International Journal of Environment and Climate Change

Volume 13, Issue 11, Page 4491-4500, 2023; Article no.IJECC.110060
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Effect of Biochar Application on Heavy Metal accumulation in Different Parts of Paddy Plant

Sayon Mukherjee [a*], S. K. Singh [a*], Surendra Singh Jatav [a], Abhik Patra [b] and Gorantla Prathap Reddy [a]

[a] Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221005, India.
[b] Krishi Vigyan Kendra, Narkatiaganj, West Champaran, Bihar-845455, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i113629

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/110060

Original Research Article

Received: 27/09/2023
Accepted: 02/12/2023
Published: 07/12/2023

ABSTRACT

Heavy metal contamination in agricultural field is a challenging aspect globally. Various methods are employed to address the issue; biochar among the most cost-effective and promising one. Our study encompasses biochar preparation from Parthenium, a noxious weed of agricultural field, and its subsequent modification using ferric chloride and orthophosphoric acid. Results revealed that more than 20% reduction of Pb, Cd and Ni in Rice roots under 5 and 7.5 t ha-1 biochar treatments. Moreover, greater than 30% reduction of abovementioned heavy metals in rice grains is also noted in 10 t ha-1 biochar application rates. So, it can be concluded from our study that biochar application to a metal contaminated soil can be a promising approach to reduce metal accumulation in different parts of rice and subsequently addressing the adverse effect of it in human body.

Keywords: Biochar application; heavy metal contamination; biochar preparation.

**Corresponding author: E-mail: sayon.m@bhu.ac.in, satishks@bhu.ac.in;*

1. INTRODUCTION

The presence of heavy metals (HMs) in soil and water poses a significant threat to both ecosystems and human health. This issue primarily stems from the discharge of metal-contaminated wastewater by industries like metallurgy, steel production, tanneries, and cement manufacturing [1]. To combat this problem, one effective method of metal removal is through adsorption process. This approach is known for its high efficiency, operational simplicity, and economic benefits, while avoiding the generation of sludge [2]. Biochar, with its advantageous characteristics like liming effect, extensive surface area, high cation exchange capacity, porous structure, negatively charged surface, and oxygen-containing functional groups, has the potential to remediate soil contaminated with metals. Biochar, with its extensive surface area and reactivity, has gained importance as an adsorbent for removing metals from soil and wastewater [3]. Notably, iron-based materials have been a focal point for environmental applications and the treatment of various pollutants in recent days [4]. In their study, Singaraj et al. [5] demonstrated that use of humic acid coated iron oxide nanoparticle was able to sorb Cr which was not easily released even after acid-alkali treatment. Recent research focuses on enhancing ability of biochar to immobilize HMs through modifications. This includes introduction of organic or inorganic materials, such as Fe-compounds [6] and phosphate materials [7], to improve its performance in HM immobilization. In a study by Yang et al. [8], it was found that incorporating phosphorus-rich biochar derived from pig carcasses into paddy soils might be a promising technique for reducing Pb risks to human health. Additionally, biochars derived from iron-rich green waste were effective in immobilizing Cd and minimizing its impact in paddy soils and the environment. Rice, a crucial cereal for half the global population, can accumulate heavy metals (HMs), posing a significant source of HMs in the human body [9-11]. In this respect, urgent attention addressing the simultaneous immobilization and reduction of bioavailability of HMs in paddy soils is crucial for sustainable soil management and safeguarding human health. Considering the aforementioned possibilities, primary aim of our study to reduce heavy metal accumulation in different parts of Rice cultivated in a heavy metal contaminated soil through graded dose of simple and modified biochar administration preparing from Parthenium considering and indirect environmental benefit through reducing weed load.

2. MATERIALS AND METHODS

2.1 Pot Experiment Details

Heavy metal contaminated soil is collected from industrial wastewater irrigated farmers field near Jajmau area in Kanpur, India and the soil was transported to Glass house of Institute of Agricultural Sciences, Banaras Hindu University. The soil was slightly alkaline (pH = 7.6 in 1: 2 :: soil : solution), non-saline (EC = 1.8 dS m^{-1}) with loamy texture. The soil contains 200 ppm Pb, 100 ppm Ni and 17 ppm Cd which is much higher than the permissible limit of 100, 50 and 3 ppm for Pb, Ni and Cd respectively. Subsequently, the soil was air-dried, ground and sieved through 2 mm sieve and filled up to the plastic lined 10 kg pot after uniform mixing with biochar according to the treatments detailed. Rice seedlings (HUR-105) was transplanted after flooding the soil.

2.2 Treatment Details

The treatments used in the experiment is outlined as: T1: Control, T2: Raw biochar @ 5 t ha^{-1} (RB_5), T3: Raw biochar @ 7.5 t ha^{-1} ($RB_{7.5}$), T4: Raw biochar @ 10 t ha^{-1} (RB_{10}), T5: Phosphoric acid modified biochar @ 5 t ha^{-1} ($PAMB_5$), T6: Phosphoric acid modified biochar @ 7.5 t ha^{-1} ($PAMB_{7.5}$), T7: Phosphoric acid modified biochar @ 10 t ha^{-1} ($PAMB_{10}$), T8: Iron chloride modified biochar @ 5 t ha^{-1} ($ICMB_5$), T9: Iron chloride modified biochar @ 7.5 t ha^{-1} ($ICMB_{7.5}$), T10: Iron chloride modified biochar @ 10 t ha^{-1} ($ICMB_{10}$). All treatments are replicated thrice in a completely randomized design.

2.3 Biochar Preparation and Modification

Succulent plants of Parthenium were harvested, cleansed, chopped, sundried, and subjected to biochar preparation as outlined by Venkatesh et al. [12]. Subsequently, the prepared biochar was sieved with 2 mm sieve, washed with distilled water and modified with 1 M $FeCl_3$ solution and concentrated H_3PO_4 at 1:10 (w/v) and 1:5 (w/w) ratio respectively with 1 hour shaking and 24-hour contact period followed by filtration [13,14]. Following modification, the biochar was thoroughly washed, air dried, then oven dried at 60 ^{0}C for 8 hours, and finely grounded before mixing with soil.

2.4 Plant Sample Analysis and Data Calculation

Digestion of plant samples is done using diacid digestion mixture (HNO_3: $HClO_4$ :: 9:4) as per the Jatav et al. [15] followed by volume was made up to 100 mL, filtered through Whatman 42 filter paper and reading was taken with atomic absorption spectroscopy (Agilent 240 FS-AA, USA). Percent reduction of metal concentration in any part of Rice is calculated by the following formula:

$$\% \text{ reduction} = [(X - Y) / X] \times 100$$

Where, X = Concentration of metal in respective part under control treatment (µg g^{-1}), Y = Concentration of metal in respective part under in the treatment concerned (µg g^{-1})

The diagrams are prepared using Microsoft excel.

3. RESULTS AND DISCUSSION

3.1 Effect of Biochar Application in Root Heavy Metal Concentration

Heavy metal concentration in Rice roots considerably reduced after application of graded dose of biochar. A maximum of 26.71% reduction in Pb concentration in T10 has been reported followed by 26.28% in T7 (Table 1). Treatment T9 also performed better than other treatments. Least reduction of Pb concentration over control in root was in T2 (Fig. 1). Similarly, reduction of Cd (Fig. 3) and Ni (Fig. 5) accumulation over control was also lowest in T2 than other treatments. Treatment T4 and T6 performed similarly in reducing of Cd concentration over control plot in rice roots (Table 1). Performance of T9 was 1.6% better than even T7 also (Fig. 3). In case of Ni accumulation in roots, T7 and T10 had produced similar results in reduction of Ni accumulation in rice roots over control (Fig. 5). Here, T6 performed 3.5% better than T9 (Table 1). But in all the cases, it was evident that application of modified biochar performed better than simple biochar. Zibaei et al. [16] outlined that after application of chitosan modified biochar, root and shoot accumulation of heavy metal was significantly reduced than the unmodified biochar. Chatzimichailidou et al. [17] concluded that enhancement of surface area of biochar through modification process can better perform in absorbing arsenic from aqueous solutions. Phosphorus-rich materials, as indicated by Xenidis et al. [18], have the capacity to stabilize Cd and Pb in soils by creating insoluble metal-phosphate precipitates.

3.2 Effect of Biochar Application in Reducing Heavy Metal Concentration in Stem

As compared to Cd and Ni reduction of Pb accumulation in Rice plant was more over the control plot (Table 2). This indicates that transfer of lead from soil to plant was highly affected by biochar application. Peng et al. [19] reported that iron modified biochar derived from fruit shell significantly fixed Pb in soil (about 9.9%) in comparison with raw biochar treatment. Performance of T7 was also better than other treatments in reducing Pb accumulation in rice stem (Fig. 1). Treatments T4, T5 and T8 were almost similar in this respect. Lowest reduction of Cd concentration in rice stem had been in T2 followed by T8 and T5, respectively, where biochar was applied @ 5 t ha^{-1} (Table 2). Performance of T4, T6 and T10 were also almost similar in reducing Cd accumulation in rice stem over control (Fig. 3). However, modified biochar application proved to be better than simple biochar in our study. Irshad et al. [20] reported that goethite-modified biochar proved to reduce Cd uptake in Rice. Accumulation of Ni has also reduced after biochar administration. Despite lowest reduction of Ni accumulation in stem in T2, simple biochar at higher dose of 10 t ha^{-1} has proved to reduce it by 15.3% (Fig. 5). A maximum of 21.2% reduction of Ni accumulation has been obtained under T7. Yang et al. [21] demonstrated reduction of heavy metal accumulation in Rice after application of phosphorus enriched biochar by > 40%.

3.3 Effect of Biochar Application in Reducing Heavy Metal Concentration in Grain

Transport of heavy metals from soil to plant depends on several factors. Root is considered as the first barrier of metal transport from soil to grain of Rice [22]. Application of Fe-modified biochar @ 10 t ha^{-1} has diminished the Pb accumulation by 50% over control in our study. While, P-modified biochar reduced it by 45% (Fig. 2). Yang et al. [21] reported that application of P-enriched biochar had reduced Pb concentration of grain by 49.3%. However, application of modified biochar had performed better in reducing Pb accumulation in rice grain than simple biochar treatments depicted by similar performance of T4, T5 and T8 (Table 4). Chatzimichailidou et al. [17] noted that presence of most promising functional groups in modified biochar were responsible for metal binding in soil rendering it unavailable for plants. Iron modified biochar performed better in reducing Cd concentration in rice grain as well as in husk than simple or P-modified biochar (Fig. 4). Yoneyama et al. [23] depicted that Fe transport in rice can alter Cd transport and accumulation of Cd in rice grain. A maximum of 32.8% reduction of Cd concentration in grain was recorded in T7. Ren et al. [24] indicated that phosphate modified biochar has reduced DTPA-extractable Cd in soil and its subsequent uptake in *Brassica rapa*. The maximum reduction of Ni in rice grain was in T7 followed by T10 (Fig. 6). However, performance of T4 and T8 were not much different indicating substitution of higher dose of simple biochar application with lower dose of modified biochar (Table 4). Kumarathilaka et al. [25] observed that addition of iron-modified Si-rich biochar can be an effective strategy to reduce the concentrations of heavy metal in different rice tissues.

3.4 Effect of Biochar Application in Reducing Heavy Metal Concentration in Husk

Despite a 24.8% reduction in Pb concentration in rice grain husk after application of simple biochar, Fe-modified biochar enhanced it almost twice (Table 3). Performance of T4, T5 and T8 were similar in reducing Pb concentration in rice grain husk (Fig. 2). Lowest reduction of Cd (Fig. 4) and Ni (Fig. 6) accumulation was noted in T2 followed by T3 and T5. There was no difference in performance of T9 and T10 in reducing husk Cd accumulation. While T7 followed by T10 showed highest diminution of Ni accumulation in husk over control treatment (Fig. 6). Liu et al. [26] showed that biochar incorporation can effectively reduce Cd accumulation below the safe limits in alfalfas. Ahmad et al. [27] indicated that P-loaded biochar application not only enhanced maize growth and yield but also reduced heavy metals uptake by immobilizing them in soil. Khan et al. [28] outlined that biochar application can reduce the human health risk associated with heavy metals toxicity in Rice by immobilizing them in a heavily contaminated mine soil.

Table 1. Percentage reduction of Pb, Cd and Ni concentration over control (T1) in roots of Rice with graded dose of biochar

Treatment	Abbreviations of the treatments	Pb	Cd	Ni
T2	RB_5	5.34	9.32	3.07
T3	$RB_{7.5}$	9.55	11.50	7.14
T4	RB_{10}	10.47	19.82	15.97
T5	$PAMB_5$	8.97	13.84	14.59
T6	$PAMB_{7.5}$	14.10	19.94	18.96
T7	$PAMB_{10}$	26.28	22.23	20.84
T8	$ICMB_5$	13.25	15.50	13.34
T9	$ICMB_{7.5}$	20.94	23.46	16.06
T10	$ICMB_{10}$	26.71	26.80	20.32

Table 2. Percentage reduction of Pb, Cd and Ni concentration over control (T1) in stem of Rice with graded dose of biochar

Treatment	Abbreviations of the treatments	Pb	Cd	Ni
T2	RB_5	25.22	6.04	3.54
T3	$RB_{7.5}$	30.27	11.28	6.65
T4	RB_{10}	32.83	17.37	15.29
T5	$PAMB_5$	32.97	9.74	12.36
T6	$PAMB_{7.5}$	39.06	18.79	16.85
T7	$PAMB_{10}$	44.89	20.87	21.20
T8	$ICMB_5$	33.64	8.87	11.08
T9	$ICMB_{7.5}$	40.97	15.90	13.87
T10	$ICMB_{10}$	49.61	17.00	18.24

Table 3. Percentage reduction of Pb, Cd and Ni concentration over control (T1) in husk of Rice with graded dose of biochar

Treatment	Abbreviations of the treatments	Pb	Cd	Ni
T2	RB_5	24.79	8.05	4.78
T3	$RB_{7.5}$	30.40	14.16	7.19
T4	RB_{10}	32.01	18.54	11.67
T5	$PAMB_5$	32.86	13.03	10.40
T6	$PAMB_{7.5}$	38.66	17.60	14.12
T7	$PAMB_{10}$	44.06	23.76	20.97
T8	$ICMB_5$	32.77	23.67	9.39
T9	$ICMB_{7.5}$	41.25	28.73	14.29
T10	$ICMB_{10}$	48.66	28.90	17.65

Table 4. Percentage reduction of Pb, Cd and Ni concentration over control (T1) in grain of Rice with graded dose of biochar

Treatment	Abbreviations of the treatments	Pb	Cd	Ni
T2	RB_5	25.31	15.41	17.85
T3	$RB_{7.5}$	30.95	20.51	27.31
T4	RB_{10}	32.69	25.56	33.76
T5	$PAMB_5$	33.22	21.47	24.19
T6	$PAMB_{7.5}$	39.03	28.16	37.96
T7	$PAMB_{10}$	44.97	32.84	50.32
T8	$ICMB_5$	33.80	24.34	31.29
T9	$ICMB_{7.5}$	42.70	30.02	40.65
T10	$ICMB_{10}$	50.26	31.77	48.17

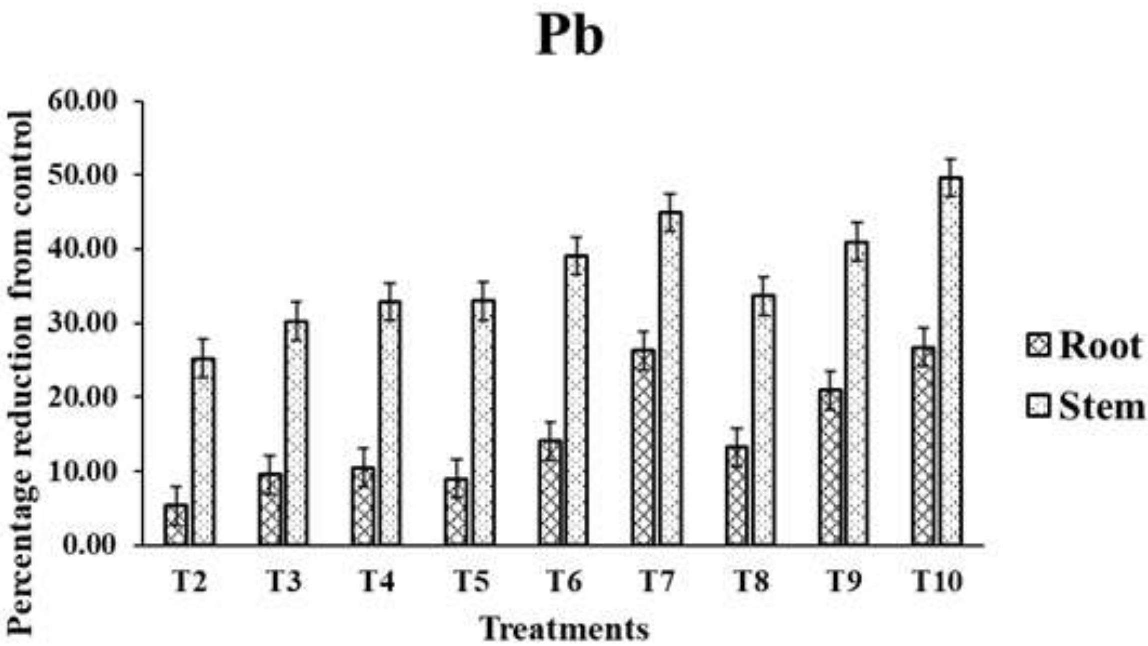

Fig. 1. Percentage reduction of Pb accumulation (mean ± SE) over control (T1) in root and stem

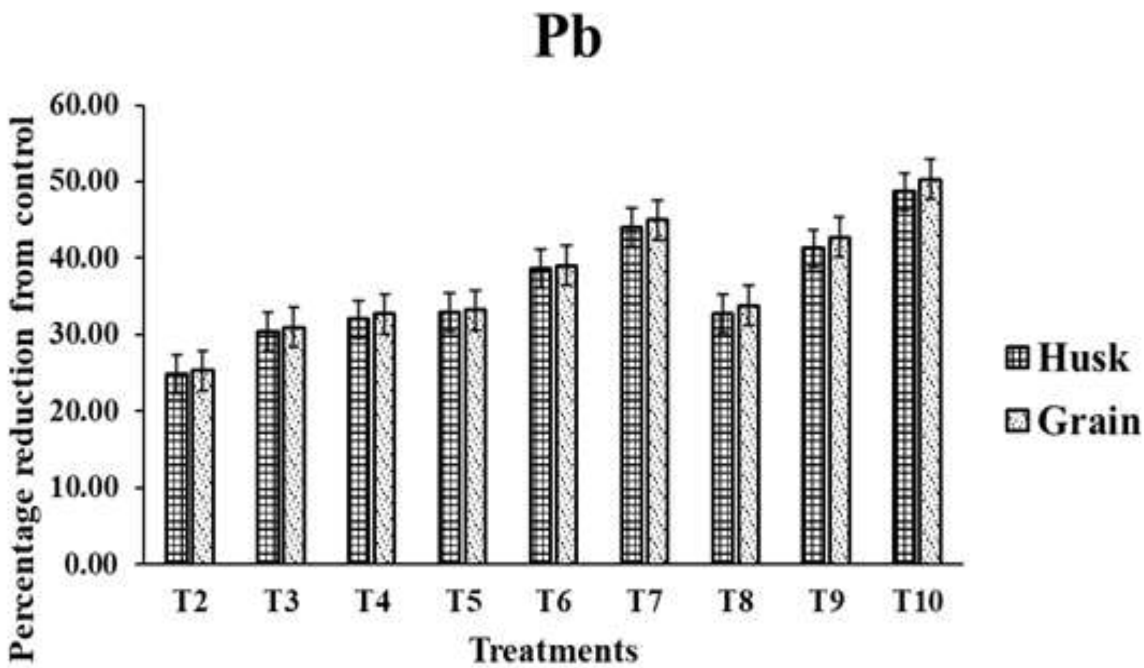

Fig. 2. Percentage reduction of Pb accumulation (mean ± SE) over control (T1) in husk and grain of Rice under varying biochar treatments in metal contaminated soil

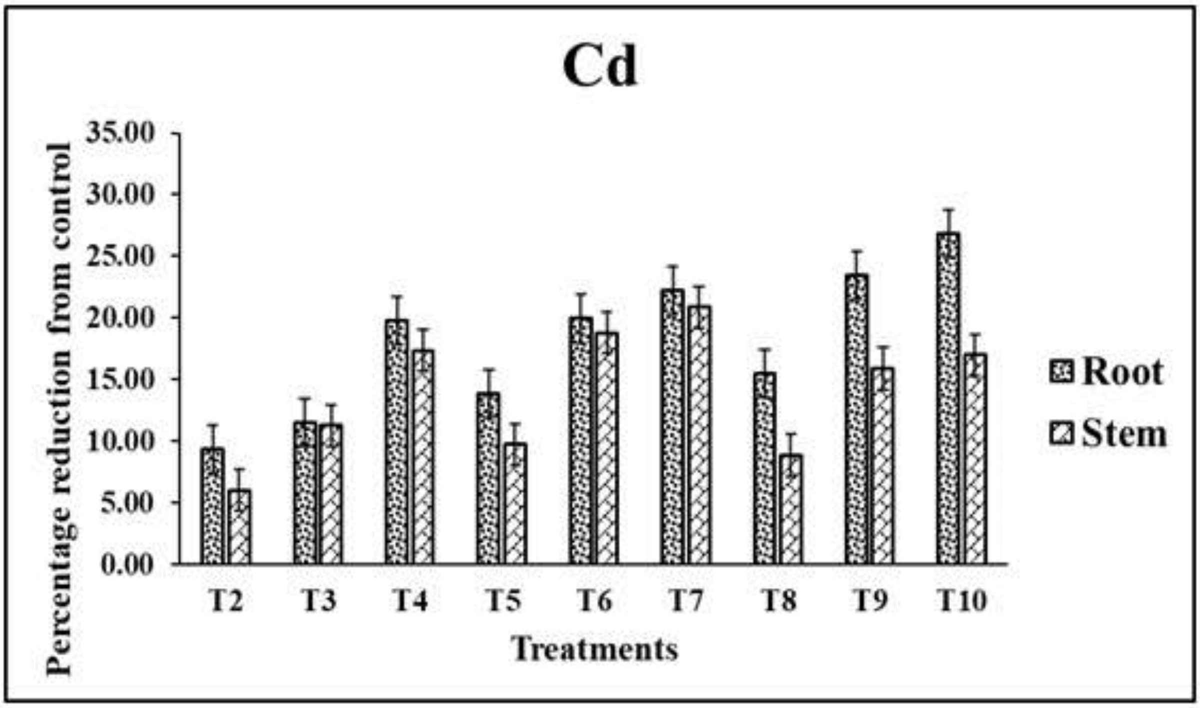

Fig. 3. Percentage reduction of Cd accumulation (mean ± SE) over control (T1) in root and stem of Rice under varying biochar treatments in metal contaminated soil

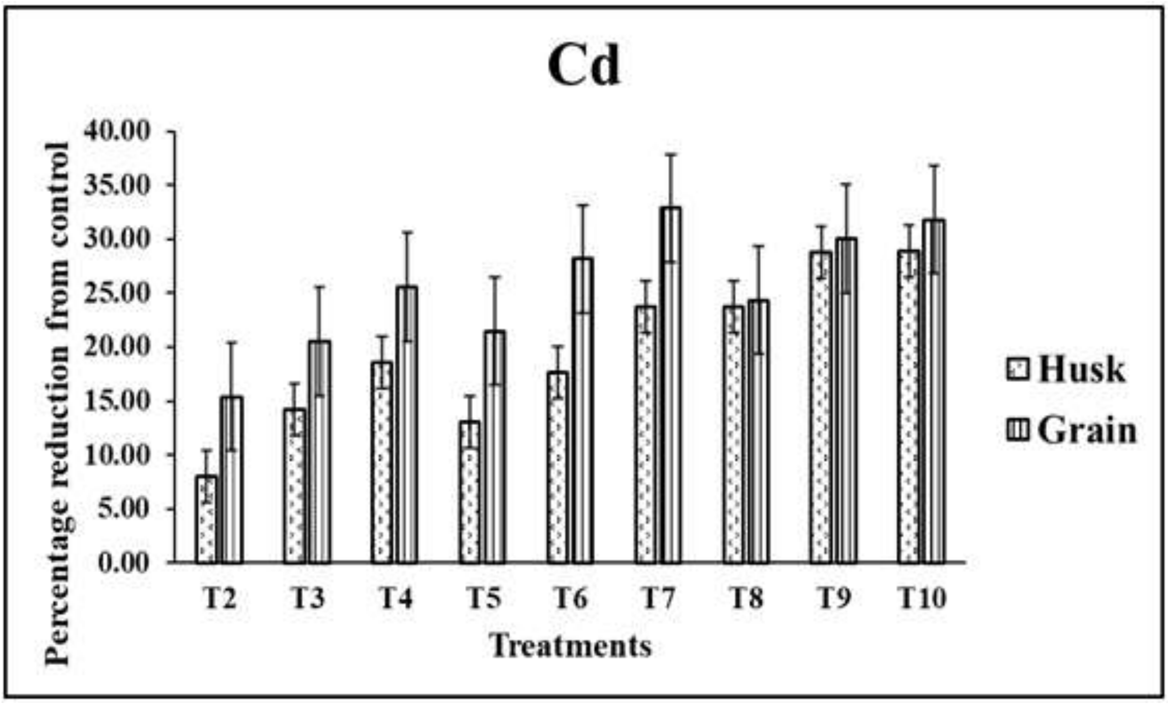

Fig. 4. Percentage reduction of Cd accumulation (mean ± SE) over control (T1) in husk and grain of Rice under varying biochar treatments in metal contaminated soil

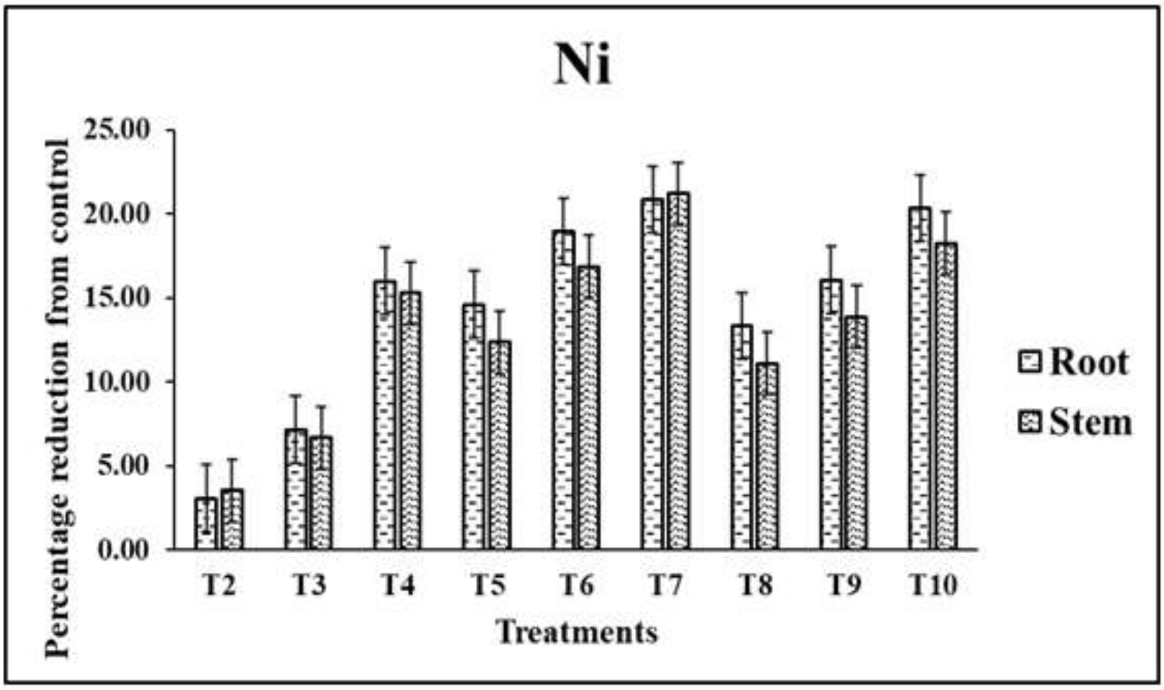

Fig. 5. Percentage reduction of Ni accumulation (mean ± SE) over control (T1) in root and stem of Rice under varying biochar treatments in metal contaminated soil

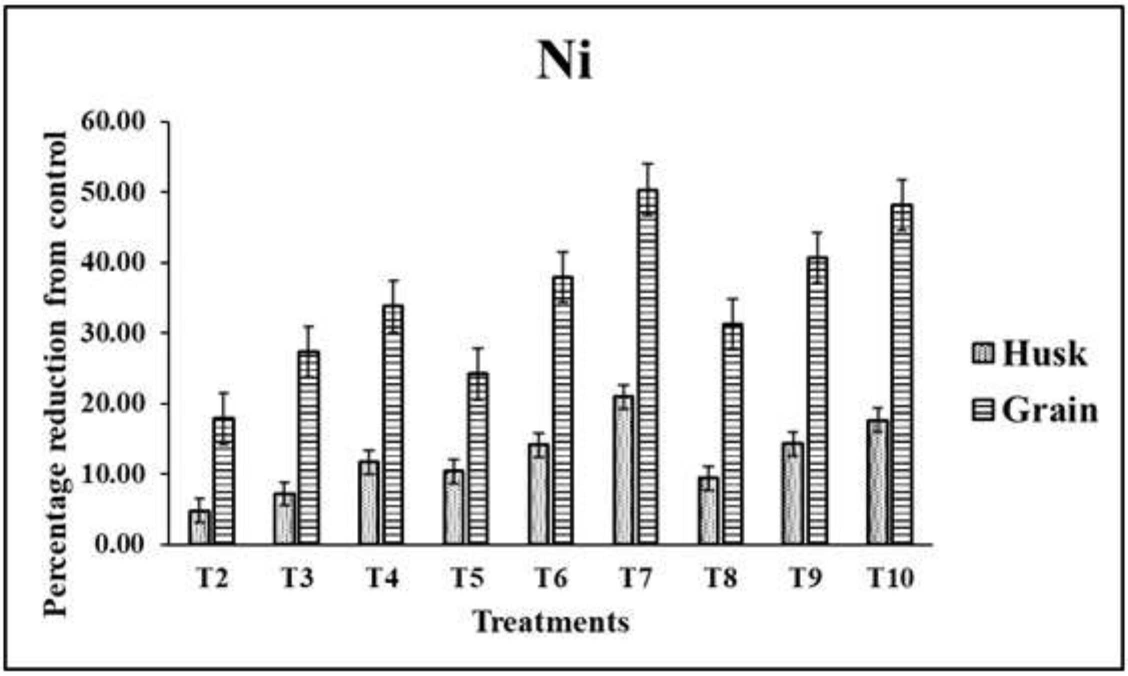

Fig. 6. Percentage reduction of Ni accumulation (mean ± SE) over control (T1) in husk and grain of Rice under varying biochar treatments in metal contaminated soil

4. CONCLUSION

Our study reveals that biochar application in a metal contaminated soil can effectively reduce metal accumulation in different parts of Rice (root, stem, husk and grain). However, metal accumulation in grain, husk and stem can vary for different metals; might be due to their different behavior in plant body. Modification of biochar was helpful not only in reducing metal accumulation but also cutting off application dose as compared to simple biochar. Thus, *Parthenium* biochar application can be a promising strategy to mitigate metal toxicity in contaminated soil besides reducing weed load of agricultural fields.

ACKNOWLEDGEMENT

The authors acknowledge Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University and IRRI-SARC Varanasi for providing funds and research facilities and help me to prepare biochar.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Crisostomo CAB, Lima FA, Dias RM, Cardoso VL, De Resende MM. Joint assessment of bioreduction of chromium (VI) and of removals of both total chromium and total organic carbon (TOC) in sequential hybrid bioreactors. Water, Air, & Soil Pollution. 2016;227:1-14.
2. Wu Z, Zhao D. Ordered mesoporous materials as adsorbents. Chemical Communications. 2011;47(12):3332-3338.
3. Beiyuan J, Awad YM, Beckers F, Wang J, Tsang DC, Ok YS, Wang SL, Wang H, Rinklebe J. (Im) mobilization and speciation of lead under dynamic redox conditions in a contaminated soil amended with pine sawdust biochar. Environment International. 2020;135:105376.
4. Niu H, Zhang D, Zhang S, Zhang X, Meng Z, Cai Y. Humic acid coated Fe3O4 magnetic nanoparticles as highly efficient Fenton-like catalyst for complete mineralization of sulfathiazole. Journal of Hazardous Materials. 2011;190(1-3):559-565.
5. Singaraj SG, Mahanty B, Balachandran D, Padmaprabha A. Adsorption and desorption of chromium with humic acid coated iron oxide nanoparticles.

Environmental Science and Pollution Research. 2019;26:30044-30054.

6. Bian P, Zhang J, Zhang C, Huang H, Rong Q, Wu H, Li X, Xu M, Liu Y, Ren S. Effects of silk-worm excrement biochar combined with different iron-based materials on the speciation of cadmium and lead in soil. Applied Sciences. 2018;8(10): 1999.
7. Zhang H, Shao J, Zhang S, Zhang X, Chen H. Effect of phosphorus-modified biochars on immobilization of Cu (II), Cd (II), and As (V) in paddy soil. Journal of Hazardous Materials. 2020;390:121349.
8. Yang X, Pan H, Shaheen SM, Wang H, Rinklebe J. Immobilization of cadmium and lead using phosphorus-rich animal-derived and iron-modified plant-derived biochars under dynamic redox conditions in a paddy soil. Environment International. 2021;156: 106628.
9. Li J, Wang SL, Zhang J, Zheng L, Chen D, Wu Z, Shaheen SM, Rinklebe J, Ok YS, Wang H, Wu W. Coconut-fiber biochar reduced the bioavailability of lead but increased its translocation rate in rice plants: Elucidation of immobilization mechanisms and significance of iron plaque barrier on roots using spectroscopic techniques. Journal of Hazardous Materials. 2020;389:122117.
10. Jatav SS, Singh SK. Evaluation of different methods of Zinc application on growth and yield of hybrid rice (*Oryza sativa* L.) in inceptisol of Varanasi. Journal of Pharmacognosy and Phytochemistry. 2018;7(4):1739-1744.
11. Jatav SS, Singh SK, Singh Y. Effect of Zinc application methods on yield and zinc bio-fortification in Hybrid Rice (*Oryza sativa* L.). Journal of the Indian Society of Soil Science. 2019;67(4):468-471.
12. Venkatesh G, Venkateswarlu B, Gopinath KA, Srinivasrao C, Korwar GR, Reddy BS, Prasad JNVS, Grover M, Raju BMK, Sasikala C, Venkanna K. Biochar production technology for conversion of cotton stalk bioresidue into biochar and its characterization for soil amendment qualities. Indian Journal of Dryland Agricultural Research and Development. 2013;28(1):48-57.
13. Zheng Z, Duan X. Mitigating the Health Effects of Aqueous Cr (VI) with Iron-Modified Biochar. International Journal of Environmental Research and Public Health. 2022;19(3):1481.
14. Wu Y, Cha L, Fan Y, Fang P, Ming Z, Sha H. Activated biochar prepared by pomelo peel using H3PO4 for the adsorption of hexavalent chromium: performance and mechanism. Water, Air, & Soil Pollution. 2017;228(10):1-13.
15. Jatav SS, Singh SK, Parihar M, Alsuhaibani AM, Gaber A, Hossain A. Application of sewage sludge in a rice (Oryza sativa L.)-wheat (*Triticum aestivum* L.) system influences the growth, yield, quality and heavy metals accumulation of rice and wheat in the Northern Gangetic Alluvial Plain. Life. 2022;12(4):484.
16. Zibaei Z, Ghasemi-Fasaei R, Ronaghi A, Zarei M, Zeinali S. Effective immobilisation of chromium in a polluted calcareous soil using modified biochar and bacterial inoculation. Chemistry and Ecology. 2020; 36(9):827-838.
17. Chatzimichailidou S, Xanthopoulou M, Tolkou AK, Katsoyiannis IA. Biochar Derived from Rice by-Products for Arsenic and Chromium Removal by Adsorption: A Review. Journal of Composites Science. 2023;7(2):59.
18. Xenidis A, Stouraiti C, Papassiopi N. Stabilization of Pb and As in soils by applying combined treatment with phosphates and ferrous iron. Journal of Hazardous Materials. 2010;177(1-3):929-937.
19. Peng D, Wu B, Tan H, Hou S, Liu M, Tang H, Yu J, Xu H. Effect of multiple iron-based nanoparticles on availability of lead and iron, and micro-ecology in lead contaminated soil. Chemosphere. 2019; 228:44-53.
20. Irshad MK, Noman A, Wang Y, Yin Y, Chen C, Shang J. Goethite modified biochar simultaneously mitigates the arsenic and cadmium accumulation in paddy rice (*Oryza sativa*) L. Environmental Research. 2022;206:112238.
21. Yang X, Wen E, Ge C, El-Naggar A, Yu H, Wang S, Kwon EE, Song H, Shaheen SM, Wang H, Rinklebe J. Iron-modified phosphorus-and silicon-based biochars exhibited various influences on arsenic, cadmium, and lead accumulation in rice and enzyme activities in a paddy soil. Journal of Hazardous Materials. 2023;443:130203.
22. Qi X, Tam NFY, Li WC, Ye Z. The role of root apoplastic barriers in cadmium translocation and accumulation in cultivars of rice (*Oryza sativa* L.) with

different Cd-accumulating characteristics. Environmental Pollution. 2020;264: 114736.

23. Yoneyama T, Ishikawa S, Fujimaki S. Route and regulation of zinc, cadmium, and iron transport in rice plants (*Oryza sativa* L.) during vegetative growth and grain filling: metal transporters, metal speciation, grain Cd reduction and Zn and Fe biofortification. International Journal of Molecular Sciences. 2015;16(8):19111-19129.
24. Ren J, Zhao Z, Ali A, Guan W, Xiao R, Wang JJ, Ma S, Guo D, Zhou B, Zhang Z, Li R. Characterization of phosphorus engineered biochar and its impact on immobilization of Cd and Pb from smelting contaminated soils. Journal of Soils and Sediments. 2020;20:3041-3052.
25. Kumarathilaka P, Bundschuh J, Seneweera S, Marchuk A, Ok YS. Iron modification to silicon-rich biochar and alternative water management to decrease arsenic accumulation in rice (*Oryza sativa* L.). Environmental Pollution. 2021;286: 117661.
26. Liu M, Zhao Z, Chen L, Wang L, Ji L, Xiao Y. Influences of arbuscular mycorrhizae, phosphorus fertiliser and biochar on alfalfa growth, nutrient status and cadmium uptake. Ecotoxicology and Environmental Safety. 2020;196: 110537.
27. Ahmad M, Usman AR, Al-Faraj AS, Ahmad M, Sallam A, Al-Wabel MI. Phosphorus-loaded biochar changes soil heavy metals availability and uptake potential of maize (*Zea mays* L.) plants. Chemosphere. 2018;194:327-339.
28. Khan AZ, Khan S, Khan MA, Alam M, Ayaz T. Biochar reduced the uptake of toxic heavy metals and their associated health risk via rice (*Oryza sativa* L.) grown in Cr-Mn mine contaminated soils. Environmental Technology & Innovation. 2020;17:100590.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/110060