BCSIR

Available online at www.banglajol.info/index.php/BJSIR

Bangladesh J. Sci. Ind. Res. **59(3)**, 149-158, 2024

BANGLADESH JOURNAL OF SCIENTIFIC AND INDUSTRIAL RESEARCH

ISSN. 0304-9809

Effect of organic amendments on morphological, physiological and root characteristics of red amaranth (*Amaranthus gangeticus*) grown on Cd contaminated saline soils

M. Z. Hossain[1]*, M. A. Islam[2], M. A. Islam[3] and K. Q. Kibria[1]

[1]*Soil, Water and Environment Discipline, Khulna University Khulna 9208, Bangladesh*
[2]*Environmental Science Discipline, Khulna University, Khulna 9208, Bangladesh*
[3]*Forestry and Wood Technology Discipline, Khulna University Khulna 9208, Bangladesh*

ARTICLE INFO

Received: 23 May 2024

Revised: 07 July 2024

Accepted: 25 July 2024

DOI: https://doi.org/10.3329/bjsir.v59i3.73320

Abstract

A pot experiment was conducted to investigate the effects of six different types of organic amendments (OAs) applied to Cd contaminated saline soils with varying rates on red amaranth (*Amaranthus gangeticus*) growth. Two levels of salinity (4 dSm^{-1} and 8 dSm^{-1}) were developed in the experimental soil that was previously contaminated with 5 mg kg^{-1} Cd. In slightly (4 dSm^{-1}) saline soil, 1% vermicompost (VC) produced 18.77 times higher fresh weight as compared to the control while 32.37 times higher found with 2% cowdung (CD). VC produced the maximum fresh weight in moderately saline soil (8 dSm^{-1}). Other morphological traits were improved with the addition of OAs. VC increased the plant's relative water content, chlorophyll-a and chlorophyll-b. Root characteristics were improved irrespective of the OA rates and salinity. The efficiency of OAs followed the order VC=CD>compost>WT>SD=RH. Therefore, OA could be a promising way of alleviating the saline soil contaminated with Cd.

Keywords: Cd; Salinity; Red amaranth; Morphology; Physiology; Root

Introduction

Heavy metal contamination of soils has gained global attention due to their hazardous impacts of on soil quality, crop yield and quality (Seleiman and Kheir, 2018), and food safety and human health (Antoniadis *et al*. 2017; Bashir *et al*. 2020). Among the heavy metals, cadmium (Cd) is one of the most toxic and mobile contaminants in surface soils that may arise from anthropogenic sources (Okrikata and Nwosu, 2023; Patil *et al*. 2024). The toxic effects of Cd on plants are well-documented (Azhar *et al*. 2019; Rehman *et al*. 2020). These effects ultimately result in cell death and pose a serious threat to agricultural productivity and food safety (El Rasafi *et al*. 2020; Yildirim *et al*. 2023). The impact of Cd on plants is a matter of great concern due to its potential threat to human health primarily through dietary intake via the food chain (Ma *et al*. 2021; Islam *et al*. 2023; Ghasemi-Soloklui *et al*. 2023). Therefore, it is essential to explore and implement effective remediation strategies to mitigate Cd contamination and its adverse effects on the environment and human health (Ahmad *et al*. 2023; Xing *et al*. 2023).

High levels of salinity in soil is another environmental stress that has rapidly increased worldwide. Climate change, limited rainfall, human induced causes are mainly responsible for increasing salinity in soil. These factors lead to diminish agricultural yields on a global scale and creates a great challenge to global food security (Yupeng *et al*. 2018). Salt stress in soil has been shown to reduce plant growth, biomass, and mineral nutrient uptake (Loudari *et al*. 2022).

*Corresponding author's e-mail: zaber@swe.ku.ac.bd

Soil salinity has an important impact on elevated levels of bioavailable Cd (Lutts and Lefèvre, 2015). Because salt-based ions can form complexes with Cd and increase Cd mobility (Abbas *et al*. 2018; Parvin *et al*. 2022; Wang *et al*. 2023). Moreover, cations present in salts can compete with Cd for soil adsorption sites. This phenomenon allows the desorption of Cd from the exchange complex which increases Cd mobility in soil. In addition, the ionic strength and pH of the soil solution are altered by soil salinity which affect Cd bioavailability (Raiesi *et al*. 2018).

The stress that salinity and Cd imposed in soil can be reduced with a focused remediation program. According to research, there are several methods available today for improving the physical, chemical, and biological characteristics of soil (Abbas *et al*. 2018; Loudari *et al*. 2022; Wang *et al*. 2023). The use of organic amendments (OA) in soil is a cost effective strategy for reclaiming saline soils contaminated with Cd and improving crop productivity (Alcívar *et al*. 2018; Gangwar *et al*. 2020; Leogrande and Vitti, 2019). Likewise, OA can function as a biosorbent to facilitate the sorption of Cd from contaminated soils (Anastopoulos *et al*. 2013).

Red amaranth (*Amaranthus gangeticus*) is a popular leafy vegetable in Bangladesh because of its low price, quick-growing character, and higher yield potential (Miah *et al*. 2013). The leaves and stems of red amaranth are rich in protein, fat, Ca, K, P, Na, Fe, ascorbic acid, niacin, and riboflavin (Prakash and Zaidi, 2000). However, red amaranth plant may intake excess amount of heavy metals which can pose threat to the people upon consumption (Adewuyi *et al*. 2010; Guo *et al*. 2020).

The utilization of OA can alleviate the deleterious effects of salinity and Cd stress which leads the improved growth of red amaranth plants. This could reduce threats to food security and enhance the health of the soil. This study aims to investigate how different OAs affect the morphological, physiological, and root characteristics of red amaranth plants growing in salinity and under cadmium stress.

Materials and methods

Soil and amendments

Before the experiment, surface soil sample (0-30 cm) was collected from the agricultural field of Khulna university campus (22.8022° N, 89.5339° E). The soil sample was prepared by air drying, grinding, sieving through a 2 mm mesh size sieve, mixing and was homogenized before filling the pots. Approximately 0.5 kg of the prepared soil was preserved for the basic physico-chemical characteristics of the studied soil. Cadmium chloride salt ($CdCl_2.2H_2O$) was added to maintain a contamination level of 5 mg Cd kg^{-1} soil. In this polluted soil, two salinity levels e.g. slightly saline (4 dSm^{-1}) and moderately saline (8 dSm^{-1}) were developed by adding NaCl, $CaCl_2$ and $MgCl_2$ (1:1:1). For obtaining the desired Cd and salt levels, soil was spread over a polythene sheet, field capacity water was maintained and left the soil for one month. After one month, cowdung (CD), vermicompost (VC), waste tea leaves (WT), saw dust (SD), rice hull (RH) and ACI commercial organic fertilizer (compost) were added to the Cd laden saline soil with 1% and 2% rates. A control treatment was also kept where no organic amendment was added. The general properties of soil and organic amendments used in this experiment are described in Table I.

Table I. General properties of soil and organic amendments

Properties	Unit	Soil	CD	VC	WT	SD	RH	Compost
Sand	%	14.25	-	-	-	-	-	-
Silt	%	50.57	-	-	-	-	-	-
Clay	%	35.18	-	-	-	-	-	-
Texture	-	Silty Clay Loam	-	-	-	-	-	-
pH		7.86	7.31	7.08	6.83	7.37	7.46	8.02
EC	dSm^{-1}	1.90	3.03	0.49	0.78	0.12	0.09	1.92
CEC	Cmolc/kg	48	219	68	310	171	226	45
OC	%	1.28	24.57	14.82	34.13	27.01	29.32	5.07
Total N	%	0.04	1.48	0.90	1.08	0.97	0.91	0.48
Total P	%	0.03	0.21	0.30	0.21	0.04	0.05	0.19
Total K	%	0.05	0.10	0.09	0.26	0.79	0.68	0.10
Total Cd	$mgkg^{-1}$	2.60	0.32	0.05	0.05	0.05	0.05	0.49
Bioavailable Cd	$mgkg^{-1}$	0.50	0.001	0.001	0.001	0.001	0.001	0.001

Pot experiment

The experiment was laid out following a completely randomized design with three replications. Ten red amaranth seeds were sown into each pot (16 cm diameter and 18 cm height) containing five kg of organic amended and control soil. After seed germination, 5 seedlings in each pot were maintained. Irrigation was done according to the plant requirement of water and moisture content present in the soil using tap water. After 2 months, the mature plants were harvested and further plant and soil analyses were performed.

Plant analysis

After collecting the leaves from the top, the relative water content (RWC) was calculated according to the following formula:

$$RWC = \frac{F\ W - D\ W}{T\ W - D\ W}\ 100$$

Where, FW = fresh weight of leaves, TW = turgid weight of leaves, DW = dry weight of leaves

To avoid moisture loss from the leaves, the FW was taken as soon as possible after leaf collection. For obtaining the TW, the leaves were kept in a container filled with distilled water for 12 hours until the leaves reached a constant weight which was considered 100% hydration. The TW was determined immediately after removing the leaves from the water. The DW was taken after oven drying fully turgid leaves for 48 hours at 70ºC (Turner, 1986). The chlorophyll-a (chl-a) and chlorophyll-b (chl-b) content of the plant was determined by Arnon's (1949) technique. Morphological data for shoot and root were collected using standard methods. Root length was measured by the grid method (Delory *et al*. 2017).

Soil analysis

After the crop harvest, soil samples were taken from each pot, and soil pH and EC were measured. Soil pH was determined by taking 20 g air dried soil where soil to distilled water ratio was 1(w):2.5(v) using a glass membrane electrode pH meter (Hanna, HI110, USA). (Li *et al*. 2005). For the determination of soil EC, 10 g air dried soil was taken with soil to distilled water ratio was 1(w):5(v) was determined using a glass membrane electrode EC meter (Hanna, HI2315, USA) (Hardie and Richard, 2012). Bioavailable Cd contents from each potted soil were estimated using the $CaCl_2$ extractable technique described by Houben *et al*. (2013).

Statistical analysis

Collected data were analyzed using the statistical package "Statistix 10.0". One-way analysis of variance (ANOVA) technique was used to test the significance of the data. Microsoft Excel was used for the calculation of standard errors of means and graphical presentation. The differences among treatment means were assessed using the Tukey HSD test at 5% probability.

Results and discussion

Morphological characteristics

Fresh weight (g/pot) of red amaranth improved after the addition of organic amendments in saline soil contaminated with Cd (Fig. 1a). In slightly saline soil (4 dSm^{-1}), application of 1% VC, enhance the fresh weight by more than 18 times as compared to control. This was further enhanced with compost (11 times) followed by CD (8 times) and RH (6 times). However, the increment in fresh weight after the application of WT and SD did not vary significantly. There was a dramatic change in the fresh weight of red amaranth after the application OA with 2%. Here, CD showed the highest increase followed by VC and compost. In moderately saline soil (8 dSm^{-1}), VC increase the red amaranth's fresh weight applied either 1% or 2% rate. But the addition of VC at higher rate was not significant as compared to the low rate of application. CD also showed greater increase in the fresh weight applied to high saline soil. However, other types of OA had relatively less influence on the change in the fresh weight of red amaranth under this condition. Dry weight of red amaranth plant showed variations with varying the types and rates of OA in the experiment (Fig. 1b). In slightly saline soil, lower rate (1%) of VC influenced the dry weight more than that of the other types of OAs. On the other hand, highest dry weight was obtained with CD after rising the rate to 2%. Conversely, VC followed by CD, was found effective for increasing the dry weight applied to moderately saline soil invariably the rate used. Height of the red amaranth plant was also changed as a consequence of the application of OA (Fig. 1c). Application of VC at low rates showed the highest plant height (20.07cm) which did not differ from the height obtained with the application of compost (16.93cm) under low soil salinity. CD produced a height of 13.34 cm under this condition and was insignificantly varied with the height of plant obtained with compost. In this soil, the change in plant height was found only for CD with higher rate (2%) of application. However, in moderately saline soil, CD and VC behave similarly with 1% application rate but the behavior of CD and VC changed when applied with 2% rate. Change in leaf area of red amaranth plant after OA application was also studied under Cd contaminated saline soils (Figure 1d). In slightly saline condition, leaf area was found highest with the application of 1% VC which was 61.43 cm^2. Compost and CD produced a leaf area of 44.10 cm^2 and 30.85 cm^2 respec-

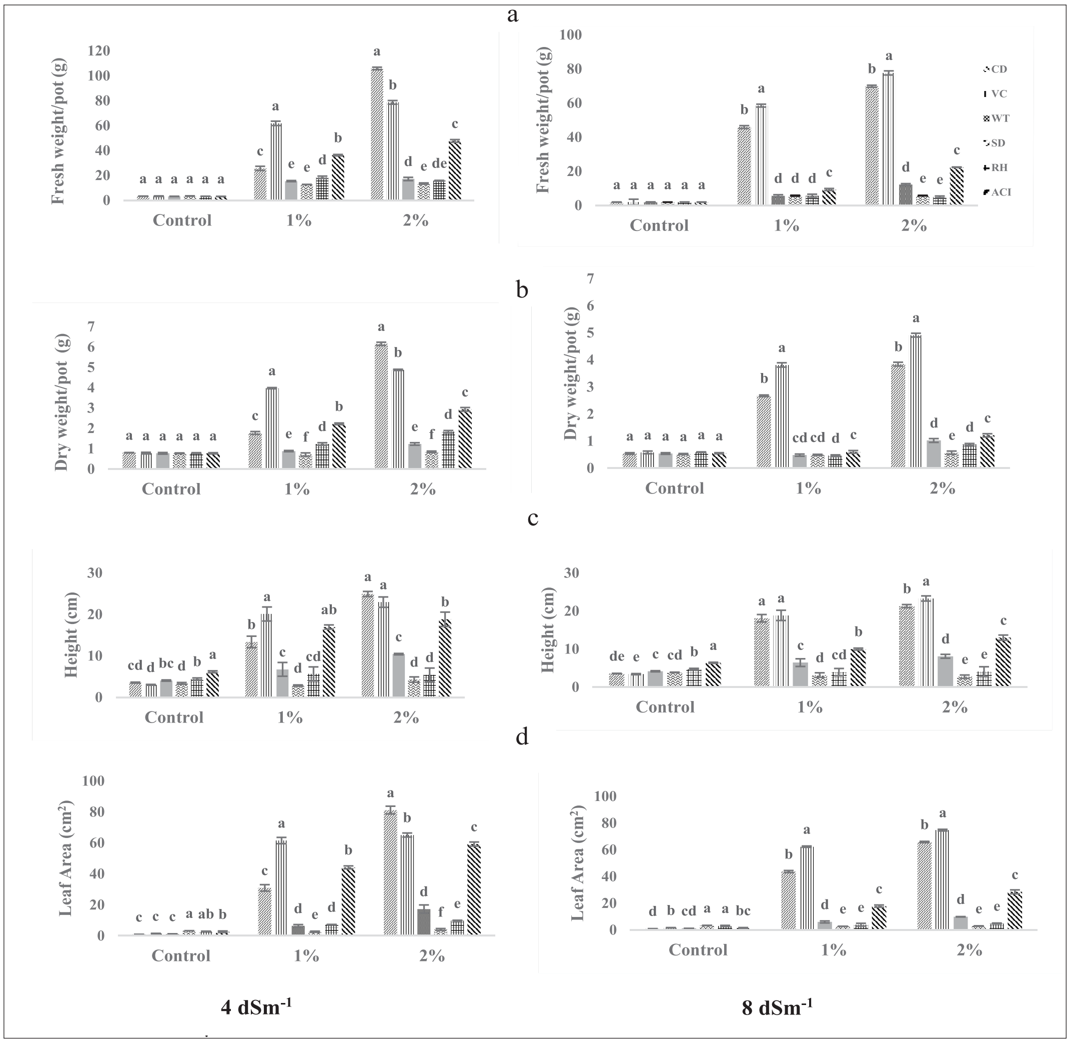

Fig. 1. Effects of organic amendments on (a) fresh weight (g/pot) (b) dry weight (g/pot) (c) height (cm) and (d) leaf area (cm2) of red amaranth plant grown on Cd contaminated saline soils. Bars with the same letter are not significantly different at p<0.05 level.

tively. Whereas, the response of other OA was found lower in terms of leaf area. The increased rate of OA's further increased the leaf area of red amaranth but noticeable increase was obtained with CD, VC and compost. In moderately saline soil, OAs behave similarly with the application of either 1% or 2% rate. The order for the increase leaf area followed VC>CD>ACI>WT>SD=RH.

After the treatment of Cd contaminated saline soil with various OAs, the improvement in red amaranth biomass might be attributed to the nutritious significance of OA that improves the soil productivity. Other possible reason might be considered because of their potential to boost the organic matter mineralization and enhanced crop yield and growth (Shinomol *et al*. 2016; Abbas *et al*. 2020; Ali *et al*. 2020). VC played an important role for increasing plant growth due to its highly porous nature and high nutrients and minerals contents. Such porous structure enhanced physiochemical properties of soil that have a great impact on the movement of nutrients, water and air through soil. It stimulates plant growth and have a significant effect on the absorption efficiency (Blouin *et al*. 2019). Our study revealed that the cation exchange capacity of CD (219 Cmolc/kg) and VC (68 Cmolc/kg) create sufficient voids contributed to adsorption of cadmium from soil. Similar to findings of Adamipour *et al*. (2019) who reported application of vermicompost increased the morpho-physiological indices and mineral nutrient uptake in the plants and could increase the plant yield by alleviating the harmful effects of salinity.

Physiological Characteristics

The effects of various OA's on the relative water content (RWC) in the leaves of red amaranth plant grown under Cd contaminated saline soil is described in Fig. 2a. In slightly saline soil, application of 1% VC, WT, RH and compost produced RWC with insignificant variations. Lower RWC were obtained with the CD and SD. However, with the increased rate of OA, CD increased the RWC in the leaf of the plant. In moderately saline soil, lower RWC were found for WT, SD and RH applied at 1% rate. But when the rate of application increased in this soil, WT regained the RWC in the leaf of the plant as compared to SD and RH. The result indicated that SD and RH were ineffective for the enhancement of RWC in all cases in the study. The results revealed that addition of various kinds of OA can increase chlorophyll-a (chl-a) content in the leaves of red amaranth plant (Fig. 2b). In slightly saline soil (4 dSm^{-1}), the greatest increase in chl-a in the leaf was recorded by approximately 2.5 times when added the VC either at 1% or 2% over control. Likewise, incorporation of CD, WT, SD, RH and ACI also increased the chl-a content but no significant variations were observed when applied at both rates. The scenario was quite different in moderately saline soil (8 dSm^{-1}) in which the chl-a content doubled with the application of 1% WT. However, VC and ACI acted quite similar in this condition. CD, VC, WT and ACI raised the chl-a content invariably with increased rate but the efficiency was found low. Chlorophyll-b (Chl-b) content in the leaf of red amaranth plant showed variations with the added OA in saline soils contaminated with Cd (Fig. 2c). When 1% OA was added to low saline soil, chl-b content increased over control but the variations were insignificant irrespective of the OA. But the behavior of CD, VC, WT and RH with 2% application rate were similar in soil with low salinity. On the contrary, SD and ACI produced low amount of chl-b in the leaf at this rate of

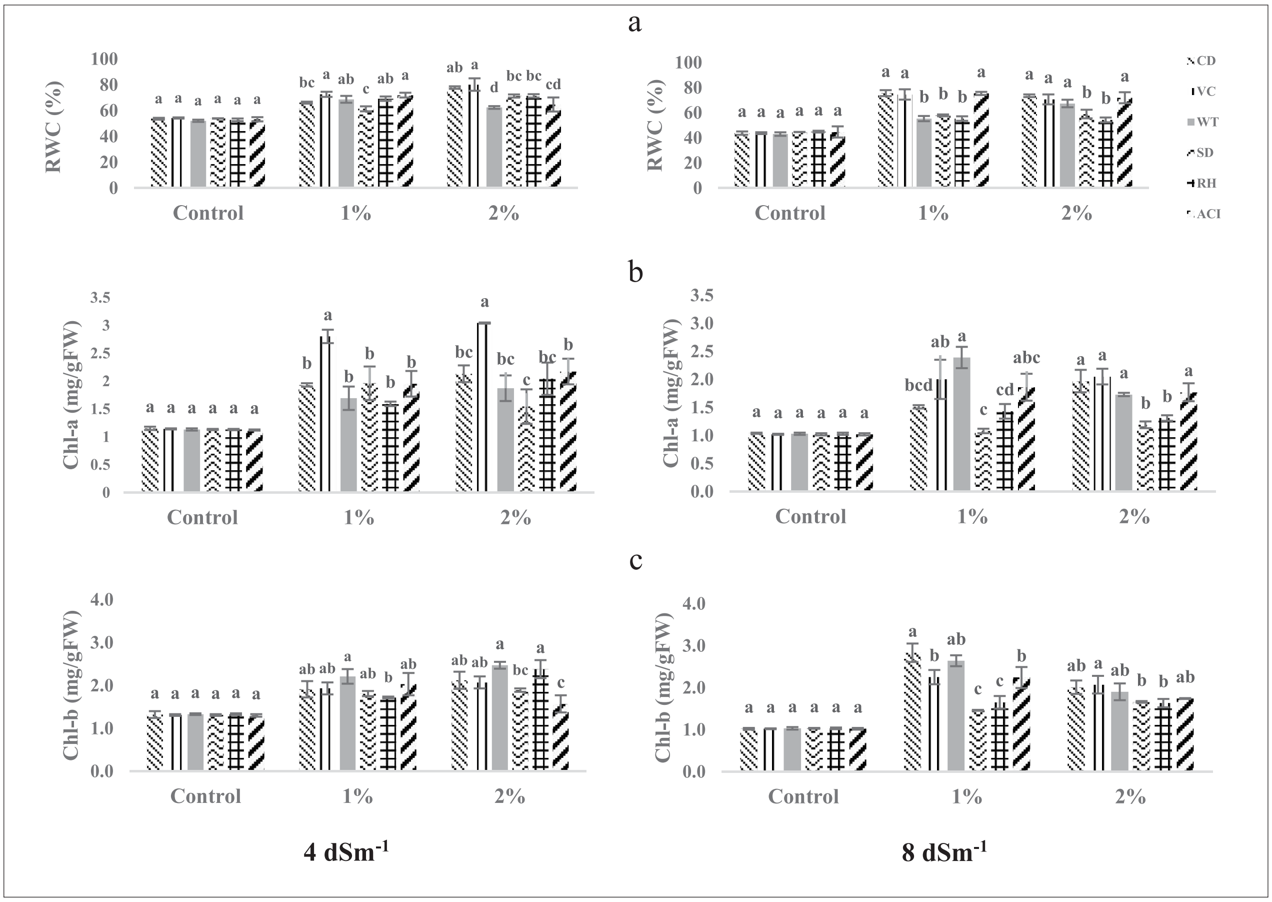

Fig. 2. Effects of organic amendments on (a) RWC (%) (b) Chl-a (mg/g FW) and (c) Chl-b (mg/g FW) of red amaranth plant grown on Cd contaminated saline soils. Bars with the same letter are not significantly different at $p<0.05$ level.

application. In moderately saline soil, CD showed the highest chl-b (approximately 3 times) followed by WT (approximately 2.5 times) over control. However, with 2% application rate, OA showed increased chl-b content but the values did not vary among themselves.

The addition of OA (CD, VC, WT, SD, RH and compost) effectively minimized the Cd mobility in contaminated soil which might be possible due to the presence of organic substance and functional groups that have great contribution to stabilize Cd through complexation. Furthermore, influence of soil salinity was also reduced with the application of OA. OA increase the porosity of saline soil through which salts may exclude from the soil upon irrigation. The reduced Cd entry to plant cells make a barrier for lipid peroxidation in the cell. In addition, oxidative stress is reduced in the absence of salinity. This might be the cause of increasing chl-a and chl-b content in the leaves. Shahid *et al*. (2019) found that organic amendments alleviated Cd toxicity in terms of Cd content, lipid peroxidation to bean plants.

Root characteristics

Root fresh weight (RFW) as affected by the addition of various OA on Cd contaminated saline soils depicted in Fig. 3a. The highest RFW was recorded with the application of 1% VC which was 10.11 g/pot in slightly saline soil. This is followed by compost (4.2 g/pot), CD (3.01 g/pot), RH

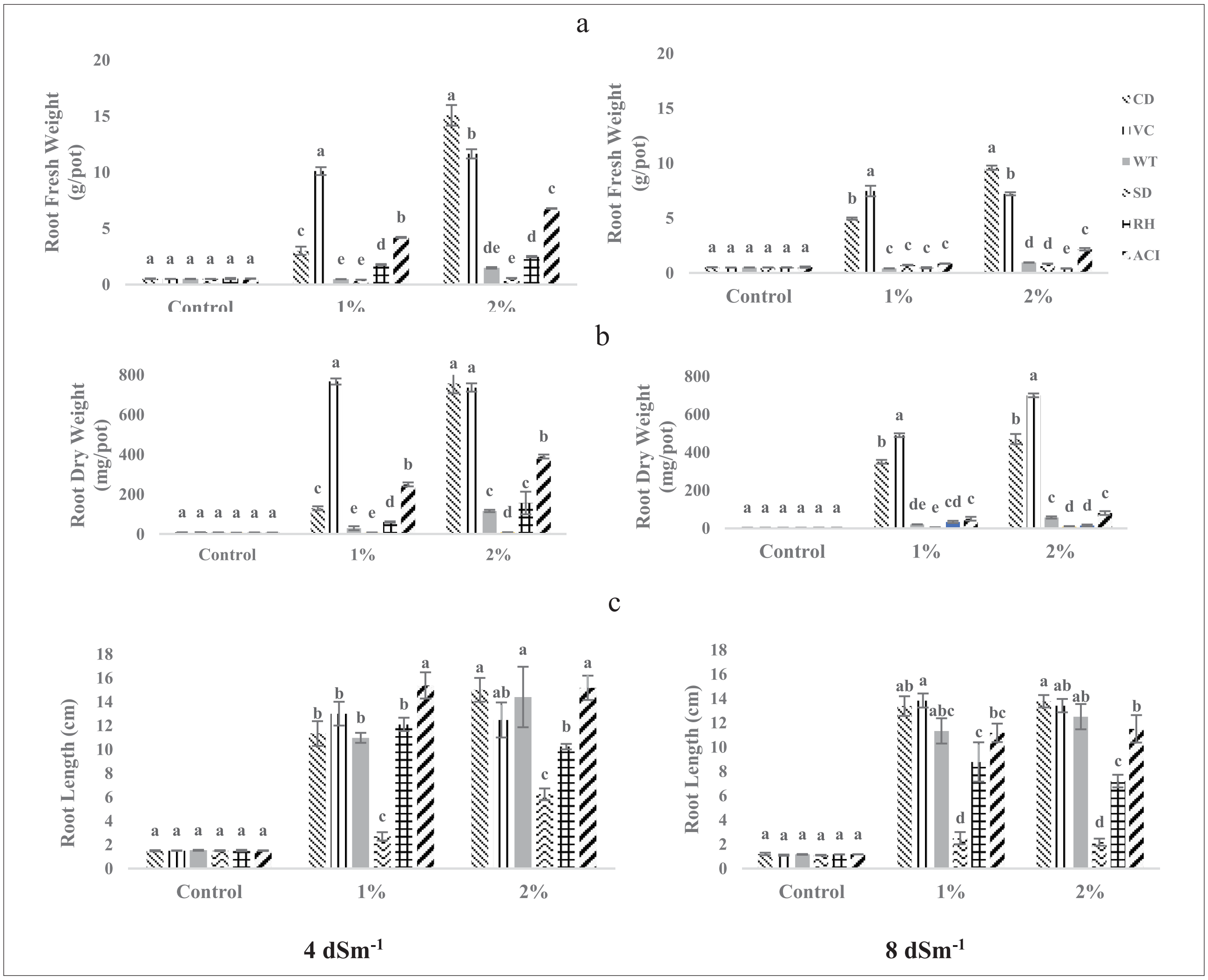

Fig. 3. Effects of organic amendments on (a) Root fresh weight (g/pot) (b) Root dry weight (mg/pot) and (c) Root length (cm) of red amaranth plant grown on Cd contaminated saline soils. Bars with the same letter are not significantly different at $p<0.05$ level

(1.78 g/pot), WT (0.48 g/pot) and SD (0.43 g/pot). After the application of 2% rate, the highest RFW was found with CD which was 15.08 g/pot. RFW was found 11.65 g/pot with VC and 6.78 g/pot with ACI. In moderately saline soil, maximum RFW was found with VC at 1% application rate which was 7.47 g/pot followed by CD which was 4.96 g/pot. With 2% application rate, CD yielded the highest RFW which was 9.60 g/pot and VC produced 7.22 g/pot. Root dry weight (RDW) of red amaranth plant was also affected by the addition of different OA (Fig. 3b). In slightly saline soil, 1% VC showed the highest RDW which was 766.67 mg/pot. Next to VC, compost and CD yielded RDW of 250 mg/pot and 130 mg/pot respectively. However, 2% application rate increase twice the RDW with CD and VC. Root length (RL) was affected by the application of various OA in Cd contaminated saline soils (Fig. 3c). In slightly saline soil, application of 1% ACI exhibited the highest RL which accounted more than 10 times higher than that of control. Increased RL were also found with 2% rate of application of CD, VC, WT and compost but no variations were obtained in this treatment. In moderately saline soil, CD, VC and WT increased the RL in a same way after the application either 1% or 2% rate. The addition of OA caused noticeable improvement in soil properties. This creates a more supportive environment for plant growth and yield. Several researches pointed out that upon decomposition OA provides binding sites for plant nutrients, improve soil structure, and increase microbial activity (Nardi *et al*. 2021; Rashad *et al*. 2022; Tiwari *et al*. 2023). As evidenced from our findings, VC treatment led to the maximum increase in plant growth parameters including root characteristics of plant due to these positive effects of OA on soil fertility and structure.

Conclusion

This study demonstrated the effects of various organic amendments (OA) on the morphological, physiological and root characteristics of red amaranth (*Amaranthus gangeticus*) plants grown in Cd contaminated saline soils. OA application improved the growth parameters depending on the types and rates of OA added to the soil. In slightly saline soil (4dSm^{-1}), morphological, physiological and root characteristics were boosted with VC applied at 1% rate. These parameters were further enhanced with the application of 2% CD and VC. However, WT played an important role in the enhancement of chl-b and RL with higher rate. In moderately saline soil (8dSm^{-1}), growth parameters were accelerated with 1% or 2% of VC and CD. The findings revealed that VC applied at either 1% or 2% rate plays a dominant role in the enhanced growth parameters of red amaranth plant. Therefore, it is recommended to use VC for the cultivation of red amaranth in Cd contaminated saline soils.

Acknowledgment

The authors acknowledge the Research and Innovative Center, Khulna University for their financial support.

References

Abbas A, Azeem M, Naveed M, Latif A, Bashir S, Ali A, Bilal M and Ali L (2020), Synergistic use of biochar and acidified manure for improving growth of maize in chromium contaminated soil. *International Journal of Phytoremediation* **22**(1): 52-61.

Abbas T, Rizwan M, Ali S, Adrees M, Rehman MZ, Qayyum MF, Ok YS and Murtaza G (2018), Effect of biochar on alleviation of cadmium toxicity in wheat (*Triticum aestivum L.*) grown on Cd-contaminated saline soil, *Environ. Sci. Pollut. Res. Int.* **25**(26): 25668-25680. https://doi.org/ 0.1007/ s11356-017-8987-4

Adamipour N, Khosh-Khui M, Salehi H and Rho H (2019), Effect of vermicompost on morphological and physiological performances of pot marigold (*Calendula officinalis* L.) under salinity conditions. *Advances in Horticultural Science* **33**(3): 345-358.

Adewuyi GO, Dawodu FA, Jibiri NN (2010), Studies of the concentration levels of heavy metals in vegetable (*Amaranthus caudatus*) grown in dumpsites within Lagos Metropolis, Nigeria, *The Pacific Journal of Science and Technology* **11(1)**: 616-620.

Ahmad W, Zubair M, Ahmed M, Ahmad M, Latif S, Hameed A, Kanwal Q and Iqbal DN (2023), Correction to: assessment of potentially toxic metal(loid)s contamination in soil near the industrial landfill and impact on human health: an evaluation of risk, *Environ. Geochem. Health* **45**: 4371. https://-doi.org/10.1007/s10653-023-01581-0

Alcívar M, Zurita-Silva A, Sandoval M, Muñoz C, and Schoebitz M (2018), Reclamation of saline-sodic soils with combined amendments: impact on quinoa performance and biological soil quality. *Sustainability* **10**(9): 3083.

Ali S, Noureen S, Shakoor MB, Haroon MY, Rizwan M, Jilani A, Arif MS and Khalil U (2020), Comparative evaluation of wheat straw and press mud biochars for Cr(VI) elimination from contaminated aqueous solution. *Environmental Technology and Innovation* **19**: 101017. https://doi.org/10.1016/ j.eti.2020. 101017.

Anastopoulos I, Massas I and Ehaliotis C (2013), Composting improves biosorption of Pb^{2+} and Ni2+ by renewable lignocellulosic materials. Characteristics and mechanisms involved, *Chemical Engineering Journal* **231**: 245-254.

Antoniadis V, Golia EE, Shaheen SM and Rinklebe J (2017), Bioavailability and health risk assessment of potentially toxic elements in Thriasio Plain, near Athens, Greece. *Environ, Geochem. Health* **39**: 319-330. https://doi.org/ 10.1007/ s10653-016-9882-5.

Arnon D (1949), Copper enzymes isolated chloroplasts, polyphenoloxidase in *Beta vulgaris*. *Plant Physiology* **24**: 1-15.

Azhar M, Rehman MZ, Ali S, Qayyum MF, Naeem A, Ayub MA, Haq MA, Iqbal A and Rizwan M (2019), Comparative effectiveness of different biochars and conventional organic materials on growth, photosynthesis and cadmium accumulation in cereals, *Chemosphere* **227**: 72-81. https://doi.org/10.1016/j.chemosphere.2019.04.041

Bashir S, Hussain Q, Zhu J, Fu Q, Houben D and Hu H (2020), Efficiency of KOH modified rice straw-derived biochar for reducing cadmium mobility, bioaccessibility and bioavailability risk index in red soil. *Pedosphere* **30**(6): 874-882.

Blouin M, Barrere J, Meyer N, Lartigue S, Barot S and Mathieu J (2019), Vermicompost significantly affects plant growth, A meta-analysis. *Agronomy for Sustainable Development* **39**: 34.

Delory BM, Weidlich EWA, Meder L, Lutje A, van Duijnen R, Weidlich R and Temperton VM (2017), Accuracy and bias of methods used for root length measurements in functional root research, *Methods in Ecology and Evolution* **8**: 1594-1606. https://doi.org/10.1111/2041-210X.12771

El Rasafi T, Oukarroum A, Haddioui A, Song H, Kwon EE, Bolan N, Tack FMG, Sebastian A, Prasad MNV and Rinklebe J (2020), Cadmium stress in plants: a critical review of the effects, mechanisms, and tolerance strategies, *Crit. Rev. Environ. Sci. Technol*. **52**: 675-726. https://doi.org/10.1080/10643389. 2020. 1835435

Gangwar P, Singh R, Trivedi M and Tiwari RK (2020), Sodic soil: Management and reclamation strategies. Environmental Concerns and Sustainable Development, *Biodiversity, Soil and Waste Management* **2**: 175-190.

Ghasemi-Soloklui AA, Didaran F, Kordrostami M and Al-Khayri JM (2023), Plant mediation to tolerate cadmium stress with selenium and nano-selenium Nanomaterial Interactions with Plant Cellular Mechanisms and Macromolecules and Agricultural Implications, Springer International Publishing, Cham 455-470. https://doi.org/ 10.1007/978- 3-031-20878-2_17

Guo SH, Jiang LY, Xu ZM, Li QS, Wang JF, Ye HJ, Wang LL, He BY, Zhou C and Zeng EY (2020), Biological mechanisms of cadmium accumulation in edible Amaranth (*Amaranthus mangostanus* L.) cultivars promoted by salinity: A transcriptome analysis. *Environmental Pollution* **262**: 114304. https://doi.org/10.1016/j.envpol.2020.114304

Hardie M and Richard D (2012), Measuring Soil Salinity. *Methods in Molecular Biology* **913**: 415-425. https://doi.org/10.1007/978-1-61779-986-0_28.

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

Islam F, Parvin A, Parvin A, Akhtar US, Shaikh MAA, Uddin MN, Moniruzzaman M, Saha B, Khanom J, Suchi PD, Hossain MA and Hossain MK (2023), Sediment-bound hazardous trace metals(oid) in south-eastern drainage system of Bangladesh: First assessment on human health. *Heliyon* **9**: e20040. https://doi.org/10.1016/j.heliyon.2023.e20040

Leogrande R and Vitti C (2019), Use of organic amendments to reclaim saline and sodic soils: a review, *Arid Land Research and Management* **33**(1): 1-21.

Li Z, Li L and Chen GPJ (2005), Bioavailability of Cd in a soil-rice system in China: soil type versus genotype effects, *Plant and Soil* **271**: 165-173.

Loudari A, Mayane A, Zeroual Y, Colinet G and Oukarroum A (2022), Photosynthetic performance and nutrient uptake under salt stress: Differential responses of wheat plants to contrasting phosphorus forms and rates, *Front. Plant Sci.* **13**: 1038672. https://doi.org/10.3389/fpls.2022.1038672

Lutts S and Lefèvre I (2015), How can we take advantage of halophyte properties to cope with heavy metal toxicity in salt-affected areas? *Annals of Botany* **115**: 509-528.

Ma L, Liu Y, Wu Y, Wang Q, Sahito ZA, Zhou Q, Huang L, Li T and Feng Y (2021), The effects and health risk assessment of cauliflower co-cropping with *Sedum alfredii* in cadmium contaminated vegetable field, *Environ. Pollut.* **268**: 115869. https://doi.org/10.1016/j.envpol.2020.115869

Miah MY, Monira US, Fazal KI and Roy PK (2013), Nutrient accumulation and their uptake by red amaranth as influenced by different levels of N, *Journal of Bangladesh Agril. Univ.* **11**(1): 29-32.

Nardi S, Schiavon M and Francioso O (2021), Chemical structure and biological activity of humic substances define their role as plant growth promoters. *Molecules* **26**(8): 2256

Okrikata E and Nwosu LC (2023), Heavy Metals and Pesticides as Hazardous Wastes and Strategies for Minimizing their Hazards, *Int. J. Res. Publ. Rev.* **4**: 4920-4934.

Parvin A, Moniruzzaman M, Hossain MK, Saha B, Parvin A, Suchi PD and Hoque S (2022), Chemical Speciation and Potential Mobility of Heavy Metals in Organic Matter Amended Soil. Applied and Environmental Soil Science ID: 2028860. https://-doi.org/10.1155/2022/2028860

Patil G, Divya MP, Shah P and Maitry A (2024), Metal Accumulation Ability of Different Eucalyptus Species at the Early Stage. *Forestist* **74**: 26-34. https://doi.org/10.5152/forestist.2023.22078

Prakash OM and Zaidi PH (2000), Effect of amaranth (*Amaranthus spinosus* L.) supplemented maize diet on blood haemoglobin and lipid metabolism in rats. *Annals of Agricultural Research* **21**(2): 223-232.

Raiesi F, Razmkhah M and Kiani S (2018), Salinity stress accelerates the effect of cadmium toxicity on soil N dynamics and cycling: Does joint effect of these stresses matter? *Ecotoxicology and Environmental Safety* **153**: 160-167. https://doi.org/10.1016/j.ecoenv.2018.01.035

Rashad M, Hafez M and Popov AI (2022), Humic substances composition and properties as an environmentally sustainable system: A review and way forward to soil conservation, *Journal of Plant Nutrition* **45**(7): 1072-1122

Rehman MZ, Zafar M, Waris AA, Rizwan M, Ali S, Sabir M, Usman M, Ayub MA and Ahmad Z (2020), Residual effects of frequently available organic amendments on cadmium bioavailability and accumulation in wheat, *Chemosphere* **244**: 125548. https://-doi.org/10.1016/j.chemosphere.2019.125548

Seleiman MF and Kheir AMS (2018), Maize productivity, heavy metals uptake and their availability in contaminated clay and sandy alkaline soils as affected by inorganic and organic amendments, *Chemosphere* **204**: 514-522. https://doi.org/10.1016/j.chemosphere.2018.04.073.

Shahid M, Shamshad S, Farooq ABU, Rafiq M, Khalid S, Dumat C, Zhang Y, Hussain I and Niazi NK (2019), Comparative effect of organic amendments on physio-biochemical traits of young and old bean leaves grown under cadmium stress: a multivariate analysis, *Environmental Science and Pollution Research* **26**: 11579-11590. https://doi.org/ 10.1007/ s11356-018-2689-4

Shinomol GK, Bhanu RK, Deepa N, Pooja SC, Ashwini TS and Das S (2016), A study on the potential of moringa leaf and bark extract in bioremediation of heavy metals from water collected from various lakes in Bangalore, *Procedia Environmental Sciences* **35**: 869-880.

Tiwari J, Ramanathan AL, Bauddh K and Korstad J (2023), Humic substances: Structure, function and benefits for agroecosystems—a review. *Pedosphere* **33**(2): 237-249.

Turner NC (1986), Crop Water Deficits: A Decade of Progress, *Advances in Agronomy* **39**: 1-51.

Wang L, Qin L, Sun X, Zhao S, Yu L, Chen S and Wan M (2023), Salt stress-induced changes in soil metabolites promote cadmium transport into wheat tissues, *Journal of Environmental Sciences* **127**: 577-588. https://doi.org/10.1016/j.jes.2022.06.017

Xing Q, Hasan MK, Li Z, Yang T, Jin W, Qi Z, Yang P, Wang G, Ahammed GJ and Zhou J (2023), Melatonin-induced plant adaptation to cadmium stress involves enhanced phytochelatin synthesis and nutrient homeostasis in *Solanum lycopersicum*, *J. Hazard Mater.* **456**: 131670. https://doi.org/ 10.1016/j.-jhazmat.2023.131670

Yildirim E, Agar G, Ors S, Yuksel EA, Aydin M, Ekinci M and Kul R (2023), Growth, physiological, biochemical and DNA methylation responses to cadmium stress of bean (*Phaseolus vulgaris* L) grown under different irrigation levels, *Plant Growth Regul.* **101**: 537-556. https://doi.org/ 10.1007/ s10725- 023-01039-4

Yupeng W, Yufei L, Yi Z, Yanmeng B and Zhenjun S (2018), Responses of Saline Soil Properties and Cotton Growth to Different Organic Amendments, *Pedosphere* **28**: 521-529. https://doi.org/10.1016/S1002-0160(17)60464-8.