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Influence of rice straw biochar addition on soil traits and nutrient uptake of Artichoke (*Cynara carduncululus*) grown in Mercury-contaminated soils

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सार – पारा प्रदूषित मिट्टी के चयनित गुणों पर बायोचार अनुप्रयोग के प्रभाव की जांच करने और प्रदूषित मिट्टी में उगाए गए आर्टिचोक (सिनारा कार्डुनकुलस) के अवशोषण की जांच करने के लिए वर्तमान पॉट प्रयोग किया गया। चावल के भूसे से प्राप्त बायोचार को विभिन्न सांद्रता (0, 10, 20 ppm) पर पारे से कृत्रिम रूप से दूषित मिट्टी में विभिन्न दरों (0, 5, 10 टन/हेक्टेयर) पर जोड़ा गया । शोध ने विद्युत चालकता, PH, उपलब्ध फास्फोरस, कुल नाइट्रोजन, विनिमय आधार, धनायन विनिमय क्षमता और बायोचार संयोजन के कारण जैविक कार्बन मेंएक महत्वपूर्ण (P<0.01) सुधार संकेत दिया है। इसके अतिरिक्त, बायोचार अनुप्रयोग द्वारा आर्टिचोक (सिनारा कार्डुनकुलस) द्वारा पोटेशियम, फास्फोरस और नाइट्रोजन के अवशोषण में काफी वृद्धि हुई। भारी पारा-प्रदूषित मिट्टी (20 ppm) में बायोचार अनुप्रयोग के कारण पारे के ग्रहण में उल्लेखनीय कमी भी देखी गई। इसलिए, मिट्टी की गुणवत्ता और उर्वरता में सुधार, पोषक तत्वों के अवशोषण में सुधार, प्रदूषित मिट्टी में सुधार और बायोमास जलने के कारण बनने वाले कार्बन की मात्रा को कम करने के लिए बायोचार का अनुप्रयोग सबसे महत्वपूर्ण है।

ABSTRACT. The present pot experiment was therefore conducted to investigate the effect of biochar application on the selected properties of mercury polluted soils and uptake of Artichoke (Cynara cardunculus) grown in polluted soils.Biochar obtained from rice straw was added at various rates (0, 5, 10 t/ha) on the soil artificially contaminated with mercury at a different concentration (0, 10, 20 ppm). The research indicated a significant ($P < 0.01$) improvement in electrical conductivity, pH, available phosphorus, total nitrogen, exchangeable bases, cation exchange capacity and organic carbon owing to biochar addition.Additionally, uptake of potassium, phosphorus and nitrogen by Artichoke (Cynara cardunculus) was significantly enhanced by biochar application. A significant decrease in uptake of mercury owing to biochar application was also noticed in heavily mercury-contaminated soil (20 ppm). Hence, biochar application is mostvital to improve soil quality and fertility, improve nutrients uptake, amend Hg contaminated soil and decrease the quantity of carbon formedowing to the biomassburning.

Key words – Mercury, Contaminated soil, Un-contaminated soil, Biochar, Significant

1. Introduction

Particularly, mercury is an imperative heavy metal to ponder when investigating the environmental issues of coal burning. Though, mercury is discharged into the environment from anthropogenic activities such as coal combustion, waste incineration, industrial uses, and mining and natural causes such as volcanoes and rock weathering have been recognized as the biggest source of Hg releases (Li *et al*., 2017). Mercury discharged from different sources in the environment has enhanced mercury contamination ofthe soil, water and air. Plants can absorb Hg from soil and water by their roots. Hg can be unsafe at absolutely low amountsdue to its ability to bio-accumulate and high toxicity (Liu*et al*., 2019). Mercury pollution is a substantial concern globallydue to its lethal effect on public health. A higher amount of Hg has been observed to be dangerous to vegetation (A level of 0.36 mg kg^{-1} of Hg in soils is proposed to be a critical concentration above which plant and soil organisms will be affected) and it severely affects various biological parameters (Gworek *et al*., 2020). Biochar addition to soil has revealed definite enhances pH and CEC (Murtaza *et al*., 2021a). Biochar addition also amends the overall sorption capability of the soil and thus, it might affect transport, the fate and toxicity of various heavy metals in soil (Murtaza *et al*., 2021b). Conversely, some researchhas been carried regarding the effect of biochar addition on the traits of mercury-contaminated soil and the fate of Hg in soil. Consequently, the aim of the present research was to evaluate the influence of biochar treatment on selected traits of mercury-contaminated soil and to examine the results of biochar addition to uptake of the plants nutrient and mercury.

2. Methodology

2.1. *Biochar production and experimental procedure*

Rice straw for biochar manufacturewas taken from an agriculture farm of The University of Lahore (Abbasid Agri-Farms 31°37'39.6" N 74°25'36.8" E). Biochar was obtained at 450 °C pyrolysis temperature for 4 h. Plastic pots 15 cm in diameter were filledwith 1.5 kg of dry soil. Soil was artificially contaminated using mercuric oxide (HgO) and biochar obtained from rice straw was added at rates of 0, 5 and 10 t/ha. Thus, Mercury concentrations selected for this research was 10, 20 ppm, also 0 ppm (control). The pot was organized in a complete randomized scheme. Five seeds of Artichoke (Cynara cardunculus) were sown in every pot and after germination; only one plant was kept in every pot until flowering (92 days). Plants were left until flowering in order to confirm maximum uptake of Hg and the plant nutrient. Normal growth conditions were assured and the pots were irrigated whenever required to retain soil moisture to field capability.

2.2. *Laboratory study*

The pH was determined by the pH meter (MP511 Benchtop pH Meter) and soil texture measured through a hydrometer. Available phosphorus was determined by Bray I extraction technique (This test outlines the procedure for the determination of available phosphorus in soils. Bray No 1 solution is designed to extract adsorbed forms of phosphate only and is for use with soils with a pH <7.5. Phosphorus is extracted from the soil using Bray No 1 solution as extractant) total nitrogen was determined through the Kjeldahl method and organic carbon through the Walkley Black method (Van Reewijik, 1992). Total exchange-able bases were measured after seepage the soil with $C_2H_7NO_2$. Levels of $Mg^{2+}$and Ca^{2+} in leachate were investigated through Atomic absorption; Na^+ and K^+ were measured through a flame photometer. CEC was analyzed at 7 pH after displacement through 1N $C_2H_7NO_2$ procedure in which it was, afterward estimated titrimetrically through distillation of $C_2H_7NO_2$ that was displaced thru Na.

TABLE 1

The selected physiochemical traits of experimental soil

Clay	40 %
Silt	20 %
Sand	20 %
Texture class	Clay
pH	5.12
Electrical conductivity	0.33
OC	2.18
Total nitrogen (TN)	0.36 %
Available Phosphorus (AVP)	25.39 ppm
Cation exchange capacity (CEC)	26.32 (meq/100gm)
Exchangeable potassium (K)	0.81 (meq/100gm)
Exchangeable potassium (Ca)	12.78 (meq/100gm)
Exchangeable potassium (Mg)	7.02 (meq/100gm)
Exchangeable potassium (Na)	0.91 (meq/100gm)

2.3. *Analysis of plant tissue*

The plants were taken from every pot and washed using distilled water. Air-dried plant tissues were ground into 0.20 mm size, subjected to the wet digestion and analysed for K, P, and N. The nitrogen contents of plant tissues were measured through a colorimeterically method (Murphy and Riley, 1962) and the content of K was measured using a flame photometer. Total mercury content in plant tissue was measured through chromatography procedure.

2.4. *Statistical determination*

One way determination at the variance was implemented to evaluate significant differences in the soil parameters between various treatments, applying the general linear model method of SAS 9.2. Mean separation was performed using the least significant difference after treatments were noticed significant at $P <0.05$. A Simple correlation examination was done by SAS 9.2 in order to investigate interrelation among selected variables.

3. Results and discussion

3.1. *Influence of Biochar addition on the Soil CEC and pH*

The influences of biochar addition on CEC and pH of mercury-contaminated soil are presented in (Table 2).

TABLE 2

Influence of biochar addition on the available phosphorous, total Nitrogen content and organic carbon of Mercury-contaminated and uncontaminated soils

Mercury level (ppm)	Addition rate of biochar (t/ha)	pH	Electrical conductivity	Organic carbon (OC) %	Total nitrogen (TN) %	Available phosphorus (AVP) ppm
0	0	5.22b	0.20c	2.31b	0.39c	25.39b
0	5	5.37b	0.22b	2.96a	0.43b	27.99b
0	10	5.61a	0.26a	2.99a	0.46a	36.00a
P- value		**	**	**	**	**
10	0	5.12a	2.20b	2.89c	0.41c	24.19c
10	5	5.25b	0.21b	3.09a	0.44b	26.83b
10	10	5.34a	0.25a	3.22b	0.48a	35.11a
P- value		**	**	**	**	**
20	0	5.10b	0.21b	2.86c	0.42c	23.67c
20	5	5.31a	0.23b	3.04b	0.46b	25.89b
20	10	5.34a	0.26a	3.66a	0.49a	29.48a
P- value		**	**	**	**	**

The statistical determination exhibited a significant ($P<0.01$) enhance in CEC and pH owing to biochar application.In un-contaminated and mercury-contaminated soil, the maximum mean ranges of CEC and pH were noticed in soil applied with 10 t/ha rice straw biochar while minimum values were observed at 0 t/ha (Control). Enhance in soil CEC and pH owing to biochar addition was mostlyattributed to ash accumulation as ash residues are normally dominated by carbonates of alkaline and alkali earth metals, variable quantity of heavy metals, silica, small quantities of inorganic and organic nitrogen, phosphates and sesquioxides (Hamidi *et al*., 2021). Moreover, enhance in soil CEC and pH owing to biochar application might be because of the higher porous nature and surface area ofbiochar that enhances the CEC of soil (Murtaza *et al*., 2021a,b). The correlation matrix also exposed a positive and significant ($P<0.01$, $r = 0.70$) relationship between CEC and pH (shown in Table 5). These outcomes therefore, show that biochar might be applied as an alternative for lime substances to enhance pH of the acidic soil.

3.2. *Influence of Biochar addition on available P total N Contents and soil organic carbon*

Biochar application on un-contaminated and mercury-contaminated soil significantly enhanced the mean ranges of total N and soil organic carbon (Table 2). The maximum levels of total N and soil organic carbon were noticed in soil ameliorated with 10 t/ha rice straw biochar. The increases in total N and soil organic carbon owing to biochar application might be causedby of the higher contents of nitrogen and carbon in rice straw. The maximum ranges of the organic carbon in rice biochar ameliorated soilshow the recalcitrancy of carbon organic in biochar. The highest organic C in the soil amended by biochar has been described by (Pan *et al*., 2021). The concentration of available P in un-contaminated and mercury-contaminated soil was significantly enhanced through biochar treatment. The noticed enhance in available P owing to biochar application might be because of the existence of the higher P in rice straw. Improvement in soil CEC and pH that decrease the activity of Al and Fe could leadto maximum levels of available P in the soil altered by biochar. The correlation matrix also indicated a significant and positive interrelation between pH and available P($P<0.01$; $r = 0.83$ and CEC ($P<0.01$; $r = 0.70$). Tesfaye *et al*., (2021) also described that enhance in available P after biochar application.

3.3. *Influence of biochar addition on exchangeable bases and CEC*

The influence of biochar addition to exchangeable bases and CEC wasin un-contaminated and mercury-contaminated soilis displayed in (Table 3). The study of variance exhibited that exchangeable bases and CEC were significantly enhanced by biochar addition. The maximum levels of CEC were noticed when rice straw biochar was added at 10 t/ha (Table 3). Enhance in the CEC owing to biochar addition might be contributed from inherent traits of biochar. Biochar has highly porous, the higher surface area, variable charges has the potential to enhance soil CEC, sorption capacity of surface and base saturation when applied to the soil (Cao *et al*., 2019; Maikol *et al*., 2021). Many authors also reported, enhance in soil CEC

TABLE 3

Influence of biochar addition on the mean values of soil CEC and exchangeable bases (meq/100g)

Mercury level (ppm)	Addition rate of biochar (t/ha)	CEC	Na	K	Mg	Ca
0	0	26.33c	0.78b	0.74b	7.01c	14.09b
0	5	30.56b	1.10a	0.80b	7.16b	15.87b
0	10	32.97a	1.21a	0.84a	7.14a	16.17a
P- value		**	**	**	**	**
10	0	25.59c	0.96c	0.74c	7.31c	13.92c
10	5	32.39b	1.14b	0.80ab	7.44b	15.83b
10	10	33.67a	1.24a	0.85a	7.68a	16.61a
P- value		**	**	**	**	**
20	0	29.33c	1.06c	0.76	7.29c	14.99c
20	5	32.91b	1.20b	0.82	7.86b	16.09b
20	10	34.41a	1.31a	0.91	8.43a	17.08a
P- value		**	**	**	**	**

TABLE 4

Influence of biochar addition on nutrient uptake of Cynara cardunculus grown in mercury-contaminated and uncontaminated soils

Mercury level (ppm)	Addition rate of biochar (t/ha)	TN (%)	TP (%)	K(mg/Kg)	Hg(µg/Kg)
0	0	3.09c	7.13c	53.30b	1.79
0	5	3.18b	7.29b	56.54a	1.81
0	10	3.26a	7.39a	56.97a	1.89
P- value		**	**	**	Non-significant
10	0	2.71c	6.78c	52.74a	2.67
10	5	2.97b	6.81b	54.18ab	2.89
10	10	3.21a	6.99a	56.47a	2.58
P- value		**	**	*	Non-significant
20	0	2.67c	5.99c	52.79c	4.01a
20	5	3.07b	7.00b	56.74b	3.48b
20	10	3.19a	7.87a	61.67a	3.24c
P- value		**	**	**	**

capacity after biochar treatment (Al-Wabel *et al*., 2017; Jindo *et al*., 2020; Nguyen *et al*., 2020). Rice straw biochar addition to non-contaminated and mercury-contaminated soil has significantly enhanced the levels of exchangeable bases. The noticed maximum levels of exchangeable bases in biochar improved soil could be attributed to the existence of the ash content in biochar. Biochar ash content aids for contiguous discharge ofoccluded mineral nutrient such as N, K and Ca for crop use (Singh *et al*., 2018). The findings of this research also meet with Domingues *et al*., (2017) and Hailegnaw *et al*., (2021) who described the maximum exchangeable bases in biochar ameliorated soil.

3.4. *Influence of biochar addition on the nutrient uptake of artichoke (Cynara cardunculus)*

According to findings of this research, nutrient uptake of the Artichoke (*Cynara cardunculus*) was significantly enhanced by biochar addition (Table 4). In mercury-contaminated and un-contaminated soil, the maximum N uptake was noticed in the soil ameliorated with 10 t/ha biochar, whereas maximum levels were noticed at control. Krounbi *et al*., (2021) stated similar results of biochar on nitrogen uptake in which it was noticed that biochar addition significantly enhanced uptake of plant nitrogen. Chan *et al*. (2008) also presented

TABLE 5

Pearson correlation matrix for the selected parameters

	pH	CEC	OC	TN	AVP	Exchangeable K
pH	-	-	-	-	-	-
CEC	0.70**	-	-	-	-	-
OC	0.26**	0.71**	-	-	-	-
TN	0.52**	0.79**	0.81**	-	-	-
AVP	0.83**	0.65**	0.41*	0.55**	-	-
Exch. K	0.66**	0.80**	0.70**	0.87**	0.77	-
EC	0.66**	0.72**	0.66**	0.80**	0.74**	0.88**
Na	0.41*	0.81**	0.85**	0.87**	0.38*	0.75
Ca	0.47*	0.81**	0.84**	0.89**	0.63	0.89**
Mg	0.11	0.44*	0.75**	0.67**	0.01	0.48**
N uptake	-0.11	0.45*	0.23	0.30	0.10	0.24
P uptake	0.10	0.34	0.49**	0.45*	0.39*	0.55**
K uptake	0.24	0.40*	0.53**	0.42*	0.26	0.38*
Hg uptake	-0.43*	-0.46*	0.38*	0.27	-0.44*	0.07

the higher nitrogen uptake of *Raphanus sativus* is grown in biochar ameliorated soil. The noticed enhance in *Cynara cardunculus*nitrogen uptake by biochar addition shows the potential of biochar to amend fertilizer application efficiency, particularly, in soil where nitrogen loss is a main agronomic and environmental issue. Like potassium, phosphorous and nitrogen uptake were considerably enhanced after biochar addition. In mercury-contaminated and un-contaminated soil, maximum uptake of K and P were noticed in soil treated with 10 t/ha rice straw biochar. Enhance in P amount in the plants with enhancing biochar addition (Thomas, 2021). Enhance phosphorus content uptake by biochar addition might be attributed to high phosphorus contents in rice straw biochar and maximum soil P level in biochar treated soil (Table 2). The correlation matrix also indicated a significant and positive ($P<0.05$; $r = 0.39$) inter-correlation between soil available P and uptake P (Table 5). Enhance in potassium uptake in biochar ameliorated soil might be attributed to the existence of potassium enriched ash content in biochar. Liao *et al.*, (2020) also stated that enhanced nutrient uptake owing to biochar addition in the tropicalenvironment. Enhance in microbial activity owing to biochar application could be another reason tomaximum nutrient uptake in biochar altered soil. Biochar provides habitat for soil microbes involved in S, P, and N transformations.

3.5. *Influence of biochar addition on the uptake of Mercury*

The influence of biochar addition in mercury level of *Cynara cardunculus* tissue in is displayed in (Table 4). Slight levels of mercury in *Cynara cardunculus* tissue were noticed in soil amended by rice biochar. Conversely, a significant influence of biochar addition to uptake of mercury was noticed only in highly mercury-contaminated soil (20 ppm Hg). The minimum amount of Hg in plant tissue ameliorated by rice biochar could be owing to ahigher Hg adsorption ability of biochar. Potent adsorption affinity of the rice biochar for various ionic solutes was stated by numerous authors (Liang *et al.*, 2021; Liao*et al.*, 2020; Thomas, 2021; Hamidi *et al.*, 2020). The minimum uptake of Hg in biochar altered soil could results from enhance in CEC and pH of the soilcomplying biochar application (Tables 2 & 3). Concording to Palansooriya *et al.*, (2020), the concentration of Hg adsorbed to the soil enhanced with enhance in CEC and pH of the soil. The correlation matrix exhibited a significant and negative relationship among Hg uptake and the pH of soil ($P<0.05$; $r = -0.43$) and CEC ($P<0.05$; $r = 0.46$). A substantial role of the active C (produced biochar at high pyrolysis) as a sorption medium for de-contamination and de-colorization also results from to its high CEC range.

4. Conclusion

The results obtained in this study reveal that addition of biochar increased soil EC, pH, organic carbon, available phosphorous, total nitrogen, exchangeable cations and CEC of Hg-contaminated and uncontaminated soils. Uptake of potassium, phosphorous and nitrogen were also increase by biochar addition. The presence of plant nutrients and ash in the biochar, porous nature and high surface area of biochar and the capacity of biochar to act as a medium for micro organisms are identified as the leading reasons for the improvement in soil characteristics and highest nutrient uptake at biochar amended soils. Further more, due to high Hg adsorption capacity of biochar created from rice straw, the concentrations of Hg in Artichoke (C*ynara cardunculus*) tissues were reduced *via*biochar addition. Thus, biochar application is imperative in order to improve soil fertility, increase nutrient uptake and ameliorate Hg-contaminated soils. Additionally, further studies are required to assess the biochar effects on the uptake and fate of heavy metals in contaminated soils.

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