants by comparing the concentration in the plant part and an external medium (Rezvani and Zaefarian, 2011). It can be seen (Figures 1 – 4) that the extent of accumulation of heavy metals by maize plant differed with the different rates of biochar application. The BAF of different heavy metals for the maize crop at 0 t/ha is presented in Figure 1.The BAF followed the order Cd (0.63)> Cu (0.41) > Zn (0.36) > Co (0.35) > Cr (0.30) >Ni (0.27) > Fe (0.04) > Pb (0.025). Cadmium was most easily taken up by the maize plant, while Pb was identified as having the lowest accumulation in crops. Figure 2, shows the BAF of different heavy metals at 1 t/ha. The BAF followed the order Cd (0.63)> Ni (0.61) > Zn (0.44) > Co (0.30) > Cr (0.29) >Cu (0.26) > Fe (0.03) > Pb (0.018). Figure 3, shows the BAF of different heavy metals at 2 tons /ha. The BAF followed the order Cd (0.83)> Zn (0.48) > Ni (0.37) > Cu (0.27) > Co (0.19) >Cr (0.16) > Fe (0.02) > Pb (0.02). Figure 4, shows the BAF of different heavy metals at 3 t/ha. The BAF followed the order Cd (0.56)> Cr (0.30) > Zn (0.26) > Ni (0.24) > Cu (0.16) >Co (0.09) > Fe (0.02) > Pb (0.015). The BAF for Cd in all the treatments were very high compared with other elements, indicating that Cadmium (Cd) was more easily absorbed by the crops, while lead (Pb) was the least absorbed as the biochar rates increased. A similar trend in the result was observed by Bifeng *et al*. (2017).

Conclusion and recommendation

The results from this research showed that soils collected within the mining area were more heavily contaminated with lead and iron ores. Biochar applied reduced the uptake of the heavy metals as the biochar rates increased. A similar sequence occurred in the accumulation of these heavy metals in the plant shoot and maize roots. Biochar also improved the growth of maize in the contaminated soil. The use of 3 tons per hectare of biochar (empty oil palm bunch) helped immobilize heavy metals in other to reduce its uptake form by plant roots and allow the uptake of macronutrients required for the effective growth of maize in the mining area. These results indicated that increasing biochar application to heavy metal polluted areas enabled maize crops have different capacities to absorb different heavy metals in the soil. Heavy metal uptake by plants was reduced greatly, indicating that soil amendments with biochar are particularly useful in cases where plant growth is severely limited by high bioavailability of heavy metals. Finally,owing to the natural deposits of this heavy metals, it would be of research relevance to increase geometrically the biochar to be applied in further experiments.

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Table 1. The physicochemical properties of experiment soils

Parameter/ unit	Mining site	Control site
Sand (g/kg)	670	710
Silt (g/kg)	240	210
Clay (g/kg)	90	80
Texture	Sandy Loam	Sandy Loam
pH (H_2O)	6.5	6.0
Available Phosphorus (mg/kg)	24	26.3
Total Nitrogen (%)	0.12	0.10
Organic carbon (%)	1.29	1.43
Exchangeable cations (cmol/kg):		
Calcium	5.32	1.12
Magnesium	2.90	0.43
Potassium	0.19	0.21
Sodium	0.12	0.09
ECEC (cmol/kg)	8.53	1.85
Heavy metals (mg/kg)		
Lead (Pb)	11219	563
Chromium (Cr)	58	0.002
Cadmium (Cd)	10	0.024
Nickel (Ni)	52	0.10
Copper (Cu)	564	92
Cobalt (Co)	19	0.3
Iron (Fe)	68241	427
Zinc (Zn)	3798	124

Table 2: Chemical composition of biochar

Parameters	Value
pH	9.24
Electrical conductivity (dS $m^{-1)}$	1.84
Availablephosphoru s(mg/kg)	27
Organiccarbon (g/kg)	53
Total nitrogen (g/kg)	4.2
Exchangeable acidity(cmol/kg)	0.32
Exchangeable bases (cmol/kg):	
Ca	6.3
Mg	3.2
K	16.5
Na	4.9
Heavy metals: (mg/kg):	
Zn	32
Fe	56
Cu	0.52
Cr	0.01
Pb	0.02
Ni	ND
Co	0.001
Cd	ND

*ND= Not detected

Table 3: Effect of biochar on the growth of maize in farmlands beside mining soil

Treatment (t/ha)	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6
				Maize height (cm)		
0	8.2	21.0	22.5	29.6	28.4	29.0
1	6.9	26.4	28.7	31.1	32.6	33.5
2	7.3	22.7	29.2	29.6	31.4	37.3
3	8.3	17.1	25.2	25.3	26.7	24.3
$LSD_{0.05}$	n.s	n.s	n.s	n.s	7.2	9.6
				Stem girth (mm)		
0	0.1	2.0	2.8	3.6	6.0	6.0
1	0.1	2.3	3.2	4.0	5.3	6.3
2	0.1	2.5	3.6	4.1	6.0	6.3
3	0.1	0.8	2.0	2.4	4.7	5.0
$LSD_{0.05}$	n.s	0.9	1.3	1.3	2.3	0.1

Table 4: Heavy metals concentration (mg/kg) in the soil after application of biochar

Treatments (t/ha)	PB	Cd	N1	Cr	Co	Fe	Cu	Zn
0	91666.7	24.4	49.6	29.0	13.8	209958.3	274.0	3465.3
1	84712.7	17.2	29.2	19.5	12.7	149041.2	259.6	2350.7
2	83751.0	9.0	36.5	31.3	11.5	141375.1	274.0	2125.3
3	80564.3	8.0	35.0	16.0	10.2	117541.0	237.3	2165.3
$LSD_{0.05}$	4353.1	9.0	19.3	n.s	n.s	n.s	n.s	n.s
FAO (PL)	100	3	50	100	50	50,000	100	300

Table 5: Heavy metals concentration (mg/kg) in maize shoots and roots after introduction of biochar

Treatment (t/ha)	Pb	Cd	Ni	Cr	Co	Fe	Cu	Zn
				Maize shoot				
0	1037.7	7.0	1.9	3.8	2.0	3222	52.1	498.7
1	416.3	4.8	8.5	2.6	1.8	2067	33.6	409.0
2	892.7	3.1	7.1	1.4	0.6	1310	26.8	292.0
3	647.7	1.8	4.6	2.0	0.3	923	16.6	178.6
$LSD_{0.05}$	175.29	0.98	2.6	0.9	1.1	530	12.1	129.1
				Maize roots				
0	1237.5	8.1	11.3	4.9	2.8	4584.1	59.6	732.3
1	1112.0	5.9	9.3	3.1	2.7	2987.4	32.8	614.3
2	819.5	4.4	6.4	3.5	1.6	1944.3	46.5	442.7
3	589.2	2.7	3.9	2.4	0.6	1678.0	21.6	393.3
$LSD_{0.05}$	158.3	1.0	3.1	0.6	2.0	470.5	10.8	204.6

*FAO (Pl) = FAO Permissible limits; n.s = not significant

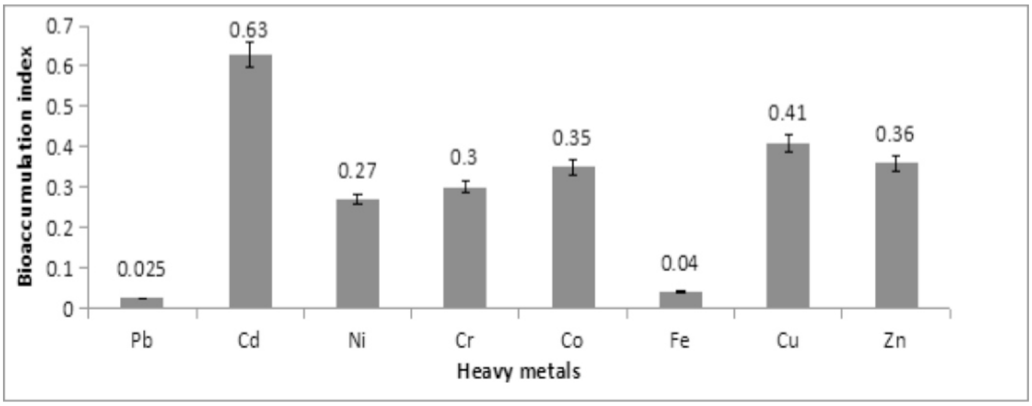

Fig 1: Bioaccumulation factor (BAF) of heavy metals of maize crop at 0 t/ha

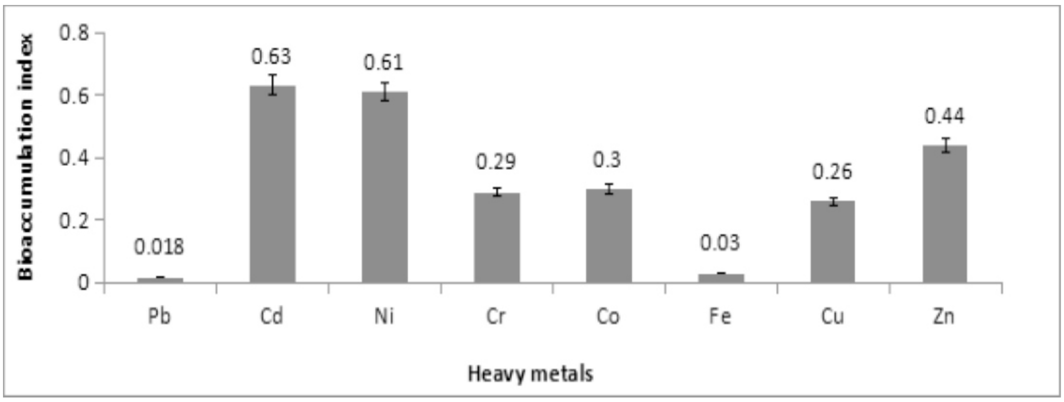

Fig 2: Bioaccumulation factor (BAF) of heavy metals of maize crop at 1 t/ha

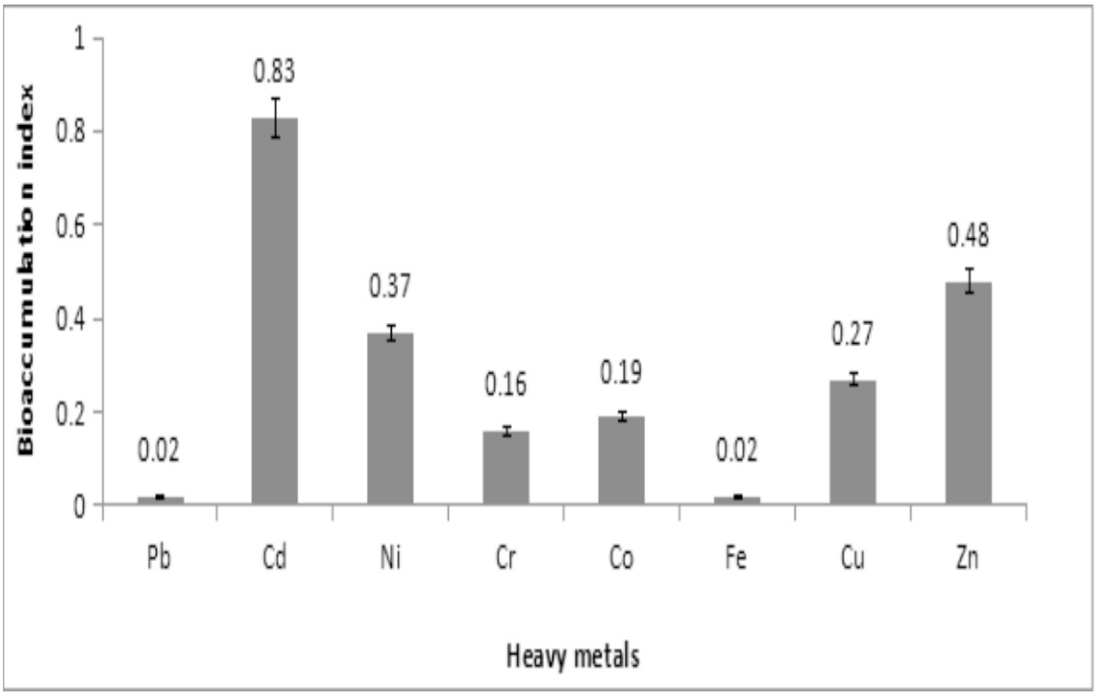

Fig 3: Bioaccumulation factor (BAF) of heavy metals of maize crop at 2 t/ha

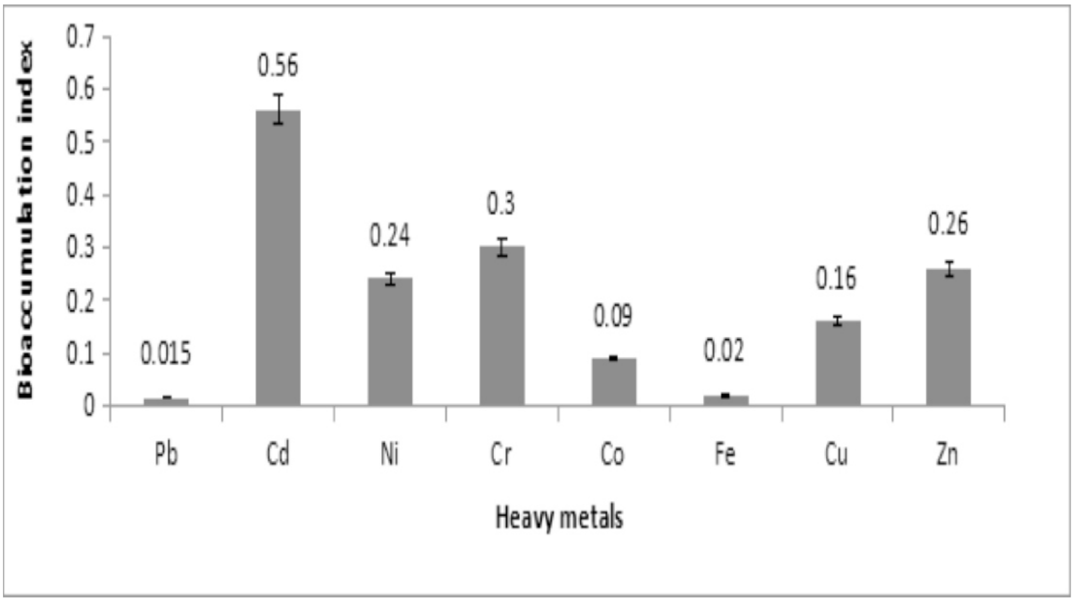

Fig 4: Bioaccumulation factor (BAF) of heavy metals of maize crop at 3 t/ha