The Andhra Agric. J 71 (3): 333-341, 2024
doi :10.61657/aaj.2024.140

Impact of biochar and lime amendments on physico-chemical parameters and uptake of heavy metals in soils contaminated with municipal and industrial waste water

Y Tejaswi, T V Sridhar, B Asha Jyothi and K Srinivasulu
Department of Soil Science, Acharya N G Ranga Agricultural University,
Agricultural College, Bapatla-522101, Andhra Pradesh, India

ABSTRACT

The physical, chemical, and biological properties of soils are influenced by industrial effluents, which provide serious concerns to soil health. The present study investigate into the effect of lime and biochar amendments to increase soil fertility and lower pollution levels in areas that have been contaminated by municipal & industrial effluents. A pot culture experiment was conducted in a greenhouse using a completely randomized design (CRD) with three replications for each treatment. Treatments applied with varying levels of biochar (1.25 t ha^{-1}, 5 t ha^{-1}, 7.5 t ha^{-1}), and lime (1.25 t ha^{-1}, 2.5 t ha^{-1}, 5 t ha^{-1}) including with and without 100% RDF. Amaranthus and fodder sorghum were grown as test crops. Soil samples were analyzed for pH, electrical conductivity (EC), nutrient content, and heavy metal concentrations, in addition, plant growth parameters, dry matter yield (DMY), and nutrient uptake were also assessed. Results indicated that both biochar and lime significantly enhanced the soil quality by increasing pH and nutrient availability by reducing heavy metal bioavailability. Biochar and lime treatments led to higher nutrient uptake (N, P, K) by amaranthus and fodder sorghum, contributing to improved plant growth and dry matter yield. The study highlights the benefits of biochar and lime in improving soil fertility and reducing heavy metal uptake by plants, demonstrating their potential as sustainable soil remediation strategies. These findings suggest that biochar and lime amendments can effectively restore the productivity of soils polluted with municipal and industrial effluents, for sustaining the agricultural production of contaminated soils.

Key words: *Amaranthus, Biochar, Effluents, Fodder Sorghum, Heavy metal, Lime and Pollution.*

The rapid industrialization and urbanization in and around Guntur city has led to substantial effluent discharge on daily basis and resulted in significant soil contamination. These effluent-affected soils are marked by altered physico-chemical properties, including shifts in pH, electrical conductivity (EC), and the accumulation of toxic heavy metals. Such changes severely impact soil fertility, crop yield, and overall soil and human health, presenting a challenge for sustainable agriculture. Conventional remediation methods are often costly and environmentally unsustainable, underscoring the need for effective and eco-friendly soil restoration strategies.

Biochar, a carbon-rich substance produced through the pyrolysis of biomass, has emerged as a promising soil amendment for remediation. It enhances soil structure, boosts nutrient retention, increases water-holding capacity, and immobilizes pollutants. The porous nature of biochar creates a habitat for beneficial microorganisms, which are vital for nutrient cycling and improving soil health. Additionally, its high cation exchange capacity (CEC) aids in nutrient retention, making essential nutrients more available to plants. Lime, widely used to correct soil acidity, also improves soil structure and fosters beneficial microbial activity. By raising soil pH, lime decreases the solubility and mobility of heavy metals, reducing their bioavailability and toxicity. This liming effect not only mitigates heavy metal contamination but also enhances nutrient availability and uptake by crops, thus improving soil fertility. This study aims to evaluate the effectiveness of biochar and lime in restoring soil health in the Guntur region, where soils are impacted by municipal and industrial effluents.

MATERIAL AND METHODS

A pot culture experiment was conducted at Department of Soil Science, Agricultural College, Bapatla. For this experiment, contaminated soil samples with highest toxic metal contents were collected from budampadu region, Guntur, where the soils were contaminated highly by Municipal and Industrial effluents. These samples were air dried in shade and were pounded to pass through 2 mm sieve and used 5 kg of soil per each pot. The experiment employed a Completely Randomized Design (CRD) with three replications. The treatments applied are absolute control, 100 % NPK and varying levels of biochar (1.25 ha $^{-1}$, 5 t ha $^{-1}$ and 7.5 t ha $^{-1}$) and lime (1.25 ha $^{-1}$, 2.5t ha $^{-1}$ and 5 t ha $^{-1}$) along with 100% recommended doses of fertilizers. Amaranthus and fodder sorghum were selected as test crops and sown uniformly in each pot. The pots were kept in a controlled environment with consistent temperature and light, and irrigation was provided as needed to maintain soil moisture.

Soil analysis involved measuring pH and electrical conductivity (EC) using a pH meter and EC meter, respectively, in a 1:2.5 soil-water suspension. Nutrient content (nitrogen, phosphorus, potassium) and heavy metal concentrations (lead, cadmium, zinc) were determined using standard chemical methods and atomic absorption spectroscopy (AAS). For plant analysis, dry matter yield (DMY) was measured by drying of harvested plant material at 70°C. Heavy metal uptake in plant samples was analyzed using standard procedures. Data were statistically analyzed to evaluate the effects of different treatments on soil properties and plant performance, with significant differences assessed using Tukey's HSD test at a 5% significance level. Quality control measures included instrument calibration, use of standard reference materials, and repeated measurements to ensure accuracy and reliability. The study aimed to provide insights into the effectiveness of biochar and lime as sustainable soil remediation strategies for contaminated soils.

RESULTS AND DISCUSSION

pH and Electrical Conductivity (EC)

The impact of biochar and lime amendments on soil pH and electrical conductivity (EC) was presented in table 1.

Soil reaction (pH) Initial soil samples from the Guntur region had a neutral pH of 7.53. This baseline pH was relatively stable, indicating that the soil was not highly acidic or alkaline at the start of the experiment. However, the application of lime and biochar resulted in noticeable changes in soil pH. Lime application significantly increased soil pH, with the most pronounced effects observed at higher application rates. For instance, lime applied at (T_8: 5 t ha $^{-1}$ +100% NPK) increased the pH to 7.83, indicating a shift towards alkaline conditions and it is on par with T_7. This significant increase in pH is consistent with lime's known role in neutralizing soil acidity, even in soils that are already near-neutral. Biochar, while also effective in increasing pH, showed a more moderate effect compared to lime. Biochar application (T_5-7.5 t ha $^{-1}$ +100% NPK) raised the soil pH to 7.76 as mentioned in table 1. This increase, while beneficial, was less dramatic than that achieved with lime. The alkaline nature of biochar contributes to raising soil pH, but its effect is generally more gradual compared to the immediate and substantial impact of lime.

Electrical Conductivity (EC): The EC of the control soil was 0.54 dS/m, reflecting a high concentration of soluble salts due to industrial effluent contamination. The lime application resulted in a marked increase in EC across all application rates. The highest was observed in T_8 (100% NPK + 5 t ha^{-1} of $CaCO_3$) 0.88 dS m^{-1} followed by T_7 - (100% NPK + 5 t ha^{-1} of $CaCO_3$) 0.84 dS m^{-1} and the lowest was observed in control 0.54 dS m^{-1} as mentioned in table 1. The increase in EC with lime application can be attributed to the addition of calcium carbonate, which adds to the soluble salts in the soil. Biochar also contributed to increased EC, though the reduction was less pronounced compared to lime. Biochar's contribution to increased EC is related to its inherent mineral content and its effect on soil structure, which can lead to higher retention of soluble salts in the soil.

The results indicated that both lime and biochar lead to increases in soil EC with higher application rates. For lime, this is due to the addition of calcium carbonate, which raises the soluble salt content in the soil. While lime reduces soil acidity and improves fertility, its contribution to increased EC must be managed to avoid negative effects on plant growth. Biochar's effect on EC is linked to its mineral content and influence on soil properties. Although biochar improves soil structure and nutrient retention, higher application rates increase EC due to retained soluble salts. Both amendments improve soil health and fertility but may elevate EC due to their mineral

Table: 1. Effect of treatments on pH, EC and organic carbon content in soils after harvest of Amaranthus, Fodder Sorghum crops grown in polluted soil

TREATMENTS	AMARANTHUS		FODDER SORGHUM	
	pH	EC (dS m^{-1})	pH	EC (dS m^{-1})
T_1: Control	7.67	0.54	7.7	0.59
T_2: 100% NPK	7.69	0.61	7.75	0.65
T_3: 100% NPK + 1.25t of Biochar ha^{-1}	7.72	0.75	7.78	0.68
T_4: 100% NPK + 5t of Biochar ha^{-1}	7.74	0.78	7.81	0.73
T_5: 100% NPK + 7.5t of Biochar ha^{-1}	7.76	0.85	7.82	0.75
T_6: 100% NPK + 1.25 t ha^{-1} of $CaCO_3$	7.77	0.6	7.88	0.67
T_7: 100% NPK + 2.5 t ha^{-1} of $CaCO_3$	7.8	0.84	7.89	0.73
T_8: 100% NPK + 5 t ha^{-1} of $CaCO_3$	7.83	0.88	7.89	0.79
S. Em (±)	0.08	0.01	0.03	0.01
CD (0.05)	0.26	0.05	0.11	0.03
CV (%)	2	3.99	0.83	3.24

content. This trade-off highlights the need to balance soil pH adjustment and nutrient availability with the risk of elevated soil salinity. Thus, managing application rates is crucial for mitigating industrial effluent contamination and enhancing soil health and agricultural productivity. These findings aligned with Ahmad *et al.* (2017) Islam *et al.* (2021) and Suri *et al.* (2023).

Dry Matter Yield (DMY) and Uptake of Heavy Metals

The dry matter yield and uptake of heavy metals by amaranthus and fodder sorghum was influenced by the application of biochar and lime are depicted in tables 2 & 3.

Dry Matter Yield (DMY)

The application of biochar significantly influenced the dry matter yield (DMY) of both amaranthus and fodder sorghum, with notably high DMY observed in biochar-treated pots.

Amaranthus

Biochar treatment led to a substantial increase in DMY for amaranthus. In the control pots, the DMY was 10.5 g/pot. With the application of biochar, this yield increased progressively with the rate: 1.25 t ha^{-1} +100% NPK resulted in 14.5 g pot^{-1}, 100% NPK+5 t ha^{-1} in 16.7 g pot^{-1}, and 100 %NPK + 7.5 t ha^{-1} in 17.2 g pot^{-1} as seen in Fig 1. The highest DMY of 17.2 g pot^{-1} was achieved with the 7.5 t ha^{-1} biochar appliction, indicating a significant enhancement in plant growth. This increase can be attributed to biochar's ability to improve soil structure, enhance nutrient retention, and better root development. The same trend followed with lime application resulted in an increase in the dry matter from 13.4 to 15.9 g pot^{-1}. T_2, T_3 and T_4 are on par with the control.

Fodder Sorghum

Similarly, biochar treatment improved the DMY of fodder sorghum. The control pots yielded 11.8 g pot^{-1}, while biochar application resulted in higher yields: T_3 (100% NPK+1.25 t ha^{-1}) produced 15.7 g pot^{-1}, T_4 (100% NPK+5 t ha^{-1}) 19.7 g pot^{-1}, and T_5 (100% NPK +7.5 t ha^{-1}) produced 23.5 g pot^{-1} as seen in Fig 2. The highest yield of 23.5 g pot^{-1} was observed with the 100 % NPK + 7.5 t ha^{-1} biochar application. Whereas lime applied treatments also increased dry matter from 15.0 to 19.5 g pot^{-1} with an increased application rate. This enhancement in DMY reflects the positive effects of biochar on soil aeration, water retention, and nutrient availability, which contribute to increased biomass production. This underscores the potential of biochar as an effective soil amendment for enhancing crop productivity, particularly in contaminated soils where improved soil conditions are crucial for maximizing plant growth.

The results showed that both biochar and lime significantly increase the dry matter yield (DMY) of

Table: 2. Effect of treatments on dry matter, Pb uptake in Amaranthus, Fodder Sorghum crops grown in polluted soil

TREATMENTS	AMARANTHUS		FODDER	
	Dry matter (g pot^{-1})	Uptake (µg pot^{-1})	Dry matter (g pot^{-1})	Uptake (µg pot^{-1})
T_1: Control	10.5	25.1	11.8	27.5
T_2: 100% NPK	12	23.8	13.7	26.6
T_3: 100% NPK + 1.25t of Biochar ha^{-1}	14.5	21.6	15.7	24.2
T_4: 100% NPK + 5t of Biochar ha^{-1}	16.7	18.7	19.7	20.1
T_5: 100% NPK + 7.5t of Biochar ha^{-1}	17.2	18.5	23.5	18.2
T_6: 100% NPK + 1.25 t ha^{-1} of $CaCO_3$	13.4	20	15	23.9
T_7: 100% NPK + 2.5 t ha^{-1} of $CaCO_3$	14.3	19.5	17.4	23.7
T_8: 100% NPK + 5 t ha^{-1} of $CaCO_3$	15.9	19.2	19.5	21.7
S. Em (±)	0.49	1.26	0.7	1.8
CD (0.05)	1.49	3.8	2.21	5.42
CV (%)	6.02	10.5	7.49	13.4

Table: 3. Effect of treatments on dry matter, Cd uptake in Amaranthus, Fodder Sorghum crops grown in polluted

TREATMENTS	AMARANTHUS		FODDER	
	Dry matter (g pot^{-1})	Uptake (µg pot^{-1})	Dry matter (g pot^{-1})	Uptake (µg pot^{-1})
T_1: Control	10.5	12.3	11.8	11.8
T_2: 100% NPK	12	11.9	13.7	11.8
T_3: 100% NPK + 1.25t of Biochar ha^{-1}	14.5	10.6	15.7	10.8
T_4: 100% NPK + 5t of Biochar ha^{-1}	16.7	10	19.7	10.1
T_5: 100% NPK + 7.5t of Biochar ha^{-1}	17.2	8.1	23.5	8.2
T_6: 100% NPK + 1.25 t ha^{-1} of $CaCO_3$	13.4	11.3	15	11.5
T_7: 100% NPK + 2.5 t ha^{-1} of $CaCO_3$	14.3	10.7	17.4	11
T_8: 100% NPK + 5 t ha^{-1} of $CaCO_3$	15.9	10	19.5	10
S. Em (±)	0.49	0.68	0.7	0.74
CD (0.05)	1.49	2.05	2.21	2.22
CV (%)	6.02	11.1	7.49	12

amaranthus and fodder sorghum. Biochar improves soil structure, water and nutrient retention, and root growth, leading to higher DMY, with the maximum yield observed at 7.5 t ha^{-1}. Lime improved DMY by raising soil pH, which improves nutrient availability and reduces metal toxicity. Additionally, lime directly contributes to increased dry matter production by optimizing soil conditions for plant growth. These findings are consistent with reports by Rizwan *et al.* (2018) and Amsalu and Beyene (2020), who found increased barley yield with higher phosphorus and lime applications.

Uptake of Heavy Metals Lead

In the case of lead (Pb), lime application effectively reduced its uptake by both crops. For

Fig.1. Effect of different amendments on growth of Amaranthus crop grown in polluted soil

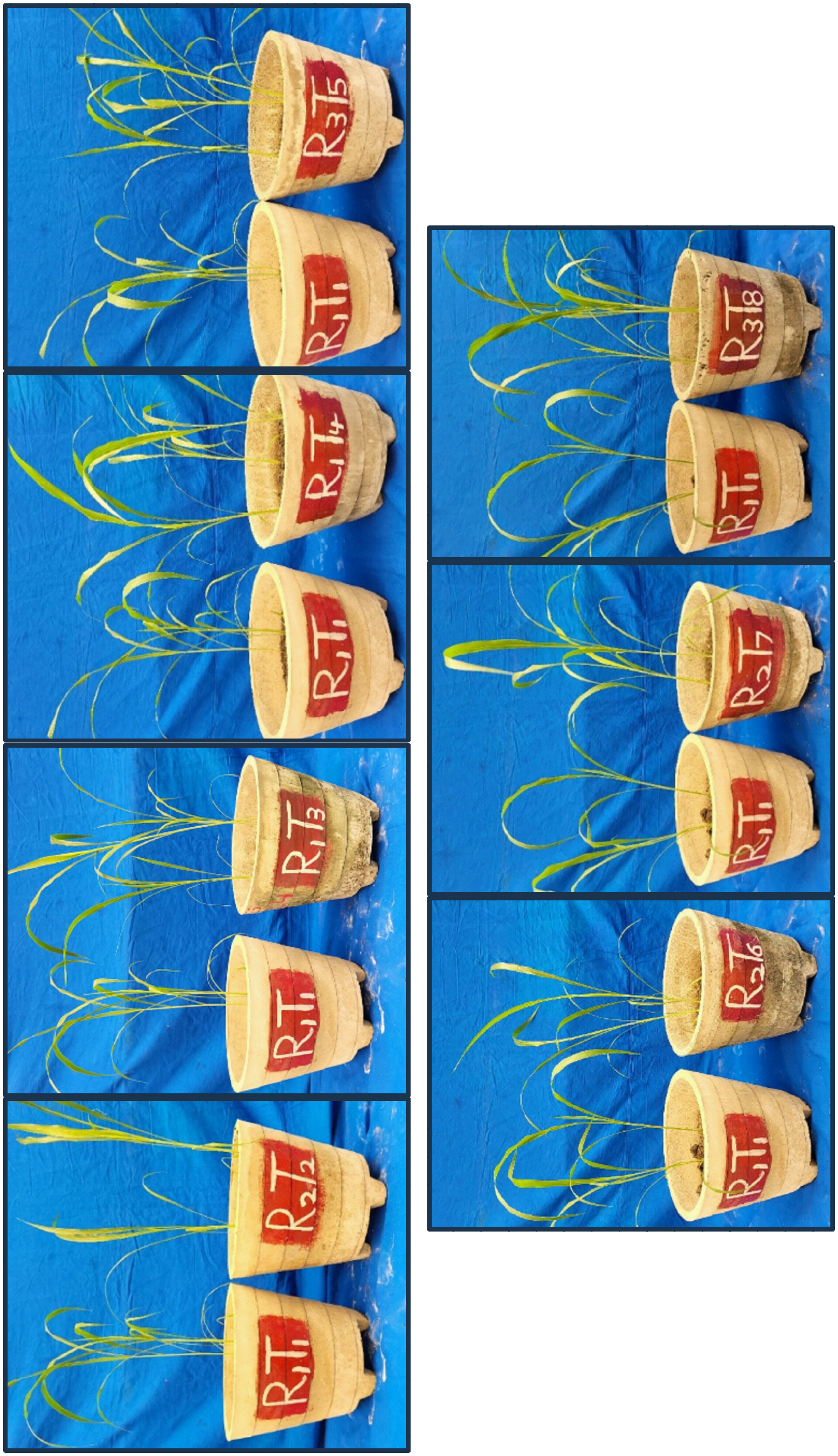

Fig. 2. Effect of different amendments on growth of Fodder Sorghum crop grown in polluted soil

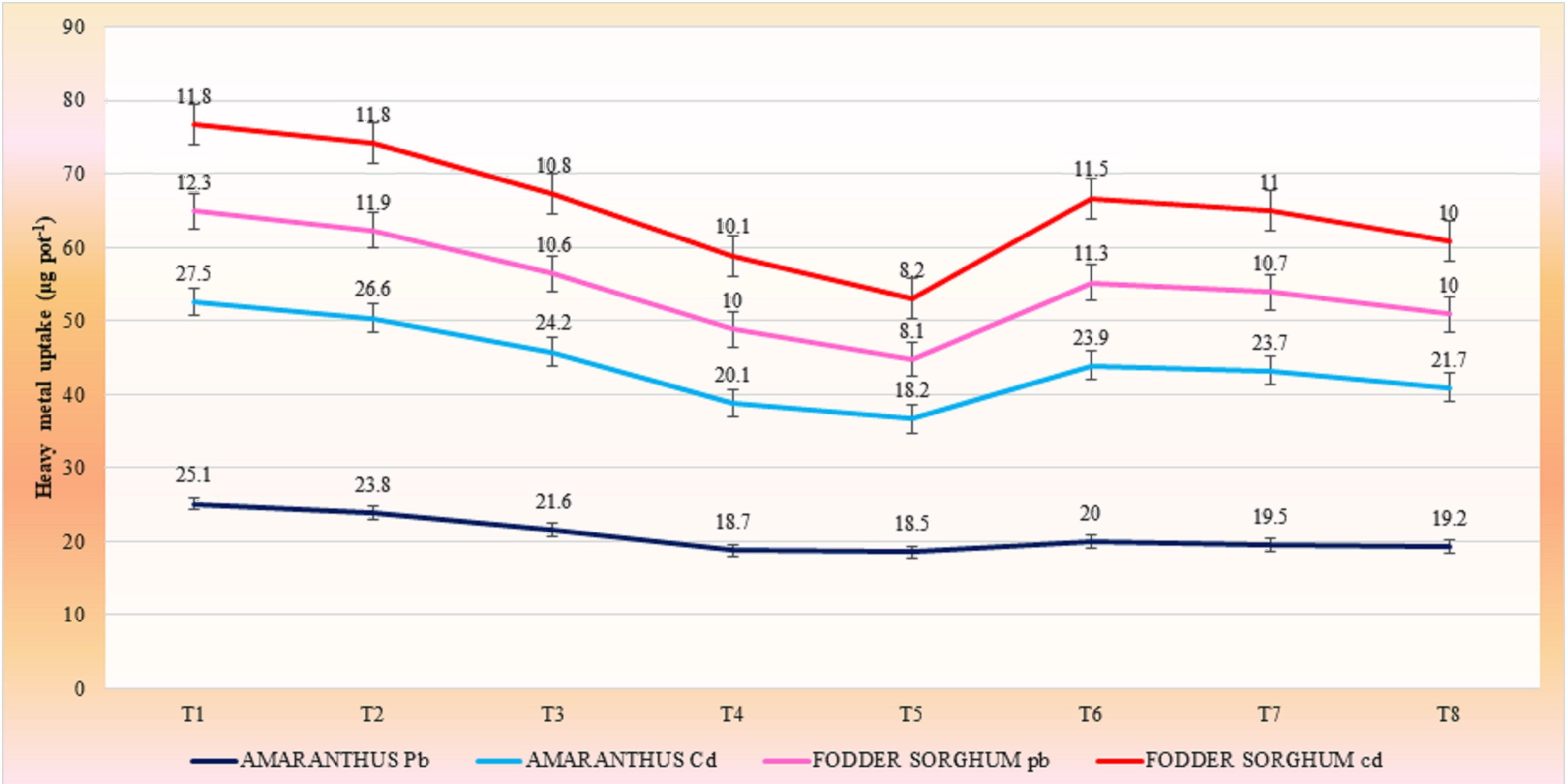

Fig. 3. Effect of treatments on Heavy metal uptake (µg pot^{-1}) in plants after harvest of Amaranthus and Fodder sorghum crop grown in pol luted soil

amaranthus, the lead concentration in plant tissues decreased from 25.1 ìg pot^{-1} in the control to 19.2 ìg pot^{-1} with T_8(5 t ha^{-1} of lime+100% NPK). Similarly, for fodder sorghum, lead uptake reduced from 27.5 ìg pot^{-1} to 21.7 ìg pot^{-1} T_8(5 t ha^{-1} of lime+100% NPK) with lime application as mentioned in table 2. This reduction is due to lime's role in increasing soil pH, which decreases the solubility and mobility of heavy metals, thereby limiting their availability to plants.

Biochar also significantly reduced lead uptake compared to lime. For amaranthus, lead concentration decreased from 25.1 ìg pot^{-1} in the control to 18.5 ìg pot^{-1} with T_5(7.5 t ha^{-1} of biochar+100% NPK). For fodder sorghum, lead uptake was reduced from 27.5 ìg pot^{-1} to 18.2 ìg pot^{-1}, T_5(7.5 t ha^{-1} of biochar+100% NPK) with biochar application. This reduction is attributed to biochar's ability to adsorb heavy metals and improve soil properties. Similar results were reported by Almaroai and Eissa (2020), who found that increasing biochar application rates gradually reduced metal concentrations and uptake in tomato crops and Khalid and Ashraf (2019), who observed that higher biochar application significantly decreased the solubility of lead (Pb) and mitigated toxicity symptoms.

Cadmium (Cd) uptake by plants was similarly affected by the amendments. Lime application reduced cadmium levels in amaranthus from 12.3 ìg pot^{-1} in the control to 8.10 ìg pot^{-1} at 7.5 t ha^{-1}, and in fodder sorghum from 11.8 ìg pot^{-1} to 10.0 ìg pot^{-1}. Biochar also decreased cadmium uptake, with amaranthus showing a reduction from 12.3 ìg pot^{-1} to 8.10 ìg pot^{-1}, and fodder sorghum from 11.8 ìg pot^{-1} to 8.20 ìg pot^{-1} at 7.5 t ha^{-1} as mentioned in table 3. Lime's effectiveness in reducing cadmium uptake is due to its role in altering soil pH, which decreases cadmium solubility and bioavailability. Biochar's high sorption capacity also lowers Cd concentration in both shoots and roots by immobilizing cadmium into more stable forms and improving soil quality.

These findings align with Rizwan *et al*. (2018) and Almaroai and Eissa (2020), who observed decreased cadmium concentrations in plant shoots with higher biochar treatments. Hamid *et al.* (2020) documented a significant reduction in Cd uptake with lime and compost amendments, while Qianqian *et al.* (2022) demonstrated that combining biochar with selenium (Se) effectively mitigated Cd accumulation in lettuce shoots. The application of CaCOƒ with RDF (NPK) also resulted in the lowest Cd content (0.67 mg kg^{-1}), showing a 46.82% reduction over the control was observed by Sridhar (2006).

CONCLUSION

Overall, the experiment showed that remediation of heavy metal contaminated sites with industrial and municipal effluents might be achieved with both lime and biochar by improving soil fertility. Lime has more direct and noticeable impacts on soil pH and heavy metal bioavailability at T_8: 100% NPK + 5 t ha^{-1} of $CaCO_3$, whereas biochar delivers longer-term benefits in soil structure for progressive decrease in metal uptake in contaminated site in T_5: 100% NPK + 7.5t of Biochar ha^{-1}. Hence It is possible to successfully treat soil contamination and support sustainable farming practices by using these amendments separately or in combination. Including lime and biochar in soil management plans can result in safer agricultural systems, better soils, and increased crop yields.

LITERATURE CITED

Ahmad M, Lee S S, Lee S E, Wabel M I, Tsang D C and O Y S 2017. Biochar-induced changes in soil properties affected immobilization/ mobilization of metals/metalloids in contaminated soils. *Journal of Soils and Sediments*. 41 (1): 95- 108.

Almaroai Y A and Eissa M A 2020. Effect of biochar on yield and quality of tomato grown on a metal-contaminated soil. *Scientia Horticulturae*. 265: 109210.

Amsalu S and Beyene S 2020. Effects of lime and phosphorous application on chemical properties of soil, dry matter yield, and phosphorus concentration of barley (*Hordeum vulgare*) grown on Nitosols of Emdibir, Southern Ethiopia. *Journal of Soil Science and Environmental Management*. 11 (4): 131-141.

Hamid Y, Tang L, Hussain B, Usman M, Gurajala H K, Rashid M S, He Z and Yang X 2020. Efficiency of lime, biochar, Fe containing biochar and composite amendments for Cd and Pb immobilization in a co-contaminated alluvial soil. *Environmental Pollution.* 257: 113609.

Islam M R, Talukder M M H, Hoque M A, Uddin S, Hoque T S, Rea R S, Alorabi M, Gaber A and Kasim S 2021. Lime and manure amendment improve soil fertility, productivity and nutrient uptake of rice-mustard-rice cropping pattern in an acidic terrace soil. *Agriculture.* 11 (11): 1070.

Khaled S B and Ashraf M A 2016. Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia. *Saudi Journal of Biological Sciences*. 23: 32-34.

Qianqian M, Haider F U, Farooq M, Adeel M, Shakoor N, Jun W, Jiaying X, Wang X W, Panjun L and Cai L 2022. Selenium treated Foliage and biochar treated soil for improved lettuce (*Lactuca sativa* L.) growth in Cd-polluted soil. *Journal of Cleaner Production*. 335: 130267.

Rizwan M, Ali S, Abbas T, Rehman M Z U and Al-Wabel M I 2018. Residual impact of biochar on cadmium uptake by rice (*Oryza sativa* L.) grown in Cd-contaminated soil. *Arabian Journal of Geosciences.* 11: 1-8.

Sridhar 2006. Characterisation and correction of soils polluted with industrial effluents through amendments and Hyper accumulators. M.Sc. (Ag) Thesis. Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad.

Suri D, Sharma R P, Sankhyan N K, Manuja S and Singh J 2023. Micronutrient availability in soil–plant system as influenced by 47 years long application of chemical fertilizers, organics and lime under maize–wheat cropping in an acid Alfisol. *Cereal Research Communications*. 1-13.

Received on 05.06.2024 and Accepted on 03.07.2024