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ARTICLE

Efficiency of Elephant Grass (Cenchrus purpureus) as Bioaccumulator Plant and Soil Weathering Enhancer

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ABSTRACT

The increasing challenges of environmental degradation, soil erosion, and climate change have driven interest in sustainable solutions like enhanced weathering (EW) and phytoremediation. Elephant Grass (*Cenchrus purpureus*), a fast-growing perennial species, shows promise as a bioaccumulator and agent for soil weathering. This study assessed the potential of *C. purpureus* to improve soil quality through heavy metal (HM) uptake and EW facilitation. A 60-day greenhouse pot experiment at Jackson State University evaluated plant performance in soils amended with metabasalt rock powder at 1:1 and 2:1 rock-to-soil ratios. Biomass, growth, and HM concentrations in roots and shoots were measured via ICP-MS after wet digestion. Soil pH and magnesium (Mg) release were also monitored to assess weathering and carbon drawdown. Results showed that *C. purpureus* accumulated more HMs in roots at higher amendment levels, while at lower levels, metals like As, Cd, and Cr were more translocated to shoots, enhancing phytoextraction potential. High treatment favored Fe and Al uptake, possibly reducing toxic metal accumulation in edible parts. Notably, *C. purpureus* contributed to the weathering of 38% of metabasalt rock, leading to a 42% increase in Mg release. With high biomass, HM tolerance, and weathering capacity, *C. purpureus* offers a sustainable strategy for soil remediation, improved soil health, and potential support for renewable energy systems.

Keywords: Elephant Grass (*Cenchrus purpureus*); Phytoremediation; Heavy Metals; Bioenergy; Soil Enhancer

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1. Introduction

The rising global concern over environmental pollution and climate change has spurred research into innovative solutions that can address both issues simultaneously [1] . In addition, an alarming rate of topsoil loss and erosion has been observed globally [2] leading to the depletion of essential soil minerals and an increase in carbon dioxide (CO_2) emissions into the atmosphere. This environmental degradation poses a significant challenge to both soil health and climate stability. To address these issues, enhanced weathering (EW) has been proposed as a promising approach. EW works by accelerating the interaction between rock materials and CO_2, thereby facilitating the sequestration of CO_2 as stable minerals or increasing soil alkalinity. These processes not only capture CO_2 and store it in the soil but also enhance soil health by replenishing lost minerals. To minimize the potential risks of heavy metal (HM) pollution from EW, phytoremediation has been proposed as a viable strategy. Phytoremediation is a safe, sustainable, and environmentally friendly method that utilizes bioenergy plants to prevent the accumulation and contamination of soils with heavy metals [3,4] . These bioenergy plants, known as hyperaccumulators, are capable of producing high biomass and can effectively accumulate heavy metals, thereby removing various concentrations of these pollutants from the soil [5]. This study tested the ability of *Cenchrus purpureus*, commonly known as Elephant Grass, in the removal of heavy metals from contaminated environments. Elephant grass is a member of the subfamily Panicoideae within the Poaceae family and is considered one of the most significant forage species and potential energy grasses in tropical and subtropical regions of Asia, Africa, and the Americas [6–8]. Recent studies have also shown that elephant grass, being a lignocellulosic plant, holds significant potential for bioenergy and paper production [9]. For instance, the alcohol yield and calorific value of elephant grass are three times higher and 0.7 times that of switchgrass and coal, respectively [10] . Moreover, elephant grass can serve as an ecological species that enhances soil fertility and protects against soil erosion, thanks to its extensive root and tiller growth [11]. Besides, to be a rapid growth, an effective phytoremediator must exhibit high tolerance to pollutants and have the capacity to either degrade or accumulate significant levels of pollutants in its biomass [12]. According to [13], *C. purpureus* (elephant grass) can thrive in highly contaminated environments. [14,15] also demonstrated that *C. purpureus* shows resistance to media contaminated with heavy metals, including soil with elevated copper levels in a pot trial and solutions containing stable caesium. The main objectives of this work are to: (1) evaluate the capability of Elephant grass (*Cenchrus purpureus*) in capturing the HMs in its tissues; (2) perform the ability of elephant grass to sequestrate the carbon from the soil; and (3) quantify the energy content, combustion efficiency, and compatibility with various bioenergy conversion technologies such as bioethanol fermentation and pyrolytic conversion.

2. Material and Methods

This study investigates the capability of *C. purpureus* to absorb contaminants from the environment and its potential for bioenergy production and weathering Enhancer.

2.1. Study Design and Plant Material

A pot experiment was conducted in a greenhouse at Jackson State University over a 60-day period to evaluate the impact of phytoremediation plants on the uptake of heavy metals (HMs) from rock-amended soils. Twelve Cenchrus purpureus (Elephant Grass) plants were used, with three replicates for each treatment group. Three of the replicates served as controls, while the other nine pots received varying concentrations of rock powder amendments: low, and high (1:1, and 2:1 rock powder to soil ratios). Each pot had a diameter of 20–30 cm and was filled with a mixture of potting soil. The rock powder was applied to a 2 cm layer on top of the soil in the amended pots. The pots were placed in the greenhouse under normal conditions, with temperatures ranging from 20 °C to 25 °C, and consistent sunlight and humidity levels from September to December. Irrigation was applied every two days to prevent drought, nutrient loss, and solute accumulation near the soil surface (as shown in **Figure 1**). At the end of the experiment, fresh biomass samples were collected, including leaves, stems, roots, and soil. These samples were then dried at temperatures between 70 °C and 100 °C to assess dry matter yield.

(**a**) (**b**)

Figure 1. Experimental setup of *Cenchrus purpureus* after application of the rock powder: (**a**) starting treatment of the plants with different levels of rock amendment powder; and (**b**) after months of treating the plants with the rock amendment. Plant samples were analyzed separately for heavy metals (e.g., Zn, Cd, Pb, Cr, Ni) and major nutrients (e.g., Mg) to examine the ability of elephant grass to uptake different concentrations in their tissues.

2.1.1. Plant and Soil Analysis

The prepared samples were subjected to wet digestion using a mixture of HNO_3 and H_2O_2, following the method outlined by [16]. After digestion, the samples were filtered and analyzed using ICP-MS. Previous studies have shown that these techniques are effective in providing detailed information on plant uptake from contaminated soils, as demonstrated in the tissues of *C. purpureus* [12–17], and in soil samples [18].

2.1.2. Soil pH Analysis

Soil pH is typically measured potentiometrically in a soil-water slurry system using an electronic pH meter [19]. It is important to regularly check the electrode to prevent residue buildup, which could interfere with its function. The electrode should also be kept in a manner that prevents it from being inserted too deeply into the slurry vessels. Additionally, it is recommended to rinse the electrode with a soil-water solution between each soil sample[20]

2.2. Weathering and CO_2 Drawdown Rates

We estimated that *C. purpureus* can play a significant role in understanding soil weathering processes, particularly in measuring the release of magnesium (Mg) and assessing CO_2 drawdown rates [21]. In our experiment, magnesium will be supplied by both the natural presence in the soil and additional sources derived primarily from metabasaltic rocks which estimate the amount of rock weathering rates based on magnesium (Mg) balance following [22]. The amount of metabasalt weathered corresponds to the Mg accumulated in the soil (Mg soil, g pot^{-1}) and in the plant biomass (Mg plant, g pot^{-1}) in excess of that amount in the control soils. The mass fraction of metabasalt weathered (Fweath) relative to metabasalt applied (Mg applied rock) is then written as:

$$Fweath\,\% = \frac{\left[Mg_{applied\_rock} - (Mg_{soil} + Mg_{plant})_{rock} - (Mg_{soil} + Mg_{plant})_{control}\right]}{Mg_{applied_{rock}}} \times 100 \quad (1)$$

where the Mass Fraction of metabasalt in brackets refer to rock treatment with metabasalt and control soil. Mg applied in the form of metabasalt is calculated in g pot^{-1}.

2.3. Bioaccumulation and Translocation Factor Calculation

The bioaccumulation factor and translocation factor were estimated as two key methods for the evaluation of *C. purpureus*'s metal accumulation efficiency using the following two formulas:

$$BCF = \frac{Cplant}{Csoil} \quad (2)$$

where C plant is the metal concentration in the plant (roots and shoots) and C soil is the metal concentration in the soil after the rock experiment.

$$TF = \frac{Cshoots}{Croots} \quad (3)$$

where concentration in shoots is the metal concentration in the shoots and concentration in roots is the metal concentration in the roots after the rock addition.

BCF is expressed as the ratio of metal in the plant to that in the soil, while TF is expressed as the ratio of the metal in the aerial parts to the roots.

2.4. Statistical Analysis

All data were analyzed using Microsoft Excel. The average concentrations of heavy metals in shoots and roots, biomass, soil carbon percentage, and Fweath% were calculated. Statistical analyses were performed to assess differences between treatment groups for each of the variables.

3. Result and Discussion

3.1. Efficiency of *C. purpureus* in Remediation of HM from High Metabasaltic Soil Treatment in Shoots and Roots

Figure 2 illustrates the varying capacity of C. purpureus tissues to accumulate heavy metals (HMs) under high-concentration rock powder amendments (2 parts rock powder: 1 part soil). The results demonstrate that roots accumulate significantly greater amounts of HMs compared to shoots. This trend is consistent for all tested metals (As, Cd, Co, Cr, Ni, Pb), highlighting the preferential sequestration of contaminants in root tissues. The higher metal accumulation in roots suggests a potential defense mechanism, where the plant restricts translocation to aboveground tissues to mitigate toxicity in photosynthetic organs.

Notably, Fe and Al showed distinct patterns of accumulation, with Fe displaying the highest uptake in shoots, particularly under high treatment, followed by Al. However, despite the increased shoot accumulation, the roots still exhibited higher uptake levels of Fe and Al compared to the shoots. This selective uptake of Fe and Al, particularly under high treatment, may be attributed to the competition between essential and non-essential metals at root absorption sites, influencing their bioavailability and mobility.

Moderate Cu accumulation was observed in the roots, though levels remained higher than in shoots. Mn and Zn displayed minimal uptake in both plant tissues, indicating lower bioavailability or selective exclusion mechanisms. These findings suggest that *C. purpureus* can efficiently extract and retain toxic metals primarily in root tissues under high metal concentrations, which could have implications for stabilizing contaminated soils without introducing metals into the food chain.

3.2. Efficiency of *C. purpureus* in Remedi - ation of HM from Low Metabasaltic Soil Treatment in Shoots and Roots

Figure 3 illustrates the uptake of HMs by *C. purpureus* under low rock powder treatment (1 part rock powder: 1 part soil). Interestingly, the results indicate that both roots and shoots accumulate significantly higher levels of HMs under low treatment compared to high treatment. This suggests that lower concentrations of rock amendments enhance metal mobility and bioavailability, potentially due to changes in soil chemistry and cation exchange dynamics.

For all metals (As, Cd, Co, Cr, Ni, Pb), root uptake remains slightly higher than in shoots, reinforcing the preferential sequestration in belowground tissues. However, Fe remains the most dominant metal in shoots under low treatment, followed by Al. The higher accumulation of Fe and Al in shoots under low treatment might be influenced by plant metabolic needs for these elements, as Fe is crucial for chlorophyll synthesis and enzyme activity.

In contrast to the high treatment condition, Zn, Mn, and Cu showed increased uptake in shoots under low treatment. This suggests that at lower contamination levels, metal translocation to aerial parts is enhanced, potentially improving phytoextraction efficiency.

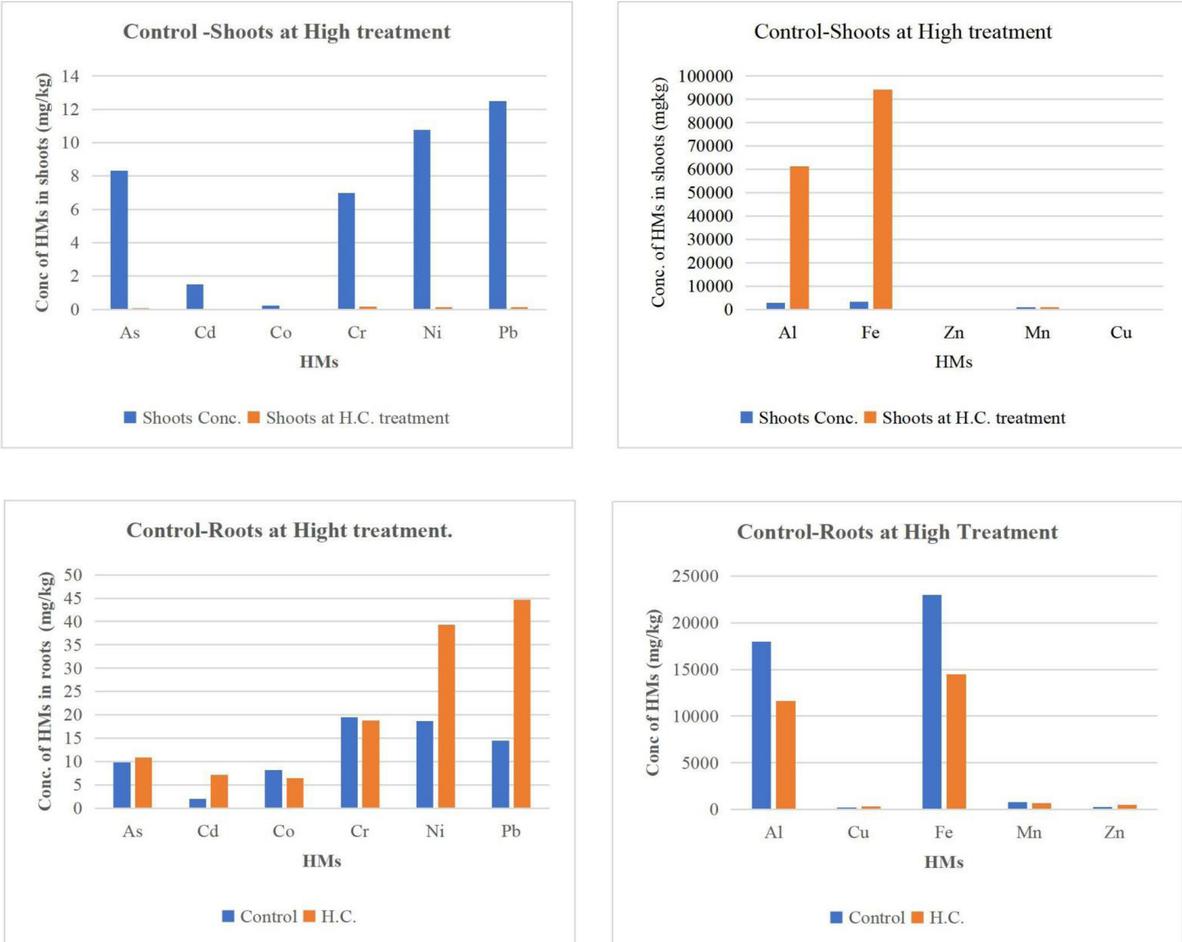

Figure 2. Efficiency of *C. purpureus* in uptake of HMs at high concentration treatment of rock in shoots and roots.

These findings suggest that selecting between high and low rock powder treatments depends on the intended remediation strategy. Low treatment conditions favor metal uptake and translocation, making it more effective for phytoremediation by promoting the removal of toxic metals such as Cr, Ni, and Pb from the soil. In contrast, high treatment conditions prioritize Fe and Al accumulation, reducing the bioavailability of more toxic metals in edible plant parts, thus ensuring agricultural safety [23].

Figure 4 illustrates the differential uptake of heavy metals (HMs) by *C. purpureus* under varying treatment conditions. The data reveal that under low treatment conditions (1:1 rock powder to soil), there is an enhanced accumulation of key toxic metals such as Cr, Ni, and Pb in both shoots and roots. This increased uptake highlights the plant's potential for phytoremediation, particularly in soils with moderate contamination levels. The ability of *C. purpureus* to sequester these metals suggests its suitability for environmental detoxification applications.

In contrast, under high treatment conditions (2:1 rock powder to soil), the uptake pattern shifts significantly, favoring Fe and Al accumulation in both plant tissues. The preferential absorption of Fe and Al likely occurs due to their increased availability in the amended soil, which may suppress the uptake of more toxic elements such as Pb, Cd, and Cr. While this selective absorption reduces the bioavailability of harmful metals in plant tissues—potentially making the crops safer for agricultural use—it also raises concerns about potential physiological stress.

Excessive accumulation of Fe and Al in plant tissues can lead to oxidative stress, interfere with essential nutrient uptake, and ultimately impair overall plant health and biomass production. This observation aligns with previous findings that excessive Fe and Al can induce metabolic imbalances and limit plant growth [21,24].

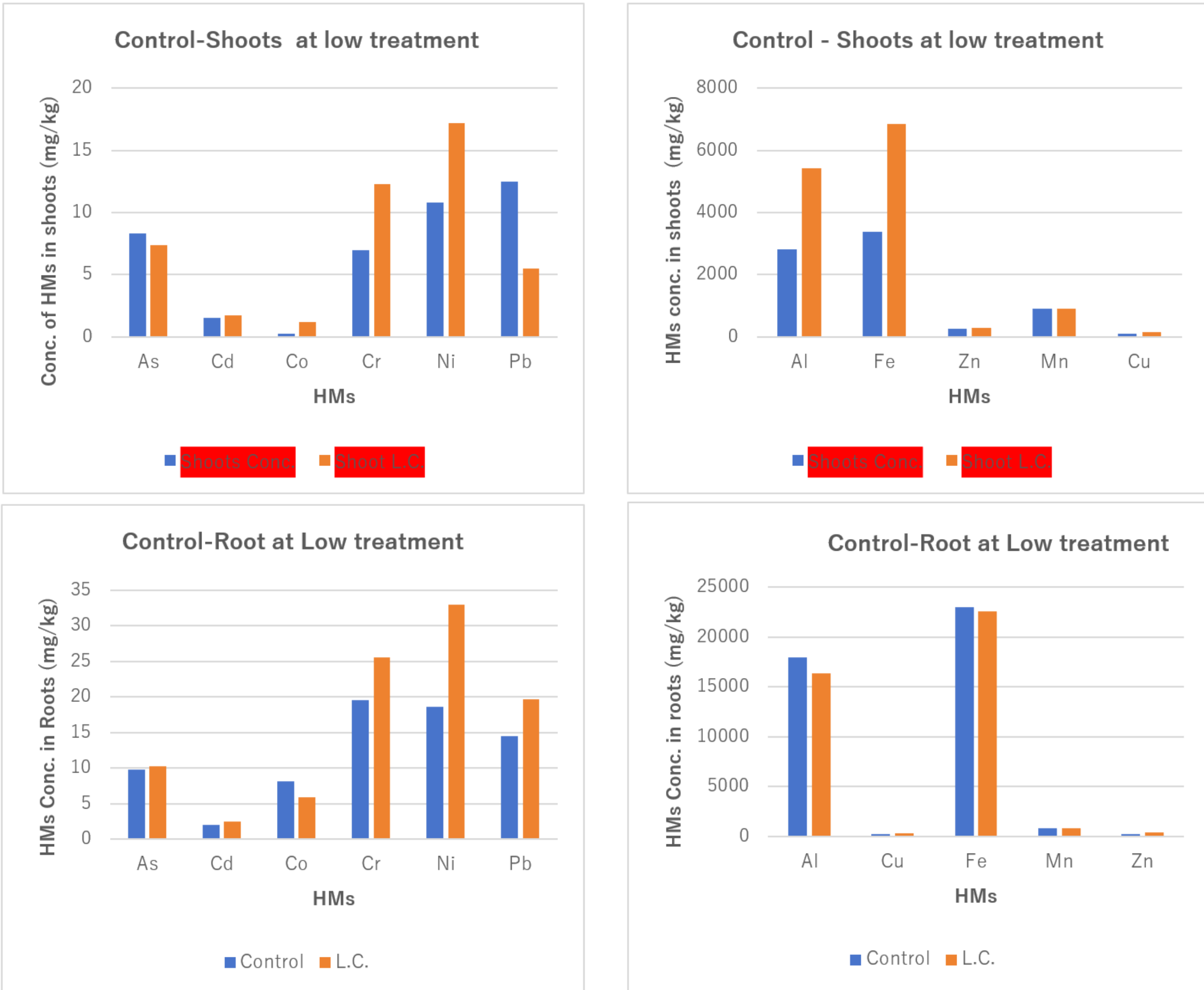

Figure 3. Efficiency of *C. purpureus* in uptake of HMs at low concentration treatment of rock in shoots and roots.

Moreover, these results suggest that the choice of rock amendment treatment should be carefully considered based on the intended application. The low-treatment approach appears more effective for phytoremediation, facilitating a broader range of HM uptake. In contrast, the high-treatment approach could be better suited for agricultural contexts where limiting toxic metal uptake is desirable, though potential Fe and Al stress must be managed. This nuanced understanding underscores the importance of balancing soil amendments to optimize both remediation potential and plant health.

3.3. Bioaccumulation Factor (BCF) and Translocation Factor (TF) of *Cenchrus purpureus*

Figure 5 evaluates the bioaccumulation and translocation efficiency of *C. purpureus* for HMs under different treatments. Under low treatment, there is a stronger accumulation of As, Cd, and Cr, indicating that *C. purpureus* is more effective at absorbing these metals when soil contamination is moderate. This suggests its potential use as a phytoremediation species for soils with low to moderate metal contamination [25].

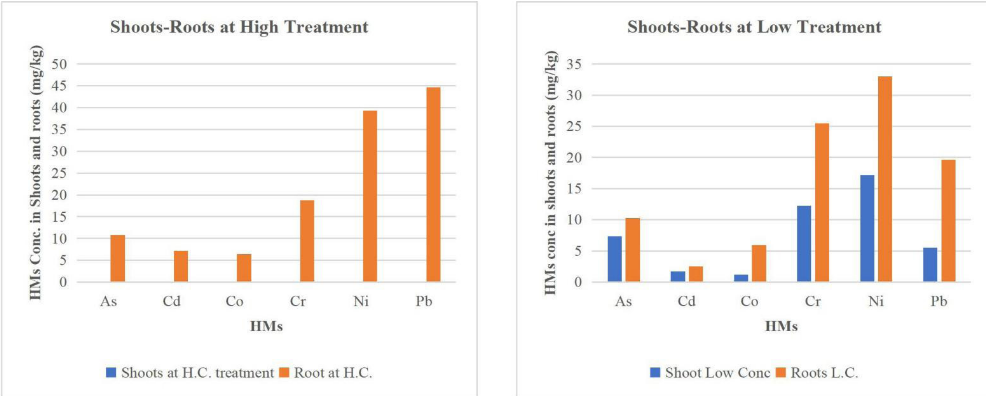

Figure 4. Capability of shoots and roots in uptake of the HMs under different treatment of rock amendment.

Under low treatment conditions, As, Cd, and Co exhibited higher translocation to shoots, enhancing the feasibility of phytoextraction through harvesting. This characteristic is advantageous for remediating lightly contaminated soils, where repeated harvesting can progressively decontaminate affected areas [4]. However, under high treatment conditions, metal translocation was limited, except for Cu, which showed higher mobility. Pb, in particular, accumulated predominantly in roots with minimal translocation to shoots, potentially due to a plant defense mechanism that restricts Pb movement to avoid toxicity in aerial tissues [26].

The bioaccumulation and translocation factors highlight the plant's adaptability to different contamination levels, suggesting its role in long-term remediation efforts. The limited translocation of highly toxic metals under high treatment conditions may indicate that *C. purpureus* could be used for phytostabilization in severely polluted areas, whereas its higher translocation efficiency under low treatment favors phytoextraction.

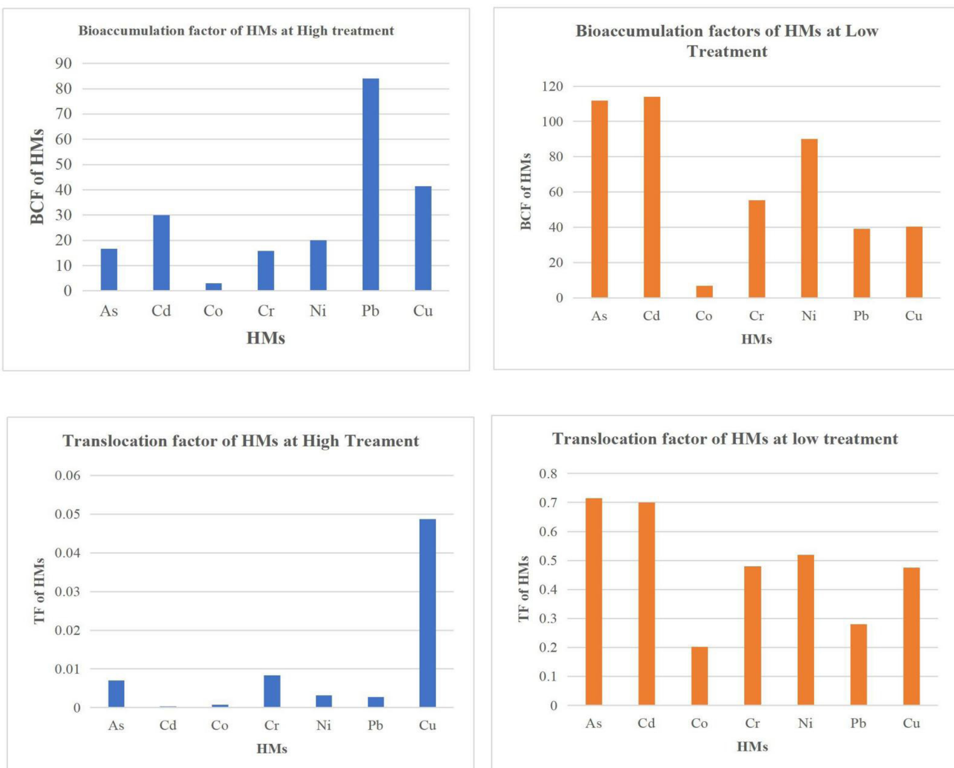

Figure 5. BCF and TF of heavy metals at hight treatment and Low treatment using *C. purpureus*.

3.4. Bioweathering

Using Equation (1), we calculated the fraction of rock weathering over the 3-month experiment, which revealed a 38% weathering rate in soils planted with *C. purpureus*. Further estimations using [27] indicate an enhancement rate of ~42% due to plant presence. **Table 1** confirms the impact of *C. purpureus* on mineral weathering, showing significant Mg mobilization.

$$Enhancment\ \% = \left(\frac{F\ plant - F\ soil}{F\ soil}\right) * 100 \qquad (4)$$

Table 1. Estimation of rock weathering using fraction weathering (F_{weath}%) calculation method based on magnesium (Mg).

Soil ID	F. Weather (%) Mg in Soil	F. Weather (%) Mg in Plants
F. Weather (%)	26.70	38%

These findings align with previous studies [21,24], emphasizing the role of *C. purpureus* in enhancing mineral weathering and carbon sequestration. The extensive root system of elephant grass, along with its high biomass production, promotes nutrient cycling and rock dissolution. Root exudates containing organic acids, such as citric and oxalic acids, further facilitate Mg release, enhancing soil fertility and weathering rates [28].

3.5. Plant Growth and Biomass and Its Potential as Bioenergy and Weathering Enhancer

The biomass analysis (**Figure 6**, **Table 2**) indicates that rock amendments led to increased shoot and root biomass in *C. purpureus* compared to control plants. The treated plants showed a steady increase in biomass over three months, reaching 33.80 g compared to the control's 18.18 g. This suggests that rock amendments contribute to improved plant vigor and productivity, further supporting its viability as a bioenergy crop.

The rapid growth rate of *C. purpureus* (40–60) tons per hectare per year, [29] and its potential for multiple harvests per year enhance its role in sustainable biofuel production. Additionally, its deep root system not only aids in HM remediation but also plays a critical role in carbon sequestration, as previously reported [30,31].

Figure 6. The change in biomass comparison of Elephant Grass (*Cenchrus purpureus*) plants subjected to different treatments of rock amendment and periods: (**a**) plants before harvesting, (**b**) plants after harvesting, (**c**) separating the plants from the soil, and (**d**) collecting some physiological analysis related to biomass before digestion.

Table 2. Plant biomass (g) in different tissues under control versus rock-amended soils and at different periods.

Tissues	Control	Treated Plant 1 after One Month	Treated Plant 2 after Two Months	Treated Plant 3 after Three Months
Shoots	8.36	11.25	14.56	18.35
Roots	9.82	10.09	12.23	15.45
Total Biomass	18.18	21.34	26.79	33.80

3.6. Soil Carbon Content

Table 3 highlights a substantial increase in soil carbon content post-planting, from 6.80% to 20.06%. This increase is attributed to enhanced root biomass and microbial interactions, which promote organic matter accumulation. The ability of *C. purpureus* to enhance carbon sequestration aligns with studies on perennial grasses improving soil health and reducing atmospheric CO_2 [32,33].

Table 3. Carbon content in the Soil before and after planting *C. purpureus*.

Soil ID	Total C %
Sample before planting	6.80
Sample 1 after planting	15.30
Sample 2 after planting	20.06

3.7. Analysis of pH and Impact on HM Release

The pH analysis (**Table 4**) shows an increase in soil pH from 6.80 (control) to 7.50 (rock amended). This shift may influence HM solubility and uptake, as previously observed [34,35]. The enhanced uptake of Cu and Pb correlates with increased pH, suggesting potential pH-mediated bioavailability changes.

A comparison of the background soil conditions before and after the addition of rock amendments revealed notable differences in heavy metal (HM) concentrations. Consistent with findings from a related study (Naira et al., under review), the results demonstrated that HM levels were generally higher in rock-amended soils compared to the control soil, with the exception of Cu. Interestingly, Cu concentrations were found to be higher in the control soil than in the rock-treated soil (**Figure 7**).

Several factors could explain this observed trend. One possible explanation is the influence of the soil's parent material, which may have naturally higher Cu content. Local environmental conditions, particularly soil pH, could also play a critical role in Cu mobility and availability. Prior research suggests that lower soil pH can increase the solubility of Cu, leading to higher bioavailability in untreated soils [36]. In contrast, the addition of rock amendments may have altered soil chemistry, potentially increasing pH and thereby reducing Cu solubility. This effect could lead to lower extractable Cu concentrations in the amended soil despite the overall increase in HM content due to the rock amendment.

Additionally, Cu behavior in soil is influenced by interactions with organic matter, competing metal ions, and mineral binding sites. It is possible that in the control soil, Cu remains in a more bioavailable form, while in the rock-treated soil, it may become more tightly bound to soil particles or precipitated as less soluble compounds. This trend aligns with previous studies indicating that rock amendments can modify metal speciation and availability, thereby affecting uptake potential and overall metal distribution in the soil matrix.

These findings emphasize the complexity of HM dynamics in amended soils and highlight the need for further investigation into metal interactions, particularly Cu speciation and mobility, in response to different soil treatments. A better understanding of these mechanisms can help refine soil remediation strategies and optimize the use of rock amendments for controlling heavy metal contamination.

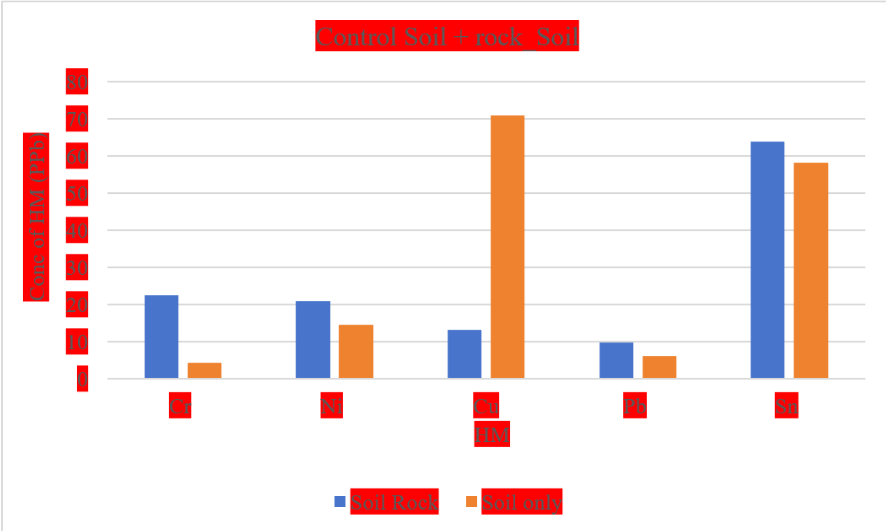

Figure 7. Concentration of select HM in control soil and soil after rock addition. The analyses were done after 1 month of rock addition without any plants.).

Table 4. pH readings in control soil and treated soil in the presence of *N. oleander* and *S. alba*.

Soil Conditions	Average Mean pH
Control	6.80
Rock amended	7.50

Our study demonstrated a significant uptake of heavy metals (HMs), particularly Cu and Pb, as illustrated in **Figure 5**. The high translocation factor (TF) and bioconcentration factor (BCF) observed in this study indicate that the plant species used were effective in accumulating and transporting these metals. These findings align with prior research by [34], which suggested a potential relationship between soil pH and HM uptake in plants. Specifically, their study reported that Cu and Mg concentrations were higher in plants growing in soils with pH levels ranging from 5.1 to 6.9, indicating that soil pH can influence metal availability and plant uptake.

To further analyze this relationship, we measured soil pH in both control and rock-amended soils under the presence of *Cenchrus purpureus* (formerly *Pennisetum purpureum*). As shown in **Table 2**, the pH of the control soil ranged from 6.80 to 6.98, while the rock-amended soil exhibited slightly higher pH values, ranging from 7.25 to 7.50. The observed increase in soil pH due to rock amendments suggests a potential shift in metal solubility and bioavailability, which could influence HM uptake patterns in plants.

Furthermore, the presence of *C. purpureus* and associated microbial communities likely contributed to soil pH modifications. Plant root exudates and microbial activity play a crucial role in altering rhizosphere chemistry [35,37,38]. Certain root exudates can either acidify or alkalinize the soil, affecting metal mobility. Additionally, microbial interactions, such as organic acid production and nutrient cycling, can further influence pH dynamics and metal speciation.

These findings highlight the intricate interactions between soil amendments, plant species, and microbial communities in shaping metal uptake efficiency. Understanding these relationships is critical for optimizing phytoremediation strategies and improving soil remediation outcomes. Future research should explore the long-term impact of soil amendments on pH stability and metal bioavailability, particularly in the presence of different plant species and microbial consortia.

3.8. Cellulose Content in the Shoots and Roots of *C-purpureus*

Table 5 shows increased cellulose content in treated plants, suggesting enhanced structural development. This increase may be linked to improved growth conditions or stress adaptation [39,40]. The higher cellulose content supports the use of *C. purpureus* in biofuel applications.

Table 5. Cellulose content (%) in shoots and roots of *C-purpureus* control compared to treatment.

Sample	Dry Biomass (g)				Cellulose (%)			
ID	Sample before Planting	Sample 1 after Planting	Sample 2 after Planting	Sample 3 after Planting	Control without Planting	Sample 1 after Planting	Sample 2 after Planting	Sample 3 after Planting
Shoots	8.36	11.25	14.56	18.35	10%	15%	20%	25%
Roots	9.82	10.09	12.23	15.45	5%	9%	11%	14%

4. Conclusions

This study highlights the multifaceted potential of *Cenchrus purpureus* (Elephant Grass) in phytoremediation, bioenergy production, and enhanced weathering. Our findings indicate that *C. purpureus* effectively accumulates heavy metals (HMs) in its tissues, with higher uptake in roots compared to shoots, particularly under high rock powder amendment. The ability to sequester metals such as Pb, Cd, and Cr in root tissues suggests that this species is a promising candidate for soil remediation efforts in contaminated environments. Furthermore, bioaccumulation and translocation factor analyses confirm that Elephant Grass efficiently captures and redistributes specific metals, with higher translocation of As, Cd, and Co to the shoots under low rock treatment. This makes it suitable for phytoextraction, a critical process in soil detoxification. In contrast, high rock amendment favors the retention of Fe and Al, thereby reducing the uptake of more toxic metals and making the soil safer for agricultural purposes. The results also demonstrate that *C. purpureus* contributes significantly to rock weathering and carbon sequestration. The study estimates a 38% enhancement in weathering processes, primarily driven by the plant's extensive root system, which promotes magnesium dissolution and CO_2 drawdown. Additionally, the organic acid exudation from the roots further accelerates mineral weathering, enhancing soil fertility. From a biomass perspective, Elephant Grass exhibits remarkable growth potential, with a continuous increase in shoot and root biomass over time.

The total biomass observed after three months reached 33.80 g in treated plants compared to 18.18 g in controls, highlighting its potential as a sustainable bioenergy source. Given its rapid growth and high lignocellulosic content, *C. purpureus* is suitable for various bioenergy conversion processes, including bioethanol fermentation and pyrolytic conversion. Additionally, soil analysis post-experimentation revealed a substantial increase in carbon content, rising from 6.80% in control soils to 20.06% in treated soils. This confirms the plant's role in carbon sequestration, which is critical in mitigating atmospheric CO_2 levels. The improvement in soil organic matter and microbial activity further supports long-term soil health and productivity.

Author Contributions

Conceptualization, Z.S. and H.H. methodology, S.C.R. software: S.C.R.; validation, S.C.R. and N.I.; formal analysis, N.I.; investigation, N.I. and S.M.I.; resources, data curation, S.C.R. and W.B.E.; writing—original draft preparation, N.I.; writing—review and editing, N.I.; visualization, N.I., Z.S. and H.H.; supervision, N.I.; project administration, N.I.; funding acquisition, N.I. and S.M.I. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

This study is Not applicable as its not involving humans or animals. As the research related to using plant to remediate the soil from Heavy metals.

Informed Consent Statement

This study Not applicable as isn't involving humans. Therefore, there is no any consent for publication must be obtained from participating patients.

Data Availability Statement

The data of ICP-OEs has been obtained from the chemistry lab by Dr. Subrata C. Roy and supervision Dr. Saiful M. Islam. While the physiological data had been recorded by Dr. Naira Ibrahim and the two students Zavier and Hayleigh under her supervision. The data for carbon amounts and primary cellulose had been analyzed under supervision of Dr. William.

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Conflicts of Interest

The authors declare no conflict of interest.

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