

# REDUCTION OF LEAD UPTAKE IN NAPIER GRASS THROUGH LIME AND ORGANIC AMENDMENTS

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## Abstract

Lead (Pb) accumulation of soil is a major concern which adversely affects crop growth, yield and food safety. This study compared the effect of lime and organic amendments (charcoal, tea waste, and vermicompost) on the growth (*Pennisetum purpureum* S.) and Pb uptake of Napier grass over two harvests. Plants were cultivated for 87 days in Pb-contaminated soil amended separately with charcoal, tea waste, vermicompost, and lime, each at 1.0, 2.5, and 5.0%. There was an unamended control. Both amendments improved plant growth and reduced Pb uptake, with stronger effects at higher rates. During the first cut, lime appeared more effective, whereas organic amendments, particularly vermicompost was found more efficient during the second harvest. In the first cut, 5.0% vermicompost reduced shoot height (cm) and dry weight (g) by factors of 1.21 and 1.40, respectively and in the subsequent cut it increased shoot height and weight by factors of 0.84 and 0.65. Lime at 0.5% and vermicompost at 5.0% rates produced similar Pb reductions during the first cut, while vermicompost reduced Pb by 1.30-fold in the second cut. Furthermore, 5.0% vermicompost resulted in 0.49-fold lower DTPA-extractable Pb compared to 5.0% lime and exhibited the highest Pb reduction (66.2%). Overall, 5.0% vermicompost was more cost-effective and efficient than lime and others, enhancing Napier growth and reducing Pb uptake by plant through the second cut with a single application.

**Keywords:** Charcoal, Lead contamination, Lime, Tea waste, Vermicompost

## 1. Introduction

Lead is a toxic, non-essential heavy metal for plants that accumulates on the soil surface, inhibiting plant growth, and yield.s. The contamination by Pb has steadily increased during the last few decades due to natural and anthropogenic factors (Alam et al., 2020). Extensive use of pesticides and chemical fertilizers, along with smelting of metal ores as raw materials, releases Pb into the environment (Islam et al., 2024). In Bangladesh, industrial wastes and effluents are commonly discharged onto agricultural lands, into canals and rivers, and along roadsides or in the vicinity of industrial operations without any primary or secondary treatment. These effluents contain a variety of noxious pollutants including Pb that are constantly polluting agricultural soils, natural water as well as ground water system, and create an extremely serious contamination problem in Bangladesh (Rumi et al., 2025; Alam et al., 2020). Heavy metals in soils

are not easily degraded by chemical or microbial degradation; therefore, the total concentrations and toxicity of metals persist in soils for a long period of time (Islam et al., 2024). Their presence in agricultural soil inevitably destroy beneficiary soil microorganisms, reduce plant growth, and eventually poses serious harmful impacts on human and animal by entering into food chain (Alam et al., 2020).

Among the heavy metals, Pb is categorized as the most hazardous metal by United States Environmental Protection Agency (ATSDR, 2022). . However, it may create different inorganic and organic compounds that are easily absorbed by plant roots and, thereby, poses serious health risk on human through the food chain (Ali et al., 2020). Consequently, there is a dire need of cost effective and environmentally friendly techniques to reduce metal contamination in soil (Islam et al., 2024).

Among the inorganic amendments, liming materials has received increased attention due to their superior metal stabilizing capacities in soil. Liming material can neutralize soil acidity and enhance metal stabilization through precipitation or complexation. Different lime-based materials, such as carbonates, oxides, and hydroxides of Ca and Mg have been extensively reported to stabilize heavy metals in soil (Ali et al., 2020).

Addition of organic amendments to soils can enhance metal immobilization by increasing soil pH, CEC as well as by providing active sorption sites for binding metal ions (Das et al., 2022). Moreover, organic amendments make soluble or insoluble complexes with heavy metals, and make them unavailable to plant, which ultimately reduces their risk to food chain. Besides, organic materials are a good source of essential nutrients that improve soil fertility and microbial interactions in soil (Hamid et al., 2020).

There are few reports on tea waste as an agent of heavy metal immobilization (Hussain et al., 2018), on the other hand vermicompost, charcoal and lime are extensively used to immobilize heavy metal in soil (Lwin et al., 2018). However, most of the past research was conducted with single amendments, focusing either inorganic or organic (Hamid et al., 2020). Practically, combined effects of lime and vermicompost on metal stabilization as well as plant growth are still far to be fully clarified. Considering this, we applied lime as inorganic amendment and tea waste, cow manure vermicompost and charcoal as organic amendments since they are cost-effective and environmentally friendly in nature. In case of plant, we used Napier grass (*Pennisetum purpureum* S.) as test crop. It is a fast growing; high biomass and drought-resistant forage grass (Negawo et al., 2017). Napier grass is a major fodder crop for the dairy farmers, and its high productivity makes it particularly suited to feed cattle and buffaloes.

Therefore, this study would provide new insights to immobilize heavy metals and suppress their uptake by plant. The objectives of this study were: (i) examine the effect of charcoal, tea

waste, and vermicompost as soil supplements on plant growth, (ii) assess the efficacy of charcoal, tea waste, and vermicompost on Pb uptake in Napier grass in two consecutive plant harvests; and (iii) compare the impact of lime on Napier grass growth and Pb uptake with that of charcoal, tea waste, and vermicompost.

## 2. Materials and Methods

### 2.1 Collection and processing of soil and amendments

This soil sample was collected from the top 0-15 cm of an uncontaminated crop field of University of Chittagong, Bangladesh (22.4716° N, 91.7877° E). It belongs to the Pahartali series and has a sandy loam (Aquepts) texture. The region experiences a tropical monsoon climate, characterized by an average annual temperature of 26°C and annual average rainfall 1551 mm. Lime was procured from a chemical company (Sigma-Aldrich Co.). Among the organic amendments charcoal was purchased from a local market and tea waste from a nearby tea stall. Vermicompost was produced in the departmental lab, the methodology as follows: vermicompost was prepared in a 90-cm-diameter and 30-cm-high cement ring following Das et al. (2022). Air-dry cow manure collected near the University of Chittagong, Bangladesh, was vermicomposted using *Eisenia fetida* (20 earthworms kg<sup>-1</sup> manure) sourced from Meherpur, Bangladesh. The ring was filled with 80 kg manure and 40 kg worm feed, maintained at ~80% moisture by watering every two days, and kept at 22–30°C for 8 weeks. Irrigation was stopped before harvest, allowing the surface layer to dry and causing earthworms to move to the lower, moist layers; vermicompost was then collected from the upper layer (Das et al., 2022). The charcoal and tea waste underwent professional processing, resulting in a sleek black appearance and a lightweight feel. On the other hand, the vermicompost underwent a similar professional treatment, resulting in a coffee-colored appearance that is both odorless and lightweight. The collected soil samples and organic amendments were dried naturally, crushed, and processed by grinding and sieving through a 2 mm mesh, and store after collection.

### 2.2 Characterization of soil and amendments

The collected soil and organic amendments were characterized for their physical and chemical properties prior to the experiment. Moisture content of soil and organic amendments was determined volumetrically (Black, 1965). Soil particle size distribution was measured using the hydrometer method (Day, 1965), and textural classes were assigned according to Marshall's Triangular Coordinates (USDA, 1951). Soil and amendment pH was measured using a Jenway glass electrode pH meter at 1:2.5 (w/v) soil–water and 1:5 (w/v) amendment–water ratios (Jackson, 1958).

Organic carbon was determined by the wet oxidation method (Walkley and Black, 1934), and organic matter was calculated using the Van Bemmelen factor (1.724) (Piper, 1950). Total

N, P, K, and Ca were analyzed after  $\text{H}_2\text{O}_2$ - $\text{H}_2\text{SO}_4$  wet digestion (Akinremi et al., 2003). Total N was measured by the micro-Kjeldahl method (Jackson, 1973), total P by the ascorbic acid blue color method (Murphy and Riley, 1962), and total K and Ca by atomic absorption spectrophotometry; Ca in lime was extracted with deionized water.

Soil cation exchange capacity was determined using 1 N  $\text{NH}_4\text{OAc}$  (pH 7.0) (Soil Survey Laboratory Staff, 1992). DTPA-extractable Pb was measured by shaking 10g soil with 20 mL of 0.005 M DTPA for 2 h at 180 rpm, followed by filtration and AAS analysis (Lindsay and Norvell, 1978). Physical and chemical properties are presented in Table 1.

### 2.3 Experimental setup

A pot experiment was conducted in the net-house of Department of Soil Science of Chittagong University and under natural light conditions. The plastic containers (with a capacity of seven kg) that were obtained for the growing experimentation were thoroughly cleaned using distilled water and 1%  $\text{HNO}_3$ . The plastic containers were filled with moist soil weighing 5 kg when dried. Additionally, 500 mg  $\text{kg}^{-1}$  of Pb (using  $\text{PbNO}_3$ ) (ACS Grade, Sigma-Aldrich Co.) was added in each pot, representing the actual contamination found in Bangladeshi urban soils and Chinese mining soils (Liu et al., 2019). Similar dosages were used in recent pot studies (Rumi et al., 2025). The experiment utilized a two-factor factorial design, focusing on Pb contamination and soil amendment treatments as the primary variables. The amendment treatments comprised one inorganic amendment (lime) and three organic amendments (charcoal, tea waste, and vermicompost), each treated separately at concentrations of 1.0% (50 g  $\text{pot}^{-1}$ ), 2.5% (125 g  $\text{pot}^{-1}$ ), and 5.0% (250 g  $\text{pot}^{-1}$ ), in addition to an unamended control group. Amendments were implemented individually to align with prevalent agricultural techniques in Bangladesh (Das et al., 2022). The factorial design facilitated the assessment of the primary and interacting influences of Pb and the kind and rate of amendments on plant growth and Pb suppression. Plant growth and Pb uptake were evaluated during the initial harvest to detect immediate impacts and at a subsequent harvest without reapplication to ascertain residual effects.

**Table 1.** Physical and chemical properties of soil and amendments. Values are the means  $\pm$ sd.

Parameters	Soil	Charcoal	Tea waste	Vermicompost	Lime
Moisture content (%)	2.78 $\pm$ 0.04	2.50 $\pm$ 0.02	3.78 $\pm$ 0.03	3.89 $\pm$ 0.06	-
Field capacity (%)	37.3 $\pm$ 1.12	-	-	-	-
pH	4.98 $\pm$ 0.03	7.12 $\pm$ 0.06	6.94 $\pm$ 0.05	7.52 $\pm$ 0.05	8.80 $\pm$ 0.09
Sand (2.0–0.05 mm) (%)	69.2 $\pm$ 1.25	-	-	-	-
Silt (0.05–0.002 mm) (%)	13.5 $\pm$ 0.57	-	-	-	-
Clay (< 0.002 mm) (%)	17.3 $\pm$ 0.84	-	-	-	-
Textural class	Sandy Loam	-	-	-	-
Organic carbon (%)	0.75 $\pm$ 0.04	27.47 $\pm$ 0.97	30.22 $\pm$ 1.01	35.15 $\pm$ 1.16	-
Organic matter (%)	1.28 $\pm$ 0.07	47.36 $\pm$ 1.25	51.72 $\pm$ 1.54	60.60 $\pm$ 1.38	-
CEC (cmol kg <sup>-1</sup> )	3.76	-	-	-	-
DTPA-Pb (mg kg <sup>-1</sup> )	nd	-	-	-	-
Total N (%)	0.11 $\pm$ 0.01	1.46 $\pm$ 0.04	1.56 $\pm$ 0.05	1.95 $\pm$ 0.04	-
Total P (%)	0.03 $\pm$ 0.00	0.52 $\pm$ 0.03	0.41 $\pm$ 0.01	1.57 $\pm$ 0.05	-
Total K (%)	0.01 $\pm$ 0.02	1.72 $\pm$ 0.05	0.55 $\pm$ 0.02	1.81 $\pm$ 0.05	-
Total Ca (%)	0.04 $\pm$ 0.00	4.79 $\pm$ 0.09	1.35 $\pm$ 0.04	2.43 $\pm$ 0.07	40.04 $\pm$ 1.33
C:N ratio	6.91 $\pm$ 0.08	18.82 $\pm$ 0.57	19.37 $\pm$ 0.61	18.03 $\pm$ 0.55	-

Every pot was given a standardised basal dose of NPK fertilisers (N-P-K = 137-32-70 kg ha<sup>-1</sup>) as urea (0.75 g pot<sup>-1</sup>), triple super phosphate (TSP) (0.40 g pot<sup>-1</sup>), and muriate of potash (MP) (0.35 g pot<sup>-1</sup>). No amendments were applied to the control treatment (CK), except Pb and NPK fertilizers. Details on the experimental design are provided in Table 2.

The Pb salt, amendments and NPK fertilizers were carefully mixed with the soil in a 10-L plastic bags r 20 minutes before filling the pot. There were no apparent particles of Pb salt, amendments, or NPK fertilizers detected following the mixing process. Every pot was carefully set alongside a plastic bag to ensure no metals or nutrients would leach into the contents. Before starting the experiment in the pot, the treated containers had been incubated for two weeks to ensure they maintained field capacity. Employing a completely randomized design (CRD), three sets of experimental pots were utilized.

**Table 2.** Details of the design of the pot experiment

Treatments	Soil (kg)	Charcoal (%)	Tea waste (%)	Vermicompost (%)	Lime (%)	Water (L)
Control	5	-	-	-	-	1.12
Charcoal-1.0	5	1.0	-	-	-	1.12
Charcoal-2.5	5	2.5	-	-	-	1.12
Charcoal-5.0	5	5.0	-	-	-	1.12
Tea waste-1.0	5	-	1.0	-	-	1.12
Tea waste-2.5	5	-	2.5	-	-	1.12
Tea waste-5.0	5	-	5.0	-	-	1.12
Vermicompost-1.0	5	-	-	1.0	-	1.12
Vermicompost -2.5	5	-	-	2.5	-	1.12
Vermicompost -5.0	5	-	-	5.0	-	1.12
Lime-1.0	5	-	-	-	1.0	1.12
Lime-2.5	5	-	-	-	2.5	1.12
Lime-5.0	5	-	-	-	5.0	1.12

In every pot seven Napier grass seeds (*Pennisetum purpureum* S.) were placed. After five days of sowing, plants were thinned to three per pot. Regularly water was added to maintain field capacity throughout the growing phase.

#### 2.4 Plant growth parameters, tissue analysis and bioaccumulation factor

Plants were harvested twice from the identical pots over 87 days' duration. The initial harvest occurred 45 days post-planting, involving the cutting of shoots (leaves and stems) just above the roots, which were preserved to facilitate regeneration without additional modification. The second and final cut occurred 42 days subsequently. Only the shoots were examined, as the roots of Napier grass are inedible.

Following each harvest, measurements of shoot height, leaf count, fresh weight, and dry weight were documented. Shoots were subjected to oven drying at 68°C for a maximum of 72 hours, thereafter crushed, and digested with concentrated HNO<sub>3</sub> (Zheljzakov and Warman, 2002). In summary, 0.5 g of plant tissue was subjected to digestion with 5 mL of HNO<sub>3</sub> at 90 °C for 45 minutes and at 140 °C for a minimum of 8 hours, subsequently diluted to 25 mL, and filtered. Lead concentration was assessed by AAS, Pb accumulation was measured from concentration and dry weight.

#### 2.5 Post-cut soil characterization

Following the first and second cuts of Napier grass, approximately 200g of soil was taken

from each pot at five separate locations using a hand auger at a depth of 0-15 cm, and the combined samples were air-dried, crushed, and sieved (2 mm). The pH and DTPA-extractable Pb content of the pot soil were determined. The soil pH and DTPA-extraction Pb were determined.

## 2.6 Statistical analysis

To ensure the purity of the reagent, a reagent blank was utilized. The mean values of triplicate samples, as well as the standard deviation (SD) of the examined parameters, were calculated using Microsoft Excel (2013). For soil samples, the maximum relative SD allowed between repetitions was set at 5%, while for plant samples, it was set at 8%. For soil samples, Pb recovery rates varied from 82% to 95%, while for plant samples, Pb recovery rates ranged from 92 to 97%. All the results were statistically presented on a dry weight (DW) basis using the Pearson correlation coefficient, and the resulting data were subjected to one way analysis of variance using the SPSS ver. 22 software (SPSS Inc., USA). Tukey's HSD test was used to determine the significance of different treatments on various indices, with  $p < 0.05$  being the level of significance.

## 3. Results

### 3.1 Effects of amendments on shoot height

As demonstrated in Table 3, the shoot height of Napier grass differed significantly with the charcoal, tea waste, vermicompost, and lime treatments due to either direct effects for the first cut or residual effects for the second cut of the grass. At the first cut of the plant, the pot treated with lime at a rate of 5.0 % had the highest and charcoal at a rate of 1.0 % had the lowest shoot height. The highest dose of vermicompost, charcoal and tea waste showed similar shoot weight as observed with 2.5% lime in the second cut. Irrespective of the lime treatments shoot height was 117 – 160% higher in the first cut than in the second cut (Table 3). However, in the second cut, vermicompost at 5.0% had higher residual effects on shoot weight compared to the other three amendments Vermicompost at a dose of 2.5 % had similar effects as that of lime at 2.5% but higher than that of charcoal at a dose of 2.5 % and tea waste at a dose of 2.5 % (Table 3).

### Number of leaves per pot

As seen in the instance of plant height, tea waste, lime, and vermicompost, each at a dose of 5.0%, had the highest number of leaves while charcoal at a dose of 1.0% had the lowest in the first cut of the plant (Table 3). In contrast, vermicompost, at both 2.0% and 5.0%, provided the highest number of leaves at the second cut of the plant. Tea waste at 2.5% yielded the same number of leaves as the lime at 2.5% treatment. Moreover, at the second plant cut, few rates of tea waste and vermicompost treatments led to an increase in the number of leaves compared to the first plant cut, but all lime treatments resulted in a decrease of the number of leaves (Table 3).

### Dry weight

For all treatments dry weight of Napier grass was higher in the second cut than in the first cut showing 0.16-5.82 g pot<sup>-1</sup> and 0.18-8.32 g pot<sup>-1</sup> in the two cuts, respectively. The control treatment (no tea waste, vermicompost or lime) had the lowest result. In case of the second plant cut, vermicompost at a dose of 5.0% had the highest dry weight of shoots (8.32 g pot<sup>-1</sup>), followed by tea waste at 5.0% (5.82 g pot<sup>-1</sup>) and lime at 5.0% (5.40 g pot<sup>-1</sup>). Compared to lime at a rate of 5.0%, the vermicompost at 5.0% supplied 140% lower shoot dry weight at the first cut but 6.5% higher shoot dry weight at the second plant cut (Table 3).

### 3.2 Effects of amendments on Pb concentration of plant

The Pb concentration of Napier shoots at the first and second cuttings was illustrated in Table 4. Results revealed that Pb concentration of shoots at both cuts went down greatly as a consequence of the inorganic and organic amendments compared to control. Lime at a rate of 5.0% and vermicompost at a dose of 5.0% had the greatest effect while lime at a dose of 1.0% had the least effect on Pb concentration of shoots as compared to control at the first cut. Similar effect was observed in the second cut of the plant where vermicompost and lime had similar impact on the suppression of Pb uptake by the plant. Among organic amendments, vermicompost was found to be more effective than other two organic amendments in reducing Pb concentrations of plant shoots (Table 4).

### 3.3 Effects of amendments on DTPA extractable Pb

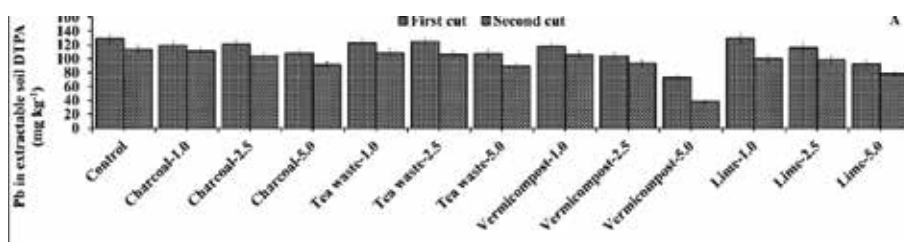
As shown in Fig. 1, DTPA extractable Pb declined markedly in all amended soils compared with the control, with greater reductions at higher amendment rates. At the first plant cut, lime at 5.0% showed the greatest reduction, followed by vermicompost at 5.0%, while charcoal at 1.0% had the least effect (Fig. 1A). DTPA-extractable Pb in charcoal 5.0% and tea waste 5.0% was comparable to that in lime 2.5%. Residual effects showed that vermicompost 5.0%, followed by charcoal 5.0%, tea waste 5.0%, and lime 5.0%, produced the greatest reduction, whereas lime 1.0% showed the least effect. Treatments with charcoal 2.5%, tea waste 2.5%, and vermicompost 2.5% were comparable to lime 2.5%. However, compost at 5.0% resulted in 0.80-fold lower DTPA-extractable Pb (Fig. 1).

**Table 3.** Effects of charcoal, tea waste, vermicompost, and lime on the shoot height, number of leaves, and dry weight of Napier grass at two consecutive plant cuts. Values are the mean  $\pm$  standard deviation (n = 3).

Treatments	Shoot height (cm)		Total no. of leaves (per pot)		Dry weight (g pot <sup>-1</sup> )	
	First cut	Second cut	First cut	Second cut	First cut	Second cut
Control	23.17d $\pm$ 1.73	14.44d $\pm$ 2.37	4.67c $\pm$ 0.58	4.33c $\pm$ 0.58	0.16e $\pm$ 0.02	0.18f $\pm$ 0.02
Charcoal-1.0	19.83d $\pm$ 2.01	24.83d $\pm$ 2.25	3.00d $\pm$ 0.5	4.11d $\pm$ 0.68	0.25f $\pm$ 0.04	0.29e $\pm$ 0.03
Charcoal-2.5	30.22c $\pm$ 2.67	33.28c $\pm$ 5.58	4.00d $\pm$ 0.33	4.56c $\pm$ 0.20	0.74e $\pm$ 0.22	1.32d $\pm$ 0.30
Charcoal-5.0	36.67c $\pm$ 11.27	44.72bc $\pm$ 7.35	4.22c $\pm$ 0.69	5.11c $\pm$ 0.19	1.81c $\pm$ 0.70	3.03 c $\pm$ 0.75
Tea waste-1.0	22.33d $\pm$ 1.16	26.55c $\pm$ 4.34	4.00d $\pm$ 0.00	5.00b $\pm$ 0.33	0.50e $\pm$ 0.21	0.52e $\pm$ 0.11
Tea waste-2.5	26.10d $\pm$ 3.91	30.89c $\pm$ 7.61	5.00c $\pm$ 0.00	5.67a $\pm$ 0.00	1.16dc $\pm$ 0.29	1.22d $\pm$ 0.20
Tea waste-5.0	61.22b $\pm$ 5.89	48.33b $\pm$ 10.59	5.89c $\pm$ 1.02	6.67a $\pm$ 0.58	5.82ab $\pm$ 1.85	6.67 a $\pm$ 2.20
Vermicompost-1.0	19.89d $\pm$ 6.04	21.33d $\pm$ 7.79	3.11d $\pm$ 0.70	5.44b $\pm$ 0.51	0.37ef $\pm$ 0.08	0.43e $\pm$ 0.32
Vermicompost-2.5	48.44c $\pm$ 1.90	57.8a $\pm$ 20.1	5.56ab $\pm$ 0.96	5.56a $\pm$ 0.51	3.51b c $\pm$ 0.32	3.94 b $\pm$ 0.52
Vermicompost-5.0	58.78b $\pm$ 4.30	60.89a $\pm$ 9.31	6.00a $\pm$ 0.33	6.23a $\pm$ 0.51	4.76b $\pm$ 0.64	8.32a $\pm$ 1.38
Lime-1.0	49.22b $\pm$ 6.87	58.89b $\pm$ 0.84	5.12b $\pm$ 0.51	5.67ab $\pm$ 0.34	2.20c $\pm$ 0.38	3.47bc $\pm$ 0.35
Lime-2.5	57.67a $\pm$ 7.86	64.33ab $\pm$ 5.69	5.22b $\pm$ 1.17	5.45b $\pm$ 0.39	3.28 b $\pm$ 0.23	5.01ab $\pm$ 1.05
Lime-5.0	50.89b $\pm$ 5.17	71.33a $\pm$ 4.93	5.44ab $\pm$ 0.20	6.00a $\pm$ 0.58	5.40b $\pm$ 0.95	6.65a $\pm$ 0.64

**Table 4.** Effects of charcoal, tea waste, vermicompost, and lime on the uptake and accumulation of Pb in the shoots of Napier grass at two consecutive plant cuts

Treatments	Shoot Pb uptake	Pb accumulation in shoots
	(mg kg <sup>-1</sup> )	(mg pot <sup>-1</sup> )
	First cut	Second cut
Control	23	19.33
Charcoal-1.0	21	17
Charcoal-2.5	13.83	15.67
Charcoal-5.0	10.83	8.17
Tea waste-1.0	18.5	14.33
Tea waste-2.5	14.17	10.83
Tea waste-5.0	8.53	7.17
Vermicompost-1.0	19.67	17
Vermicompost-2.5	9.67	5.83
Vermicompost-5.0	5.17	3.67
Lime-1.0	8	6.67
Lime-2.5	5	5.33
Lime-5.0	4	3.67



**Fig. 1** Effects of charcoal, tea waste, vermicompost and lime on the DTPA-extractable soil Pb at two consecutive plant cuts of Napier grass.

#### 4. Discussion

Role of lime was great on the growth of plants when grown in acid soils, particularly below pH 5.5. Organic amendments, including charcoal, tea waste, and vermicompost, also significantly enhanced plant growth and productivity in terms of plant height, leaf number and dry weight (Ali et al., 2020; Lwin et al., 2018; Yang et al., 2020).

Comparison between inorganic and organic treatments showed that inorganic amendments exerted a stronger short-term effect on plant growth compared to organic amendments (Hamid et al., 2020; Lwin et al., 2018). Accordingly, liming at 5.0% rate—produced superior growth performance at the first cut in comparison with the organic amendments, in agreement with previous studies (Hamid et al., 2020; Ali et al., 2020). However, the residual effects of lime at the second cut were lower than those of charcoal, tea waste, and vermicompost. This difference may be attributed to the rapid nutrient release from inorganic amendments, which provides nutrients for a limited period, whereas organic amendments function as slow-release nutrient sources that sustain nutrient availability and biomass production over time (Ali et al., 2020).

The lower Pb uptake of Napier grass treated with charcoal, tea waste, vermicompost, and lime compared with the control can be explained by the enhanced Pb suppression capacity of these amendments, as reported in the past (Hamid et al., 2020; Ali et al., 2020; Hussain et al., 2018). Similar reductions in Pb uptake following the application of vermicompost, charcoal, tea waste, and lime have been reported for various crops (Hussain et al., 2018; Ali et al., 2020).

The reduced DTPA-extractable Pb in amended soils compared with the control further indicates reduced Pb availability for plant uptake. Organic matter stabilizes Pb through adsorption and organic-metal complexation, converting labile Pb fractions into more stable forms and reducing mobility and availability (Rumi et al., 2025). Lime similarly reduces Pb availability by elevating soil pH and facilitating Pb adsorption or precipitation (Hamid et al.,

2020). In this study, charcoal, tea waste, vermicompost, and lime likely enhanced Pb stabilization through ion exchange, chelation, and co-precipitation, thereby inhibiting Pb uptake by Napier grass (Hamid et al., 2020; Negawo et al., 2017).

## 5. Conclusions

Our findings revealed that using charcoal, tea waste, and vermicompost resulted in improved plant growth and Pb suppression in Napier grass up to the second cut. Liming had also positive effect. In particular, vermicompost at the rate of 5.0% was found as the best treatment with regards to improving growth metrics and reducing Pb uptake in Napier grass. Thus, application of vermicompost at a rate of 5.0% can be recommended to Napier grass producers as a viable alternative to inorganic fertilizer for the optimum direct and residual crop performance.

## Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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