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BIOCHAR AMENDMENT ALLEVIATES CADMIUM IN CONTAMINATED SOIL AND IMPROVES NUTRIENT UPTAKE IN RICE (*Oryza sativa* L.)

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ABSTRACT

Cadmium is a toxic metallic element that, if present in high concentrations in soil, poses severe human health risks through intake of contaminated agricultural produces. A pot experiment was conducted in a net house to assess nutrient uptake by rice (*Oryza sativa* L.) in cadmium-contaminated soil amended with biochar. Six cadmium levels (0, 20, 40, 60, 80 and 100 mg kg^{-1}) and three levels of biochar @ 0, 20 and 40 t ha^{-1}, respectively, were taken. Results indicated that nutrient content and its uptake decreased with increasing levels of soil cadmium. Nutrient content and its uptake were significantly high in soils amended with biochar. Also, the nitrogen and phosphorus contents and their uptake were more in grains; whereas potassium content and its uptake were more in rice straw. Biochar may be used to alleviate the toxic effect of cadmium in cadmium contaminated soils.

Keywords: Biochar, cadmium, nutrient uptake, rice

INTRODUCTION

Heavy metal contamination due to anthropogenic activities is a global problem and has manifold negative impacts on soil and plant systems. This problem has become more severe worldwide, especially in developing countries (Bashir *et al*., 2017). Excessive toxic metal concentrations in the contaminated soils generally lead to soil quality degradation, crop yield reduction, and metal accumulation in agricultural products and thus pose increasing hazards to human health, as well as plants and animals (Wang *et al*., 2013). Presence of toxic metals in environment even in low amounts is responsible for various diseases (Algattawi *et al*., 2018). Remediation of these precarious soils by traditional practices, comprising excavation and landfilling, is impracticable on large scale because these techniques are cost-prohibitive and environmentally troublesome (Houben *et al*., 2013a), besides they generate considerable disturbance in environment and are not economically feasible (Houben *et al*., 2013b). Therefore, to limit the solubility and bioavailability of metal(oid)s in contaminated soil a special soil-management technique is required (Hattab *et al*., 2015). The phyto-availability and mobility of metals in soils may be decreased by *in-situ* immobilization of metals in contaminated soils using amendments (Sabir *et al*., 2013; Rehman *et al*., 2017). For immobilization of metals in soils, organic and inorganic amendments can be used (Chaiyarat *et al*., 2011) with varying benefits but organic amendments might be perform better owing to their capacity of improving physicochemical & biological properties and fertility status of soil (Kant *et al*., 2018a,b). Organic amendments decontaminate the ill-effects of heavy metals in soil-plant systems, because they are the resultant of raw biological waste and little pretreatment is required before their use (Yin *et al*., 2016; Bashir *et al*., 2017). Several organic amendments can decrease the solubility, leaching and bioavailability of trace elements (Angelova *et al*., 2013; Kumar *et al*., 2018). Organic amendments may enhance the soil fertility and microbial activity, leading to the amelioration of soil quality as a whole (Kumar and Sharma, 2018). The organic sources may be organic manures, green manure, rural wastes, crop residues, biofertilizers and vermicompost (Kumar *et al*., 2018; 2020).

Among the toxic heavy metals, cadmium (Cd) is one of the most widespread harmful contaminants in agricultural soils (Abbas *et al*., 2017; Liu *et al*., 2020) because of its non-biodegradability, detrimental effects on ecosystems, and threats to human health through food chain (Murtaza *et al*., 2015). Undoubtedly, Cd adversely affects not only the quality of agriculture products but also human health due to its high toxicity and bioavailability (Khan *et al*., 2018). Cd toxicity increases the oxidative stress in plants by enhancing the production of reactive oxygen species (ROS) in different parts of plant. Cd toxicity triggers the overproduction of hydrogen peroxide (H_2O_2), electrolyte leakage, and malondialdehyde contents in plants (Gallego *et al*., 2012; Younis *et al*., 2016). Various agricultural practices like use of metal hyperaccumulator plants, inorganic and organic amendments, etc. have been used to remediate Cd-contaminated soils (Qayyum *et al*., 2017).

Among organic amendments, biochar is widely used and has several benefits for soils and crops (Du *et al*. 2017; Hussain *et al*. 2017). Biochar is a solid organic material produced by slow pyrolysis of waste organic materials such as manures and agricultural residues (Ok *et al*., 2015; Rizwan *et al*., 2016). It is a carbonaceous black porous material achieved by pyrolysis of biomass under oxygen-free environment (Choudhary *et al*., 2017). It might influence the toxicity, transport and fate of heavy metals in soil (Nigussie *et al*., 2012). Biochar reportedly decreases metal bioavailability in soils and their uptake and translocation by plants (Li *et al*., 2016; Zhang *et al*., 2016). Biochar is a noble choice for heavy metal stabilization in contaminated soils, which leads to the reduction in heavy metal uptake by plants (Beesley *et al*. 2011; Lu *et al*. 2014). Biochar in comparison to other chemical and biological methods has remarkable potential to remove pollutants (Zeng *et al*., 2015) as it is eco-friendly and economic in production (Ahmad *et al*. 2014; Tan *et al*. 2015).

Rice (*Oryza sativa* L.) is primary food of over two billion people in Asia, Africa and Latin America and has been used as a model plant in studies of Cd toxicity and tolerance. Currently, Cd pollution in soils poses a serious threat to rice quality. Thus, it is important to find ways and means to increase rice tolerance to Cd and limit their accumulation. The present study was aimed to assess the effect of biochar on NPK uptake by rice in Cd-contaminated soil.

MATERIALS AND METHODS

A pot experiment was conducted in a net house during 2018. Biochar was collected from a private rice mill situated at Mirzapur, UP (India). Bulk soil was taken from Agricultural Research Farm, IAS, BHU, Varanasi (India). Soil was air-dried, ground to pass through a 2 mm sieve and homogenized. The soil samples were analyzed for chemical properties. Experimental soil had pH 7.19, EC 0.15 dSm^{-1}, organic carbon 0.25%, available N, P and K contents of 195.7, P 17.89 and 185.78 kg ha^{-1}, respectively. The available Fe, Cu, Mn, Zn and DTPA-extractable Cd contents in the soil was 18.8, 1.75, 6.05, 1.04 and 0.04 mg kg^{-1}, respectively Processed 10 kg soil was filled in polythene lined pots of adequate size. The moisture level in pots was maintained up to field capacity. The experiment was conducted in a completely randomized design having 18 treatments *viz*., six levels of Cd (0, 20, 40, 60, 80 and 100 mg kg^{-1}) and three levels of biochar @ 0, 20 and 40 t ha^{-1}. Rice (var. 'HUR-105') was taken as a test crop in *kharif* season 2018. Recommended doses of NPK were applied @ 150:60:60 kg ha^{-1} through urea, di-ammonium phosphate, muriate of potash, respectively, in all the pots.

The requisite amount of Cd for 10 kg soil was applied through cadmium chloride ($CdCl_2$) as per treatment to the pots and allowed to maintain equilibrium. After 15 days of Cd-contamination biochar was applied @ 0, 89.2 and 178.6 g pot^{-1}, respectively, and then mixed thoroughly. Pots were incubated for next 15 days with biochar and watered at field capacity almost on a daily basis after a month of incubation (four-week old-seedlings) was transplanted @ 5 seedlings pot^{-1}.

At harvest, the plant and grain samples were collected from each pot for chemical estimation and the samples were dried in an oven at 70ºC for 48 h, the plant material obtained was ground with the help of grinder, passed through 40 mm mesh sieve and preserved separately for determination of NPK content. Nitrogen content was estimated both in grain and straw by modified Kjeldahl's method, phosphorus by vanadomolybdate phosphoric acid yellow colour method and potassium by flame photometric (Systronics 130) method (Jackson, 1973). The mature harvested produce from pot was sun-dried and threshed to obtain grain yield. The straw yield was worked out by subtracting grain yield from total biological yield. The uptake of nutrients was calculated by using the formula of Weigh *et al*. (2018). For determining the statistical significance between the treatment means, statistical analysis was performed. The difference between treatment means was tested using critical difference at 1% level of probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Cadmium directly has an adverse effect on rice yield but can be mitigated by using an adequate amount of biochar (Table 1). Similar observations were made in case of straw yield. The highest reduction in yields due to Cd was observed in treatment Cd100 (Table 1). The grain and straw yields of rice were enhanced due to biochar over control treatment. The improvement in rice yield may be attributed to the addition of biochar to the soil, which increased the availability of nutrients due the improvement in important soil properties. The adverse effect of Cd on rice yield could be alleviated to some extent especially with biochar addition.

Table 1: Effect of biochar on grain and straw yield and nitrogen content and its uptake by rice in cadmium-contaminated soil

Treatments*	Grain yield (g pot^{-1})	Straw yield (g pot^{-1})	N content (%)		N uptake (g pot^{-1})		Total N uptake (g pot^{-1})
			Grain	Straw	Grain	Straw	
Cd0Bc0	45.8	50.0	1.35	0.58	0.62	0.29	0.91
Cd20Bc0	42.1	48.1	1.32	0.56	0.56	0.27	0.83
Cd40Bc0	39.1	46.8	1.25	0.54	0.49	0.25	0.74
Cd60Bc0	36.1	44.5	1.17	0.49	0.42	0.22	0.64
Cd80Bc0	33.2	42.3	1.05	0.43	0.35	0.18	0.53
Cd100Bc0	29.2	40.2	0.98	0.38	0.29	0.15	0.44
Cd0Bc20	46.2	50.3	1.38	0.59	0.64	0.30	0.94
Cd0Bc40	47.0	50.4	1.40	0.62	0.66	0.31	0.97
Cd20Bc20	42.7	48.4	1.34	0.58	0.57	0.28	0.85
Cd20Bc40	43.3	48.9	1.36	0.60	0.59	0.29	0.88
Cd40Bc20	39.8	47.1	1.28	0.56	0.51	0.26	0.77
Cd40Bc40	40.3	47.4	1.30	0.58	0.52	0.27	0.80
Cd60Bc20	36.8	45.0	1.22	0.52	0.45	0.23	0.68
Cd60Bc40	37.2	45.4	1.25	0.54	0.47	0.25	0.71
Cd80Bc20	33.9	42.6	1.10	0.45	0.37	0.19	0.57
Cd80Bc40	34.1	42.8	1.13	0.47	0.38	0.20	0.59
Cd100Bc20	29.8	40.6	1.02	0.39	0.30	0.16	0.46
Cd100Bc40	30.2	40.9	1.08	0.41	0.33	0.17	0.49
SEm±	0.15	0.41	0.031	0.015	0.006	0.009	0.006
$CD_{0.01}$	0.43	1.18	0.088	0.043	0.017	0.026	0.019

*Cd – Cadmium: 0, 20, 40, 60, 80 & 100 mg kg^{-1} soil; Bc – Biochar: 0, 20 and 40 t ha^{-1}

The maximum nitrogen content in grain and straw was found in treatment Cd0Bc40 while lowest N content was in treatment Cd100. Maximum N uptake in grain and straw and biological yield was noticed in treatment Cd0+Bc40 while the lowest N uptake was observed in treatment Cd100. With increased level of Cd application, there was significant decrease in N content and its uptake. Biochar application increased N content and its uptake in Cd contaminated soil and mitigated the toxic effect of Cd.

The phosphorus content in grain and straw was affected by Cd contamination and biochar application (Table 2). Minimum P content in grain and straw was found in treatment Cd100Bc0. Generally, P content was more in grain than straw. The reduction in P content may be due to the inhibition of enzymes involved in synthetic process. The use of biochar @ 40 t ha^{-1} alone (Cd0Bc40) recorded highest P content in grain and straw as well as highest P uptake in grain and straw. However, the lowest P content and its uptake in both grain and straw was recorded in treatment Cd100Bc0).

Potassium content in grain and straw was also affected by different level of cadmium. K uptake was more in straw than grain with respect to N and P (Table 3). The data revealed that maximum K uptake in grain and straw was in treatment Cd0Bc40, followed by Cd0Bc20. Application of biochar in control pots recorded highest K content in grain and straw and highest K uptake as compared to other treatments. Application of Cd lowered K uptake in grain and straw but the application of biochar mitigated the ill-effects of Cd application in soil and improved K uptake.

Yassen *et al*. (2007) concluded that decrease in N, P and K contents in spinach plant in a soil contaminated with heavy metals probably may be due to the adverse effect of heavy metals on plant growth rather than their interference with nutrients. Ramzani *et al*. (2016) cleared that enhanced plant growth and grain yield in rice crop can be attributed to the positive effect of biochar. Maximum crop yield in contaminated soils might be due to the furnishing of soil with nutrients like carbon, nitrogen, and phosphorus by the amendment (Shaheen *et al*., 2017; Kumar *et al*., 2020). Higher chlorophyll levels often resulted in higher crop yields because chlorophylls participate in energy creation and conversion via photosynthesis for crop growth (Alam *et al*., 2019). Kohler *et al*. (2015) showed that

Table 2: Effect of biochar on phosphorus content and its uptake by rice in Cd-contaminated soil

Treatments*	P content (%) in rice grain	P content (%) in rice straw	P uptake in grain (g pot^{-1})	P uptake in straw (g pot^{-1})	Total P uptake (g pot^{-1})
Cd0Bc0	0.36	0.19	0.16	0.10	0.26
Cd20Bc0	0.32	0.18	0.13	0.09	0.22
Cd40Bc0	0.29	0.17	0.11	0.08	0.19
Cd60Bc0	0.27	0.14	0.10	0.06	0.16
Cd80Bc0	0.23	0.12	0.08	0.05	0.13
Cd100Bc0	0.19	0.11	0.06	0.04	0.10
Cd0Bc20	0.37	0.19	0.17	0.10	0.27
Cd0Bc40	0.39	0.20	0.18	0.10	0.28
Cd20Bc20	0.34	0.17	0.15	0.08	0.23
Cd20Bc40	0.36	0.18	0.16	0.09	0.24
Cd40Bc20	0.32	0.16	0.13	0.08	0.20
Cd40Bc40	0.34	0.17	0.14	0.08	0.22
Cd60Bc20	0.29	0.14	0.11	0.06	0.17
Cd60Bc40	0.31	0.15	0.12	0.07	0.18
Cd80Bc20	0.25	0.12	0.08	0.05	0.14
Cd80Bc40	0.28	0.13	0.10	0.05	0.15
Cd100Bc20	0.21	0.11	0.06	0.05	0.11
Cd100Bc40	0.23	0.12	0.07	0.05	0.12
SEm±	0.020	0.007	0.004	0.002	0.005
$CD_{0.01}$	0.057	0.021	0.010	0.006	0.014

*Cd – Cadmium: 0, 20, 40, 60, 80 & 100 mg kg^{-1} soil; Bc – Biochar: 0, 20 and 40 t ha^{-1}

Table 3: Effect of biochar on potassium content and its uptake by rice in Cd-contaminated soil

Treatments*	K content (%) in rice grain	K content (%) in rice straw	K uptake in grain (g pot^{-1})	K uptake in straw (g pot^{-1})	Total K uptake (g pot^{-1})
Cd0Bc0	0.54	1.58	0.25	0.79	1.04
Cd20Bc0	0.51	1.43	0.21	0.69	0.90
Cd40Bc0	0.48	1.38	0.19	0.65	0.83
Cd60Bc0	0.45	1.29	0.16	0.57	0.74
Cd80Bc0	0.40	1.22	0.13	0.52	0.65
Cd100Bc0	0.36	1.16	0.11	0.47	0.57
Cd0Bc20	0.56	1.60	0.26	0.80	1.06
Cd0Bc40	0.58	1.63	0.27	0.82	1.09
Cd20Bc20	0.53	1.46	0.23	0.71	0.93
Cd20Bc40	0.55	1.48	0.24	0.72	0.96
Cd40Bc20	0.51	1.40	0.20	0.66	0.86
Cd40Bc40	0.53	1.44	0.21	0.68	0.90
Cd60Bc20	0.48	1.32	0.18	0.59	0.77
Cd60Bc40	0.52	1.35	0.19	0.61	0.81
Cd80Bc20	0.42	1.25	0.14	0.53	0.67
Cd80Bc40	0.45	1.28	0.15	0.55	0.70
Cd100Bc20	0.38	1.18	0.11	0.48	0.59
Cd100Bc40	0.40	1.21	0.12	0.49	0.62
SEm±	0.022	0.020	0.004	0.006	0.005
$CD_{0.01}$	0.062	0.056	0.012	0.018	0.016

*Cd – Cadmium: 0, 20, 40, 60, 80 & 100 mg kg^{-1} soil; Bc – Biochar: 0, 20 and 40 t ha^{-1}

the organic waste compost significantly increases the contents of foliar N, P and K in relation to non-amended plants in a heavy metal polluted soil. Nigussie *et al.* (2012) showed significant increase in N, P and K uptake by biochar addition to the artificially polluted soils. Yassen *et al.* (2007) reported that the use of organic residues increased N, P and K content in soils contaminated with heavy metals as compared to the control soil. The rise in N, P and K uptake due to organic amendments could be attributed to high N, P and K content in organic amendments and consequent high N, P and K concentration in amended soils **(**Nigussie *et al.*, 2012). Increase in nutrients content and uptake could be due to the increase in dry matter yield and impact of organics on soil (Kumar *et al.*, 2020). The role of biochar is to reduce the Cd-toxicity by improving the nutrient uptake efficacy which leads to the yield improvement in rice crop that could be attributed due to the reduction in the bioavailability of Cd and thus reduces toxic effects of Cd in soil (Devanand *et al.*, 2020). Increase in accumulation of nutrients may be due to the improved soil fertility and nutrients in biochar amended soil because biochar increases beneficial nutrients in soil solution and then their accumulation in plants (Ibrahim *et al.*, 2016). Results indicated that Cd exerted deleterious effect on rice. Nutrient content and its uptake in rice decreased with increase in Cd dose in soil. Addition of biochar significantly enhanced nutrient content and uptake in rice. The use of biochar reduces Cd toxicity to some level but not to full extent.

Conflict of interest: All the authors declare that there is no conflict of interest regarding the publication of this paper.

REFERENCES

Abbas, T., Rizwan, M., Ali, S., Rehman, M.Z., Qayyum, M.F., Abbas, F., Hannan, F., Rinklebe, J. and Ok, Y.S. 2017. Effect of biochar on cadmium bioavailability and uptake in wheat (*Triticum* *aestivum* L.) grown in a soil with aged contamination. *Ecotoxicology and Environmental Safety*, **140**: 37-47.

Ahmad, M., Rajapaksha, A.U., Lim, J.E., Zhang, M., Bolan, N., Mohan, D., Vithanage, M., Lee, S.S. and Ok, Y.S. 2014. Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere*, **99**: 19-23.

Alam, M.Z., McGee, R., Hoque, M.A., Ahammed, G.J. and Boggs, L.C. 2019. Effect of arbuscular mycorrhizal fungi, selenium and biochar on photosynthetic pigments and antioxidant enzyme activity under arsenic stress in mung bean (*vigna radiata*). *Frontiers in Physiology*, **10**: 193.

Algattawi, A.A., Hassan, M.F. and Khalil, E. 2018. Soil contamination with toxic aluminum at Mid and West Libya. *Toxicology International*, **25**(4): 198-203.

Angelova, V.R., Akova, V.I., Artinova, N.S. and Ivanov, K.I. 2013. The effect of organic amendments on soil chemical characteristics. *Bulgarian Journal of Agricultural Science*, **19**: 958-971.

Bashir, S., Hussain, Q., Akmal, M., Riaz, M., Hu, H., Ijaz, S.S., Iqbalm M., Abro, S., Mehmood, S. and Ahmad, M. 2017. Sugarcane bagasse-derived biochar reduces the cadmium and chromium bioavailability to mash bean and enhances the microbial activity in contaminated soil. *Journal of Soils and Sediments*, **18**: 874-886.

Beesley, L., Moreno, J.E., Clemente, R., Lepp, N. and Dickinson, N. 2011. Mobility of arsenic, cadmium and zinc in a multi-element contaminated soil profile assessed by *in-situ* soil pore water sampling, column leaching and sequential extraction. *Environmental Pollution*, **158**: 155-160.

Chaiyarat, R., Suebsima, R., Putwattana, N., Kruatrachue, M. and Pokethitiyook, P. 2011. Effects of soil amendments on growth and metal uptake by *Ocimum gratissimum* grown in Cd/Zn-contaminated soil. *Water, Air and Soil Pollution*, **214**: 383-392.

Choudhary, B., Paul, D., Singh, A. and Gupta, T. 2017. Removal of hexavalent chromium upon interaction with biochar under acidic conditions: mechanistic insights and application. *Environmental Science and Pollution Research*, **24**: 16786-16797.

Devanand, Sharma, P.K., Kumar, V. and Sarvajeet. 2020. Effect of biochar augments on various growth attributes of rice (*Oryza sativa* L.) In cadmium contaminated soil. *Journal of Experimental Biology and Agricultural Sciences*, **8**(3): 253-264.

Du, Z.L., Zhao, J.K., Wang, Y.D. and Zhang, Q.Z. 2017. Biochar addition drives soil aggregation and carbon sequestration in aggregate fractions from an intensive agricultural system. *Journal of Soils and Sediments*, **17**(3): 581-589.

Gallego, S.M., Pena, L.B., Barcia, R.A., Azpilicueta, C.E., Iannone, M.F., Rosales, E.P. and Benavides, M.P. 2012. Unravelling cadmium toxicity and tolerance in plants: Insight into regulatory mechanisms. *Environmental and Experimental Botany*, **83**: 33-46.

Gomez, A.K. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research* (2nd edn.), John Wiley and Sons, New York, USA.

Hattab, N., Heino, M.M., Faure, O. and Bouchardon, J.L. 2015. Effect of fresh and mature organic amendments on the phytoremediation of Technosols contaminated with high concentrations of trace elements. *Journal of Environmental Management*, **159**: 37-47.

Houben, D., Evrard, L. and Sonnet, P. 2013a. Beneficial effects of biochar application to contaminated soils on the bioavailability of Cd, Pb and Zn and the biomass production of rapeseed (*Brassica napus* L.). *Biomass and Bioenergy*, **57**: 196-204.

Houben, D., Evrard, L. and Sonnet, P. 2013b. Mobility, bioavailability and pH-dependent leaching of cadmium, zinc and lead in a contaminated soil amended with biochar. *Chemosphere*, **92**: 1450-1457.

Hussain, M., Farooq, M., Nawaz, A., Al-Sadi, A.M., Solaiman, Z.M., Alghamdi, S.S., Ammara, U., Ok, Y.S. and Siddique, K.H.M. 2017. Biochar for crop production: potential benefits and risks. *Journal of Soils and Sediments*, **17**: 685-716.

Ibrahim, M., Khan, S., Hao, X. and Li, G. 2016. Biochar effects on metal bioaccumulation and arsenic speciation in alfalfa (*Medicago sativa* L.) grown in contaminated soil. *International Journal of Environmental Science and Technology*, **13**: 2467-2474.

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice- Hall of India Pvt. Ltd., New Delhi, India.

Kant, S., Sharma, P.K., Kumar, V. and Kumar, A. 2018a. Chelating compounds influence the chemical properties of post-harvest chromium contaminated soil after maize and mustard. *International Journal of Chemical Studies*, **6**: 1672-1680.

Kant, S., Sharma, P.K. and Kumar, V. 2018b. Effect of chelating compounds on growth of maize and mustard in chromium contaminated soil. *Journal of Pharmacognosy and Phytochemistry*, **7**: 2964-2972.

Khan, M.A., Khan, S., Ding, X., Khan, A. and Alam, M. 2018. The effects of biochar and rice husk on adsorption and desorption of cadmium on to soils with different water conditions (upland and saturated). *Chemosphere*, **193**: 1120-1126.

Kohler, J., Caravaca, F., Azcon, R., Diaz, G. and Roldan, A. 2015. The combination of compost addition and arbuscular mycorrhizal inoculation produced positive and synergistic effects on the phytomanagement of a semiarid mine tailing. *Science of the Total Environment*, **514**: 42-48.

Kumar, V. and Sharma, P.K. 2018. Augmentation of nitrogen and phosphorus mineralization in chromium contaminated soils using organic amendments. *International Journal of Chemical Studies*, **6**: 3417-3422.

Kumar, V., Sharma, P.K., Kant, S., Shikha, Rai, A. and Kumar, A. 2018. Organic amendments influence mustard (*Brassica juncea*) growth in chromium contaminated soils. *Journal of Pharmacognosy and Phytochemistry*, **7**: 2026-2038.

Kumar, V., Sharma, P.K., Jatav, H.S., Singh, S.K., Rai, A., Kant, S. and Kumar, A. 2020. Organic amendments application increases yield and nutrient uptake of mustard (*Brassica Juncea*) grown in chromium-contaminated soils. *Communications in Soil Science and Plant Analysis*, **51**(1): 149-159.

Li, H., Ye, X., Geng, Z., Zhou, H., Guo, X., Zhang, Y., Zhao, H. and Wang, G. 2016. The influence of biochar type on long-term stabilization for Cd and Cu in contaminated paddy soils. *Journal of Hazardous Materials*, **304**: 40-48.

Liu, N., Jiang, Z., Li, X., Liu, H., Li, N. and Wei, S. 2020. Mitigation of rice cadmium (Cd) accumulation by joint application of organic amendments and selenium (Se) in high-Cd-contaminated soils. *Chemosphere*, **241**: 125106.

Lu, K., Yang, X., Shen, J., Robinson, B., Huang, H., Liu, D., Bolan, N., Pei, J. and Wang, H. 2014. Effect of bamboo and rice straw biochars on the bioavailability of Cd, Cu, Pb and Zn to *Sedum plumbizincicola*. *Agriculture, Ecosystems and Environment*, **191**: 124-132.

Murtaza, G., Javed, W., Hussain, A., Wahid, A., Murtaza, B. and Owens, G. 2015. Metal uptake via phosphate fertilizer and city sewage in cereal and legume crops in Pakistan. *Environmental Science and Pollution Research*, **22**: 9136-9147.

Nigussie, A., Kissi, E., Misganaw, M. and Ambaw, G. 2012. Effect of biochar application on soil properties and nutrient uptake of lettuces (*Lactucasativa*) grown in chromium polluted soils. *American-Eurasian Journal of Agricultural & Environmental Sciences*, **12**(3): 369-376.

Ok, Y.S., Chang, S.X., Gao, B. and Chung, H.J. 2015. SMART biochar technology - A shifting paradigm towards advanced materials and healthcare research. *Environmental Technology and Innovation*, **4**: 206-209.

Qayyum, M.F., Rehman, M.Z., Ali, S., Rizwan, M., Naeem, A., Maqsood, M.A., Khalid, H., Rinklebe, J. and Ok, Y.S. 2017. Residual effects of monoammonium phosphate, gypsum and elemental sulfur on cadmium phytoavailability and translocation from soil to wheat in an effluent irrigated field. *Chemosphere*, **174**: 515-523.

Ramzani, P.M.A., Khan, W.D., Iqbal, M., Kausar, S., Ali, S., Rizwan, M. and Virk, Z.A. 2016. Effect of different amendments on rice (*Oryza sativa* L.) growth, yield, nutrient uptake and grain quality in Ni-contaminated soil. *Environmental Science and Pollution Research*, **23**(18): 18585-18595.

Rehman, M.Z., Khalid, H., Akmal, F., Ali, S., Rizwan, M., Qayyum, M.F., Iqbal, M., Khalid, M.U. and Azhar, M. 2017. Effect of limestone, lignite and biochar applied alone and combined on cadmium uptake in wheat and rice under rotation in an effluent irrigated field. *Environmental Pollution*, **227**: 560-568.

Rizwan, M., Meunier, J.D., Davidian, J.C., Pokrovsky, O.S., Bovet, N. and Keller, C. 2016. Silicon alleviates Cd stress of wheat seedlings (*Triticum turgidum* L. cv. Claudio) grown in hydroponics. *Environmental Science and Pollution Research*, **23**: 1414-1427.

Sabir, M., Hanafi, M.M., Aziz, T., Ahmad, H.R., Rehman, M.Z., Saifullah, Murtaza, G. and Hakeem, K.R. 2013. Comparative effect of activated carbon, press mud and poultry manure on immobilization and concentration of metals in maize (*Zea mays*) grown on contaminated soil. *International Journal of Agriculture and Biology*, **15**(3): 559-564.

Shaheen, S.M., Balbaa, A.A., Khatab, A.M. and Rinklebe, J. 2017. Compost and sulfur affect the mobilization and phytoavailability of Cd and Ni to sorghum and barnyard grass in a spiked fluvial soil. *Environmental Geochemistry and Health*, **39**(6): 1305-1324.

Tan, X., Liu, Y., Zeng, G., Wang, X., Hu, X., Gu, Y. and Yang, Z. 2015. Application of biochar for the removal of pollutants from aqueous solutions. *Chemosphere*, **125**: 70-85.

Wang, F.Y., Shi, Z.Y., Xu, X.F., Wang, X.G. and Li, Y.J. 2013. Contribution of AM inoculation and cattle manure to lead and cadmium phytoremediation by tobacco plants. *Environmental Science: Processes and Impacts*, **15**: 794-801.

Weih, M., Hamner, K. and Pourazari, F. 2018. Analyzing plant nutrient uptake and utilization efficiencies: Comparison between crops and approaches. *Plant and Soil*, **430**: 7-21.

Yassen, A.A., Nadia, B.M. and Zaghloul, M.S. 2007. Role of some organic residues as tools for reducing heavy metals hazards in plant. *World Journal of Agricultural Sciences*, **3**(2): 204-209.

Yin, B., Zhou, L., Yin, B. and Chen, L. 2016. Effects of organic amendments on rice (*Oryza sativa* L.) growth and uptake of heavy metals in contaminated soil. *Journal of Soils and Sediments*, **16**: 537-546.

Younis, U., Malik, S.A., Rizwan, M., Qayyum, M.F., Ok, Y.S., Shah, M.H.R., Rehman, R.A. and Ahmad, N. 2016. Biochar enhances the cadmium tolerance in spinach (*Spinacia oleracea*) through modification of Cd uptake and physiological and biochemical attributes. *Environmental Science and Pollution Research*, **23**: 21385-21394.

Zeng, G., Wu, H., Liang, J., Guo, S., Huang, L., Xu, P., Liu, Y., Yuan, Y., He, X. and He, Y. 2015. Efficiency of biochar and compost (or composting) combined amendments for reducing Cd, Cu, Zn and Pb bioavailability, mobility and ecological risk in wetland soil. *RSC Advances*, **5**: 34541-34548.

Zhang, Y., Chen, T., Liao, Y., Reid, B.J., Chi, H., Hou, Y. and Cai, C. 2016. Modest amendment of sewage sludge biochar to reduce the accumulation of cadmium into rice (*Oryza sativa* L.): a field study. *Environmental Pollution*, **216**: 819-825.