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Effect of Biochar Application on Soil Properties and Nutrient Uptake of Lettuces (*Lactuca sativa)* Grown in Chromium Polluted Soils

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Abstract: The leather industry sector is one of the leading industries playing a significant role in the generation of foreign currency in Ethiopia. However, the environmental management for this industry is generally ignored. As a result, chromium (Cr) accumulates in vegetable tissues at toxic concentrations. The present pot experiment was therefore conducted to investigate the effect of biochar application on the selected properties of chromium polluted soils and uptake of lettuces grown in polluted soils. Biochar produced from maize stalk was applied at the rates of 0, 5 and 10t/ha on soils artificially polluted with Cr at the levels of 0, 10 and 20ppm. The study showed a significant ($P<0.01$) increase in pH, electrical conductivity, organic carbon, total nitrogen, available phosphorous, cation exchange capacity and exchangeable bases due to application of biochar. Moreover, uptake of nitrogen, phosphorous and potassium were significantly ($P<0.01$) increased by addition of biochar. A significant ($P<0.01$) reduction in the uptake of Cr due to application of biochar was also observed in heavily Cr polluted soils (20ppm). Therefore, application biochar is very imperative to increase soil fertility, enhance nutrient uptake, ameliorate Cr polluted soils and reduce the amount of carbon produced due to biomass burning.

Key words: Chromium · Biochar · Polluted soil · Unpolluted soil · Amendment · Ethiopia

INTRODUCTION

The leather industry sector is one of the leading industries playing a significant role in the generation of foreign currency in Ethiopia [1]. The leather sector is the second largest component of Ethiopia's exports after coffee, representing 12% of total export earnings. Reports have indicated that the country generated over US$60 million per year from leather industry [2]. Major concerns exist, however, with the environmental management from this industry, which are generally ignored. According to the Embassy of Japan in Ethiopia [3], chrome utilized in tanneries is one of the main environmental pollutants from the leather-related industry. Currently, only 10% of the existing tanning industries treat their wastes while the majority (90%) discharge their wastes into nearby water bodies, streams and open land without any treatment [4, 5].

According to Girma [6], 40% of the vegetable supplied to the capital city of Ethiopia comes from the suburban directly irrigated by rivers polluted by tannery wastes. Vegetables grown at tannery contaminated sites could take up and accumulate chromium (Cr) at concentrations that are toxic. A high concentration of Cr has been found to be harmful to vegetation and it adversely affects several biological parameters [7]. High concentration of Cr and other heavy metals/metalloids in lettuce grown at many vegetables farms in Ethiopia were also reported by [6, 8, 9].

Additions of biochar to soil have shown definite increases in cation exchange capacity (CEC) and pH [10, 11]. Biochar application also improves the overall sorption capacity of soils [12] and therefore it might influence the toxicity, transport and fate of different heavy metals in the soil. The increase in the availability of major plant nutrients due to application of biochar was also reported by Glaser *et al*. [13] and Lehmann *et al*. [14]. However, very few studies have been conducted regarding the influence of biochar application on the properties of chromium polluted soils and the fate of Cr in the soil. Therefore, the objective of the present study was to asses the effect of biochar application on the

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selected properties of chromium polluted soils and to investigate the effect of biochar on the uptake of chromium and plant nutrients.

MATERIALS AND METHODS

Description of the Study Area: The study was conducted in Jimma, Southwest Ethiopia in the year 2011. It is located at 7°, 33'N and 36°, 57' E at an altitude of 1710 meter above sea level. The mean annual maximum and minimum temperatures are 26.8°C and 11.4°C and the relative humidities are 91.4% and 39.92%, respectively. The mean annual rainfall of the study area is 1500mm [15]. The soils of the study area are dominated by Nitisol [16]. The selected soil physicochemical properties of the experimental soils are presented in Table 1.

Biochar Production: Maize stalk for biochar production was collected from Jimma University College of Agriculture and Veterinary Medicine. The biochar was produced at 500°C pyrolysis temperature based on the recommendation of Lehmann [17]. After the pyrolysis process, the biochar was grounded to small granules and pass through 2mm sieve in order to have the same particle size as that of the soil.

Experimental Procedure: Plastic pots 20 cm diameter and height were filled with 2kg of 2mm sieved dry soil. The soils were artificially polluted using potassium dichromate ($K_2Cr_2O_7$) and biochar produced from maize stalk was applied at the rates of 0, 5t/ha and 10t/ha. According to Abdul [18], applications of chromium up to 5ppm had nominal effect on plants, while there was no plant survival beyond 40 ppm. Therefore, Cr levels selected for this study were 0(control), 10ppm and 20ppm. The pots were then arranged in complete randomized design and replicated three times. Four lettuce (*Lactuca sativa*) seeds were sown in each pot and after germination only one plant was retained in each pot until flowering. The plants were left until flowering in order to ensure maximum uptake of Cr and plant nutrients. Normal growth conditions were ensured and pots were irrigated whenever needed to keep the soil moisture to field capacity.

Laboratory Analysis: Soil texture was determined by hydrometer; pH was measured by using a pH meter in a 1:2.5 soil: water ratio. Electrical conductivity (EC) was measured in water at a soil to water ratio of 1:2.5. Soil organic carbon was determined by the Walkley-Black method and total nitrogen (N) by the Kjeldahl method [19]. Available phosphorous (P) was determined using Bray I extraction method [19]. Total exchangeable bases were determined after leaching the soils with ammonium acetate. Amounts of Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer. K^+ and Na^+ were analyzed by flame photometer. Cation exchange capacity was determined at soil pH 7 after displacement by using 1N ammonium acetate method in which it was, thereafter, estimated titrimetrically by distillation of ammonium that was displaced by sodium [20].

Plant Tissue Analysis: The whole plants were collected from each pot and the collected plant samples were washed by distilled water. The air dried plant tissues were then ground into 0.25 mm size, subjected to wet digestion and analyzed for N, P and K. The N content of the plant tissue was determined by Kjeldahl procedure, whereas the P content was determined by colorimeterically according to Murphy and Riley [21] and the K content of the plant tissue was determined by flame photometer. Total chromium in the plant tissue was determined by chromatography.

Statistical Analysis: One way analysis of variance (ANOVA) was performed to assess the significance differences in soil parameters between different treatments, using the general linear model (GLM)

Table 1: The selected physicochemical properties of the experimental soil

Soil parameters		Soil parameters	
Sand (%)	20.00	TN (%)	0.39
Silt (%)	40.00	AVP (ppm)	26.40
Clay (%)	40.00	CEC (meq/100gm)	27.22
Textural class	Clay	Exchangeable K (meq/100gm)	0.76
pH-H_2O	5.23	Exchangeable Na (meq/100gm)	0.87
EC (mmhos)	0.21	Exchangeable Ca (meq/100gm)	13.87
OC (%)	2.29	Exchangeable Mg (meq/100gm)	6.91

EC = electrical conductivity; OC = organic carbon; TN= total nitrogen; AVP = available phosphorous; CEC = cation exchange capacity procedure of SAS 9.2. Means separation was done using least significant difference (LSD) after the treatments were found significant at P<0.05. Simple correlation analysis was also performed using SAS 9.2 in order to analyze the relationship between the selected variables.

RESULTS AND DISCUSSION

Effect of Biochar Application on Soil pH and EC Content: The effect of biochar application on pH and EC values of chromium polluted and unpolluted soils are given in Table 2. The statistical analysis revealed a significant (P<0.01) increase in pH and EC due to addition of biochar. In chromium polluted and unpolluted soils, the highest mean values of pH and EC were observed in soils treated with 10t/ha biochar, while the lowest values were recorded at the control (0 t/ha). The increase in soil pH and EC due to application of biochar was generally attributed to ash accretion as ash residues are generally dominated by carbonates of alkali and alkaline earth metals, variable amounts of silica, heavy metals, sesquioxides, phosphates and small amounts of organic and inorganic N [22]. In agreement with this, Arocena and Opio [23]; Khanna *et al.* [24] also reported the capacity of ashes to neutralize the acidic soil. Another reason for the increase in soil pH due to application of biochar could be because of high surface area and porous nature of biochar that increases the cation exchange capacity (CEC) of the soil. Thus, there could be a chance for Al and Fe to bind with the exchange site of the soil. The decrease in exchangeable Al and soluble Fe in biochar amended soils was also reported by Agusalim *et al*. [25]. According to Agusalim *et al*. [25], Al and soluble Fe was decrease in biochar amended soil is due to the increase in CEC. The correlation matrix (Table 5) also showed a positive and significant (P<0.01; r = 0.68) relationship between soil pH and CEC. These results therefore indicate that biochar could be used as a substitution for lime materials to increase the pH of acidic soils.

Effect of Biochar Application on Soil Organic C, Total N and Available P Content: Application of biochar on chromium polluted and unpolluted soils significantly (P<0.01) increased the mean values of soil organic C and total N (Table 2). The highest values of organic carbon and total nitrogen were observed in soils amended with 10t/ha maize stalk biochar. The increase in organic carbon and total nitrogen due to addition of biochar could be resulted from the presence of high amount of carbon and nitrogen in the maize stalk. The highest values of organic carbon at biochar treated soils indicate the recalcitrance of C-organic in biochar. High organic carbon in soils treated with biochar has been also reported by Lehmann, [17]. Solomon *et al.* [26] and Liang *et al.* [27] also revealed the higher organic C and total N at the ancient *terra preta* compared with adjacent soils.

The amount of available phosphorous in chromium polluted and unpolluted soils were also significantly (P<0.01) increased by application of biochar (Table 2). The observed increase in available phosphorus due to application of biochar could be due to the presence of high phosphorous in the maize stalk. The increase in soil pH and CEC, that reduce the activity of Fe and Al, could also contribute for the highest values of available phosphorous in soils treated with biochar. The correlation matrix (Table 5) also showed a positive and significant

Table 2: Effect of biochar application on organic carbon, total Nitrogen and available phosphorous content of chromium polluted and unpolluted soils

Chromium level (ppm)	Biochar rate (t/ha	pH-H_2O	EC (mmhos)	OC (%)	TN (%)	AVP (ppm)
0	0	5.23b	0.21c	2.29b	0.40c	26.40b
0	5	5.38b	0.23b	3.00a	0.44b	28.13b
0	10	5.72a	0.27a	3.06a	0.48a	35.99a
P-value		**	**	**	**	**
10	0	5.13c	0.21b	2.93c	0.43c	25.29c
10	5	5.27b	0.22b	3.11a	0.46b	26.91b
10	10	5.44a	0.26a	3.31b	0.49a	34.09a
P-value		**	**	**	**	**
20	0	5.09b	0.22b	2.88c	0.44c	22.95c
20	5	5.38a	0.24b	3.02b	0.48b	26.67b
20	10	5.44a	0.27a	3.59a	0.54a	30.51a
P-value		**	**	**	**	**

Means in the same column followed by the same letters are not significantly different at 5% level of significance; **significant at P<0.01; NS = non significance; EC = electrical conductivity; OC = organic carbon; TN = total nitrogen; AVP = available phosphorus

Table 3: Effect of biochar application on the mean values of soil CEC and exchangeable bases

Chromium level (ppm)	Biochar rate (t/ha)	CEC	K	Na	Ca	Mg
		---------------	------(meq/100g)	------	---------------	---------------
0	0	27.22c	0.76b	0.87b	13.87c	6.91c
0	5	31.61b	0.79b	1.09a	14.96b	7.04b
0	10	33.69a	0.86a	1.13a	15.22a	7.12a
P-value		**	**	**	**	**
10	0	26.58c	0.76b	0.98c	13.35c	7.62c
10	5	33.27b	0.79ab	1.12b	14.85b	7.72b
10	10	34.48a	0.87a	1.17a	16.43a	7.86a
P-value		**	**	**	**	**
20	0	28.11c	0.78	1.11c	14.33c	7.61c
20	5	33.08b	0.83	1.19b	15.13b	7.76b
20	10	35.22a	0.89	1.27a	16.89a	8.26a
P-value		**	**	**	**	**

Means in the same column followed by the same letters are not significantly different at 5% level of significance; **significant at P<0.01; CEC = cation exchange capacity

Table 4: Effect of biochar application on nutrient uptake of lettuces grown in chromium polluted and unpolluted soils

Chromium level	Biochar rate	TN (%)	TP (mg/Kg)	K (mg/Kg)	Cr (μg/Kg)
0	0	3.12c	6.26c	54.29b	1.62
0	5	3.22b	6.76b	58.23a	1.65
0	10	3.28a	6.91a	58.49a	1.68
P-value		**	**	**	NS
10	0	2.74c	6.18c	53.63b	2.79
10	5	2.87b	6.68b	55.10ab	2.72
10	10	3.14a	7.00a	56.87a	2.47
P-value		**	**	*	NS
20	0	2.75c	6.03c	53.47c	3.60a
20	5	3.14b	7.02b	57.90b	3.31b
20	10	3.22a	7.54a	60.26a	3.08c
P-value		**	**	**	**

Means in the same column followed by the same letters are not significantly different at 5% level of significance; NS= non significance; **significant at P<0.01; TN = Total nitrogen; TP= total phosphorous

Table 5: Pearson correlation matrix for the selected parameters

	pH	CEC	OC	TN	AVP	Exch. K
pH	-	-	-	-	-	-
CEC	0.68**	-	-	-	-	-
OC	0.27	0.69**	-	-	-	-
TN	0.53**	0.81**	0.83**	-	-	-
AVP	0.85**	0.67**	0.42*	0.56**	-	-
Exch. K	0.67**	0.81**	0.71**	0.88**	0.78	-
EC	0.67**	0.73**	0.67**	0.81**	0.75**	0.89**
Na	0.42*	0.82**	0.86**	0.88**	0.39*	0.76
Ca	0.48*	0.82**	0.85**	0.90**	0.64	0.90**
Mg	0.10	0.45*	0.76**	0.68**	0.01	0.49**
N uptake	-0.12	-0.46*	0.24	0.31	0.10	0.25
P uptake	0.11	0.35	0.50**	0.46*	0.40*	0.56**
K uptake	0.25	0.41*	0.54**	0.43*	0.27	0.39*
Cr uptake	-0.44*	-0.47*	0.39*	0.28	-0.45*	0.08

*, ** significant at P<0.05 and P<0.01, respectively; OC = organic carbon; TN = total nitrogen; AVP= available phosphorous; EC = electrical conductivity; Exch. = exchangeable

relationship between available phosphorus and pH ($P<0.01$; $r = 0.85$ and CEC ($P<0.01$; $r = 0.67$). Van Zwieten *et al*. [28] and Chan *et al*. [29] also reported the increase in available phosphorous after the application of biochar.

Effect of Biochar Application on CEC and Exchangeable Bases: The effect of biochar addition on CEC and content of exchangeable bases in chromium polluted and unpolluted soils are presented in Table 3. The analysis of variance showed that cation exchange capacity and exchangeable bases were significantly ($P<0.01$) increased by application of biochar. The highest values of CEC were recorded when maize stalk biochar was applied at 10t/ha (Table 3). The increase in CEC due to application of biochar could be resulted from the inherent characteristics of biochar. Biochar has high surface area, highly porous, variable charge organic material that has the potential to increase soil cation exchange capacity (CEC), surface sorption capacity and base saturation when added to soil [13]. Available evidence also suggested that on a mass basis, the intrinsic CEC of biochar is consistently higher than that of whole soil, clays or soil organic matter [30]. Therefore, it is quite logical that soil applied with biochar had the highest CEC. Agusalim *et al*. [25] and Chan *et al*. [29] also revealed the increase in soil cation exchange capacity after the application of biochar.

Application of maize stalk biochar on chromium polluted and unpolluted soils has also significantly ($P<0.01$) increased the values of exchangeable bases. The observed highest values of exchangeable bases at biochar treated soils might be attributed to the presence of ash in the biochar. The ash content of biochar helps for the immediate release of the occluded mineral nutrients like Ca, K and N for crop use [31-32]. The results of the present study also agree with Lehmann *et al*. [14], Rondon *et al*. [33] and Chan *et al*. [29] who reported the highest exchangeable bases in biochar applied soils.

Effect of Biochar Application on Nutrient Uptake of Lettuces (*Lactuca Sativa*): According to the results of the present study, nutrient uptake of lettuces (*Lactuca sativa* was significantly ($P<0.01$) increased by application of biochar (Table 4). In chromium polluted and unpolluted soils, the highest nitrogen uptake were observed in soils amended with 10t/ha biochar whilst the lowest values were recorded at the control. Van Zwieten *et al*. [28] reported similar effect of biochar on N uptake in which it was observed that application of biochar significantly increased uptake of plant N. Chan *et al*. [29] also reported high N uptake of radish plants grown in biochar amended soils. The observed increase in lettuces N uptake through biochar application indicates the potential of biochar to improve fertilizer use efficiency especially in soils where N loss is a major environmental and agronomic problem.

Like nitrogen, phosphorous and potassium uptake were also significantly ($P<0.01$) increased as a result of biochar application. In chromium polluted and unpolluted soils, the highest uptake of P and K were observed in soils amended with 10t/ha maize stalk biochar. Lehmann *et al*. [14] also observed an increase in P concentration in plants with increasing biochar application. The increase P uptake as a result of biochar application could be attributed to high P content in the maize stalk biochar and the highest soil P concentration in biochar-amended soils (Table 2). The correlation matrix (Table 5) also showed a positive and significant ($P<0.05$; $r = 0.40$) relationship between soil available phosphorous and P uptake. The increase in K uptake in biochar amended soils might also be attributed to the presence of K rich ash in the biochar. Lehmann and Rondon [34] and Uzoma *et al*. [35] also reported increased nutrient uptake due to addition of biochar in the tropical environment. The increase microbial activity due to application of biochar could also be the other reason for the highest nutrient uptake in biochar treated soils. According to Pietikäinen *et al*. [36], biochar act as a habitat for soil microorganisms involved in N, P or S transformations. Biochar has also the capacity to support the presence of adsorbed bacteria from which the organisms may influence soil processes [36].

Effect of Biochar Application on Uptake of Chromium: The effect of biochar application on Cr concentration of lettuces tissue is presented in Table 4. Small concentrations of chromium in lettuces tissue were observed in soils treated with biochar. However, a significance ($P<0.01$) effect of biochar application on the uptake of chromium was observed only in heavily chromium polluted soils (20ppm Cr). The smallest concentration of Cr in the plant tissue treated with biochar could be due to high Cr adsorption capacity of the biochar. Strong adsorption affinity of biochar for different ionic solutes was also reported by different authors [37-39]. The smallest uptake of Cr in biochar amended soils could also be results from the increase in pH and CEC of soils following the addition of biochar (Table 2 and 3). According to Girish *et al*. [40], the amount of Cr adsorbed to soils increased with an increase in pH and CEC of soils. The correlation matrix (Table 5) also showed a negative and significant relationship between Cr uptake and soil pH ($P<0.05$; $r = -0.44$) and CEC ($P<0.05$; $r = 0.47$). A significant role of active carbon (biochar produced at high temperature) as a sorption medium for decolourisation and decontamination also results from its extreme CEC value. In harmony with this finding, a high sorption capacity of walnut shell biochar for heavy metals, especially copper and lead was reported by Allie [41].

CONCLUSION AND RECOMMENDATION

The results obtained in this study reveal that addition of biochar increased soil pH, EC, organic carbon, total nitrogen, available phosphorous, CEC and exchangeable cations of chromium polluted and unpolluted soils. Uptake of nitrogen, phosphorous and potassium were also increase by addition of biochar. The presence of plant nutrients and ash in the biochar, high surface area and porous nature of the biochar and the capacity of biochar to act as a medium for microorganisms are identified as the main reasons for the increase in soil properties and highest nutrient uptake at biochar treated soils. Moreover, due to high Cr adsorption capacity of biochar produced from maize stalk, the concentrations of Cr in lettuces tissues were reduced by addition of biochar. Therefore, application of biochar is imperative in order to increase soil fertility, enhance nutrient uptake and ameliorate Cr polluted soils. Moreover, further researches are required to evaluate the effect of biochar on the fate and uptake of heavy metals in polluted soils.

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