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Comparative Study of the Removal Efficiency of *Chrysopogon zizanioides* (L.) and *Zea mays* (L.) of Copper (Cu) and Lead (Pb): Harnessing Phytoremediation Potential for Soil Recovery in a Former Dumpsite of El Salvador City, Misamis Oriental Philippines

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ABSTRACT

Inorganic pollutants, like heavy metals found in soil with high levels of concentration, post a serious threat to the environment. However, heavy metals such as Cu and Pb produced by waste treated with a phytoremediation technique project a positive input. An experimental-descriptive analysis was used to quantify the phytoremediation potential of vetiver grass (*Chrysopogon zizanioides* L.) and maize (*Zea mays* L.) in accumulating Cu and Pb in a former El Salvador City dumpsite, located in Misamis Oriental Philippines. The study found that the initial amounts of Cu and Pb (1,368 and 38.1 mg/kg) decreased significantly to (850 and 20.5 mg/kg) respectively. The results also showed vetiver grass exhibited concentrations of lead (of 15.12±1.20 µg/g) and copper (506.36±8.44 µg/g) in its roots. In comparison, maize concentrations were found to be: lead (10.22±5.92 µg/g) and copper (486.85±3.12 µg/g) respectively. The Translocation Factor (TF) of vetiver grass had a 0.40 value, while maize showed 0.16 and 0.17 values (for Cu and Pb). The Bioaccumulation Factor (BAF) of vetiver grass was 47.55, and for maize 32.14. The results rendered significant over the three-month study period at a 0.95 confidence level. This study concludes that vetiver grass generally accumulates higher concentrations of both lead and copper in roots and shoots compared to maize, with roots consistently showing higher metal accumulation than shoots. For future research, these results provide a foundational scientific framework for soil evaluation of dumpsite areas, and give further support to policy implementations.

HIGHLIGHTS

The study utilized phytoremediation technique with applied complete randomized block design of pot experiment using vetiver grass and maize on the contaminated soil. High concentration of heavy metals accumulated on plant system in three months was also investigated.

1. INTRODUCTION

Environmental pollution in air, water and soil as a result of human activities marked a tremendous threat to the current era (Chirilă Băbău et al., 2024). Waste materials that brought adverse effect to the environment, has been carelessly managed causing serious environmental dilemma. These unproperly manage wastes contribute high content of organic pollutants and heavy metals on soil (Khalid et al., 2017). Soil pollutants is one of the foremost environmental issues worldwide (Abriha-Molnár et al., 2023). This issue projects a serious threat for this leads to the altered physical, chemical and biological environmental composition.

In the Philippines, R.A. 9003, also known as the Ecological Solid Waste Management Act of 2000, have been put in place to address the underlying issues. The goal is to manage solid waste efficiently

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by reducing waste volume and promoting eco-friendly disposal methods. However, the Act's provisions on waste dumping have led to the accumulation of heavy metals, which has negatively impacted soil quality. This may lead to the increase of toxicity level in the soil ecosystem exceeding beyond the threshold limit if not properly monitored (Obasi et al., 2021). To address this environmental problem, strategies like phytoremediation have been introduced to mitigate the high concentrations of heavy metals in the soil resulting from increased waste dumping activities.

El Salvador City with its growing population, has opened its landfill on 2000 and started its operation on the year 2001. The area is specifically situated in the upland location of barangay Himaya. The area can hold wide range of wastes, that as it started its operation, it can accommodate approximately 108,000 kilos of waste per month. Wastes generated are combination of wastes coming from establishments, infrastructures, industries and household wastes. Through the years the landfill becomes an open-dumpsite due to the uncontrolled bulk of mixed-waste being dumped in the area. Such dumped wastes can have significant heavy metal contamination to soil (Bisht et al., 2024).

Heavy metals in contaminated soil which cannot be degraded are toxic elements that naturally occur in the environment and have an atomic density greater than 4×106 mg/kg. Such metals influence plant growth and development through biological and non-biological means. Exceeding the threshold limit beyond (20-100 mg/kg) Cu and (30-50 mg/kg) Pb may post an ecological and nutritional toxicity disrupting balance in soil ecosystem (Obasi et al., 2021). Increased level of heavy metals results to oxidative stress in plants leading to production of free radicals and reactive oxygen species, resulting in cellular damage, reduced growth, and lower biomass production (Goyal and Kahlon, 2022). These metal concentration that exceeds the WHO organization standards for plants and soil caused serious harm to the environment (Chibuike and Obiora, 2014). Hence, phytoremediation is vital.

Phytoremediation is a remediation technique that utilizes plants to absorb, sequester, and detoxify a range of pollutants from soil, water, and air (Zhang et al., 2020; Tiwari et al., 2019). It is environment friendly, cost effective and sustainable approach since it utilize plants to remove metals and organic contaminants in the soil. Common plant species that is being used for phytoremediation is the vetiver grass *Chyrsopogon zizanioides* (L.), a hyper accumulator plant belonging to the Poaceae family (Suelee et al., 2017). Maize *Zea Mays* (L.) belonging to the Poaceae family which is also globally known to being one of the most important cereal crops worldwide also renowned for its ability to tolerate heavy metals and grow rapidly with high biomass yield (Atta et al., 2023). Both plant species are tolerant to heavy metals specifically copper (Cu) and Lead (Pb), and is use as an alternative method to eliminate the presence of heavy metals on soil. Both plants are native species found in south and South-East Asia (Phusantisampan et al., 2016; Oshunsanya et al., 2023).

Numerous plant species that naturally inhabit contaminated areas have been investigated for their potential ability in phytoremediation. This includes dumpsites, landfills, mining, and quarrying sites. Certain plants are capable of thriving and surviving in metal-rich soils and are categorized as metal-tolerant species or bioindicators (Borymski et al., 2018). Such plants can effectively phytoremediate soil through exclusion from the plasma membrane, immobilization, ligand sequestration and chelation (Zhang et al., 2023).

In this light, the researcher utilized plant species, specifically vetiver grass and maize to determine the translocation and bioaccumulation factor of identified heavy metals to mitigate soil pollutants and improve soil quality. The utilized growth of plant species was observed in the study area.

2. METHODOLOGY

2.1 The study site

The study was conducted in Himaya El Salvador City, Misamis Oriental, Philippines. Situated approximately 8.5247, 124.5183, in the island of Mindanao. It geographically lies between the coordinates of 8º 28" to 8º 33" North Latitude and between 124º 27" to 124º 34" East Longitude. It is bordered by the Municipality of Alubijid to the west, Opol to the east and Manticao and Naawan to the south. On the north, lies Macajalar Bay of the Bohol Sea. The site presented in Figure 1 has an approximate elevation of 136.9 meters or 449.1 feet above mean sea level. The general land uses of the of the City's total land area of 14,265 hectares comprising of forestland with 8,271.20 hectares having the highest percent (57.98) stipulated in the existing general land use map. The area falls under climatic type III, which is relatively dry seasons from November to April and wet during the rest of the year with no pronounced maximum rain period. November to April is the relatively dry months, while May to October is often the period of heavy rainfall.

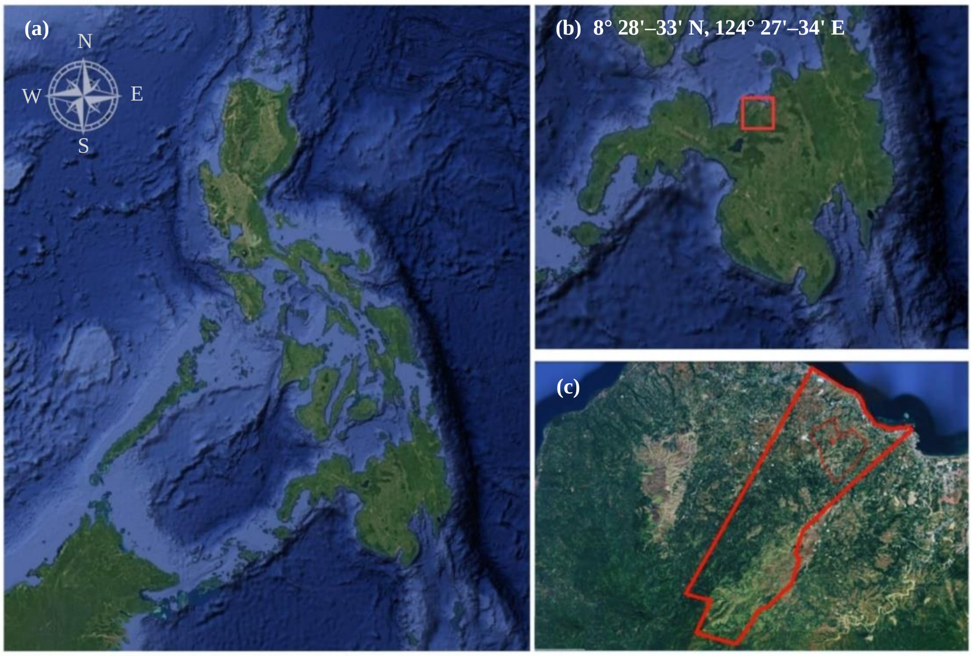

Figure 1. Location Map of the Philippines, Mindanao and Himaya El Salvador City, Misamis Oriental

2.2 Soil physicochemical analysis

2.2.1 Soil texture

To measure the relative proportion of sand, silt, and clay particles in a soil sample the research utilized the hydrometer or sedimentation method based on Stokes' Law to measure the settling rates of soil particles (University of Illinois, 2023).

In determining the soil texture, the amount of sand, silt and clay was determined using the hydrometer method or sedimentation test. One half (0.5) cup of soil sample was placed in 100ml graduated cylinder and added 3.5 cups of water. Using digital pH meter, the pH of soil water was set to ≤4.0 by adding hydrochloric acid (HCl), the graduated cylinder was covered, wobbled for five minutes, and allow to settle for 24 hours, the total depth including the depth of each layer of the soil was separated, measured and recorded. The soil separated (particle) was at the bottom, followed by the silt in the middle and the clay at the top.

The total depth, and the depth of the three separates, was calculated using the percentage of each soil separates using the formula below.

$$\%\ \text{Sand} = \frac{\text{sand depth}}{\text{total depth}} \times 100 \qquad (1)$$

$$\%\ \text{Silt} = \frac{\text{silt depth}}{\text{total depth}} \times 100 \qquad (2)$$

$$\%\ \text{Clay} = \frac{\text{clay depth}}{\text{total depth}} \times 100 \qquad (3)$$

After determining the proportion of the soil separates, the texture was determined using the soil triangle method to classify soil types based on relative proportions (Groenendyk et al., 2015).

2.2.2 Soil pH

To measure the hydrogen ion concentration in the soil solution, the research determines the soil pH a critical factor influencing nutrient availability, microbial activity, and overall soil quality (Jean-Philippe et al., 2012).

The pH meter probe was dipped into a solution-a mixture of soil and deionized water in a 1:1 ratio volume by weight. The solution was prepared by placing twenty (20 g) soil and deionized water in a 50 mL beaker. The samples were brought to a final volume of 40 mL and was shaken for one minute and allowed to settle for one (1) hour before pH was determined.

2.2.3 Soil organic matter

To be able to determine the key indicator of soil fertility, structure, and biological activity and traced the amount of decomposed plant and animal residues, cells and tissues of soil organisms, and substances, loss on ignition (LOI) method was utilized in the research. A technique used to estimate the amount of soil organic matter (Miller et al., 2013).

In soil organic matter analysis, samples that was collected dried overnight on the drying oven and set to

150°C, this process in to remove the undesirable water content in the soil. After drying, the soil was placed in a huge ceramic mortar and crushed thoroughly using mortar and pestle. The crushed soil was filtered in a 5mm soil sieved to ensure that only fine-earth fraction of the soil was analyzed. A 10 mL crucible was placed in electronic scale into zero (0) with the crucible on top. Using a soil scoop, exactly 5 grams of sieved soil was placed on the crucible and the weight was recorded. Same procedure was applied for the remaining soil samples. The samples were weighed again and the weight of the organic matter combusted was calculated.

The percent of organic matter was calculated using the formula below:

$$\% \text{ OM} = \frac{\text{weight of soil before combustion} - \text{weight of soil after combustion}}{\text{weight of soil before combustion}} \times 100 \quad (4)$$

2.3 Sampling procedure

Random Composite sampling was employed in the collection of soil samples within the dumpsite area. Multiple subsamples points were randomly identified across the area and mix into one composite sample. Pre-soil analysis was conducted. Subsurface soil samples were collected in the site using a shovel. Soil samples in triplicates was taken at a depth of 30-35 cm. Seven hundred fifty grams (750 g) of soil sample was subjected to lead (Pb) and copper (Cu) analysis. Two hundred fifty grams (250 g) of same soil sample was subjected to physicochemical analysis (Chafik et al., 2025). Unwanted debris like leaves, rocks, roots and alike was removed, and each soil sample was placed separately in a secured zip locked polyethylene bags and labelled using a waterproof marking pen. The soil samples were oven dried at 35°C to remove moisture prior to pot experiments. Background physiochemical properties of the tested soil before contamination was measured.

2.4 Plant preparation

Disease free, healthy vetiver and maize plants was grown on dumpsite soil in earthen pots (size-diameter 20 cm; height 17 cm) for a period of three months January to March 2024. Plants roots and shoots was pre-analyzed. Plastic vessels were placed below the earthen pots to collect the water that seeped out from the pots. Pot experiment of the plants was employed in the plant nursery area at home. Plants grown on the garden soil served as a control set. Two plants were planted per pot and three sets was prepared for each treatment. Plants was allowed to grow under normal environmental conditions.

2.5 Pot experiment

Pot experiments was employed for assessing the application of plants on contaminated soils. Eighteen (18) polyethylene pots were used in the conduct of the study, nine (9) experimental pots and (9) controlled pots. The pots were placed onto 240 mm plastic plant saucers. Pots were rinsed with 10% alcohol solution to sterilize the surface and eliminate microbial contaminants such as bacteria, fungi, or spores that may interfere with experimental results (Chauhan et al., 2020). In the plant nursery garden, polyethylene pots with identified plant samples were laid out completely in randomize block design with replicates. Enough space between the pots were ensured to keep plants from shading each other. Plants were planted in each pot with the same depth and amount of exposure to sunlight.

2.6 Soil preparation

Soil samples were collected from the designated subsurface sampling sites at a depth of 30-35 cm, air-dried at room temperature, and sieved through a 2 mm mesh to remove debris and coarse particles. Approximately 1.0 gram of each prepared soil sample was subjected to acid digestion to extract heavy metals. Digestion process followed adding 10 mL of concentrated nitric acid (HNO_3) to the soil sample in a digestion flask, followed by gentle heating until the reaction subsided. Subsequently, 5 mL of concentrated hydrochloric acid (HCl) was added, and the mixture was heated further until a clear solution was obtained. Standard solutions of the target Cu and Pb heavy metals were prepared to calibrate the Atomic Absorption Spectrophotometer. Flame Atomic Absorption Spectrophotometry (FAAS) was employed to determine the concentration of specific metal present. Calibration was performed using standard solutions of known concentrations, and the instrument was set to the appropriate wavelengths for Cu (324.8 nm) and Pb (283.3 nm). The method detection limits for copper and lead in soil were approximately 0.5 to 2 mg/kg and 1 to 2 mg/kg, respectively, based on standard EPA and NIST analytical procedures.

In three-month experimental period, plant roots and shoots were systematically monitored at monthly intervals. At the end of each month, representative samples were harvested from both garden and dumpsite soil treatments. Plant tissue samples were collected for heavy metal analysis to determine the concentrations of Cu and Pb accumulated over time. Plant root and shoot samples were thoroughly washed with deionized water to remove soil particles, oven-dried at 70°C until constant weight, and ground to a fine powder using a stainless-steel mill. Approximately 0.5 grams of each powdered sample was digested using a mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a digestion block under controlled heating until a clear solution was obtained. The digested samples were filtered and diluted to a known volume with deionized water. The concentrations of Cu and Pb were determined using Direct Air-Acetylene Flame Atomic Absorption Spectrophotometry (FAAS). The instrument was calibrated using standard solutions of Cu and Pb, and measurements were taken at wavelengths of 324.8 nm for Cu and 283.3 nm for Pb. The method detection limits for Cu and Pb in plant tissues using this technique were approximately 0.5 to 2 mg/kg and 1 to 2 mg/kg, respectively, based on standard EPA and NIST analytical protocols.

2.7 Statistical analysis

Gathered data were subjected to statistical analysis to ensure the reliability and significance of the results. To assess differences between dumpsite and garden soil plants samples, one-way analysis of variance (ANOVA) was performed. The level of significance was established at 0.95 confidence level.

3. RESULTS AND DISCUSSION

3.1 Soil physicochemical properties

Soil physical and chemical analysis results showed that the subsurface soil in the former dumpsite area has a clay texture with high water-holding capacity. It is slightly alkaline and is more likely to be suitable for most crops (Table 1).

Table 1. Pre-analysis of physicochemical and heavy metals analysis of the experimental subsurface soil

Soil characteristics	Value/Characterization	WHO/DUTCH Standards (mg/kg)	Method
Soil texture (%)			ASTM D 422-63 (2007) E2
Sand	44.60	40-50	
Silt	7.24	30-40	
Clay	48.16	20-30	
OM (%)	7.48		Walkley-Black (Colorimetric)
pH	7.8		
Pb (mg/kg)	38.1	85/55	Direct Air-Acetylene
Cu (mg/kg)	1,368	36/3.5	Flame AAS

Standard Method of Analysis for Soil, Plant, Tissue, water and fertilizer 1980

Table 1 shows the result obtained for the concentration of physicochemical and heavy metals on subsurface in the former dumpsite area. Soil texture identified as clay with the greatest value of 48.16 on its composition, indicating high water-holding capacity but poor drainage ability (Bradley et al., 2025). The level of pH with the value 7.8 indicates the subsurface soil to be slightly alkaline and is more likely to be suitable for most crops (Tian et al., 2024). Numerical value of the data gathered is being compared to the World Health Organization (WHO) and Dutch Standards for soil.

The lead (Pb) level of 38.1 mg/kg is below both WHO (85 mg/kg) and Dutch (55 mg/kg) standards, indicating that the lead concentration is within safe limits for soil health and plant growth. Content concentration on the subsurface soil did not exceed on the set standards. However, for copper (Cu) content level of 1,368 mg/kg is significantly higher than both WHO (36 mg/kg) and Dutch (3.5 mg/kg) standards. The high concentration of copper reveals alarming toxicity to plants and soil microorganisms, potentially leading to reduced plant growth and soil health concentration, numerical value exceeded far more beyond the tolerable amount on soil (Poggere et al., 2023).

The ratios of sand (44.60), silt (7.24), and clay (48.16) are indicated by the texture, with factors that have impacts on nutrient availability and water retention (Wei et al., 2023). Lead and copper concentrations identified in the soil samples reveals possible contamination, while the pH level shows slightly alkaline composition.

3.2 Estimated concentration of heavy metals of plant roots and shoots

The data provided in Table 3 highlights the estimated concentrations of heavy metals, specifically lead (Pb) and copper (Cu), in the roots and shoots of vetiver grass (*Chrysopogon zizanoides* L.) and maize (*Zea mays* L.). The samples were taken from two different soil types: former dumpsite soil and garden soil (Table 2).

The concentration of lead in the roots of vetiver is significantly higher (15.12±1.20 µg/g) compared to maize (10.22±5.92 µg/g). This indicates that vetiver has a higher capacity to accumulate lead in its roots from contaminated soil (Gravand et al., 2021). Similarly, the lead concentration in the shoots of vetiver (6.21±2.23 µg/g) is higher than in maize (4.10±4.11 µg/g) with 0.95 level of significance. This suggests that vetiver is more efficient in translocating lead from roots to shoots, and a heavy metal tolerant species. This result is consistent to claims that vetiver not only accumulates lead effectively in its roots but also translocate a significant portion to its shoots (Singh et al., 2024).

Table 2. Estimated concentration (µg/g) of heavy metal concentration of plant roots and shoots

	Lead (Pb)		Copper (Cu)	
	Chrysopogon zizanoides (L.)	*Zea mays* (L.)	*Chrysopogon zizanoides* (L.)	*Zea mays* (L.)
Former dumpsite soil				
Roots	15.12±1.20	10.22±5.92	506.36±8.44	486.85±3.12
Shoots	6.21±2.23	4.10±4.11	90.28±12.60	80.24±5.11
Garden soil				
Roots	<0.01	<0.01	<0.01	<0.01
Shoots	<0.01	<0.01	<0.01	<0.01

Values are mean of 3 samples±SD

The copper concentration in the roots of vetiver (506.36±8.44 µg/g) is slightly higher than in maize (486.85±3.12 µg/g). Both plants show a high capacity for copper accumulation in their roots, but vetiver is marginally more effective. The copper concentration in the shoots of vetiver (90.28±12.60 µg/g) is also higher than in maize (80.24±5.11 µg/g). This indicates that vetiver is more efficient in translocating copper from roots to shoots (Kumar et al., 2018).

For both plant samples, the concentrations of lead and copper in roots and shoots are below detectable levels (<0.01 µg/g) in garden soil. This suggests that the garden soil is not contaminated with these heavy metals, and both plants do not accumulate significant amounts of lead or copper in garden soil sample.

3.3 Translocation and bioaccumulation of heavy metals in plant roots and shoots

The data gathered provides insights into the relative translocation and bioaccumulation of heavy metals in the roots and shoots of vetiver and maize. Translocation factor (TF) of plant utilized in the research study was used to measure the plant's ability to transfer heavy metals from its roots to its shoots (Table 3).

Data gathered revealed that. vetiver, for both lead (Pb) and copper (Cu) has a TF of 0.40 value. This indicates that 40% of the heavy metals absorbed by the roots are translocated to the shoots. This relatively high TF suggests that vetiver is efficient in moving heavy metals from roots to shoots. Maize has a TF value for lead 0.17, and copper 0.16 value. The lower values indicate that maize is less efficient in translocating heavy metals from roots to shoots compared to vetiver (Dorafshan et al., 2023).

The bioaccumulation factor (BAF) was used in the research study to measure the ability of a plant to accumulate heavy metals from the soil into plant tissues (Sabir et al., 2022). For the BAF value in shoots, values indicate that vetiver has a higher capacity to accumulate lead and copper in its shoots compared to maize (Dorafshan et al., 2023).

Table 3. Relative translocation and bioaccumulation of heavy metals in plant roots and shoots

	Lead		Copper	
	Chrysopogon zizanoides (L.)	*Zea mays* (L.)	*Chrysopogon zizanoides* (L.)	*Zea mays* (L.)
Translocation factor	0.40	0.40	0.17	0.16
Bioaccumulation factor shoot	19.53	12.89	6.60	5. 87
Bioaccumulation factor root	47.55	32.14	37. 01	35.59

The BAF values in roots show that both plants have a high capacity to accumulate heavy metals in their roots. However, vetiver has a slightly higher BAF for lead with the value of 47.55, indicating it is more efficient in accumulating lead in its roots compared to maize with of 32.14 value. For copper, the BAF values are relatively similar, suggesting both plants are effective in accumulating copper in their roots (Darajeh et al., 2019; Parihar et al., 2021).

The data suggests that vetiver has a higher capacity for both bioaccumulation shoots and roots of lead 19.53 and 47.55, copper 6.60 and 37.01 and translocation lead 0.40 and copper 0.17 value of heavy metals compared to maize. This makes vetiver a more suitable candidate for phytoremediation strategies aimed at both phytoextraction and phytostabilization (Singh et al., 2024).

3.4 Plant lead (Pb) and copper (Cu) concentration analysis

3.4.1 Bioaccumulation factor analysis (BFA)

Biological accumulation factor is the ability of plants to accumulate metals into their tissues. It was calculated as ratio of heavy metal in shoots to that in the soil (Balabanova et al., 2016). In order to determine the bioaccumulation of lead and copper on plant tissues, the ratio of the contaminant in plant and the concentration in the environment at a steady state was calculated using the formula:

$$\text{Bioaccumulation Factor} = \frac{\text{metal concentration in shoots}}{\text{metal concentration in soil}}$$

3.4.2 Translocation factor analysis (TFA)

After the determination of bioaccumulation factor of pant species, translocation factor was calculated to determine the ability of the plant to accumulate metals from the roots to the aerial parts of the plants. The translocation factor is defined as the ratio of metal concentration in the shoots to the roots (Yoon et al., 2006). Translocation may also move the absorb substances throughout the plant parts. To obtain the translocation factor of lead and copper in plants the formula was used:

$$\text{Translocation Factor} = \frac{\text{metal concentration in shoots}}{\text{metal concentration in roots}}$$

Translocation factor with value greater than 1 mg/kg, indicates that the plant translocates metals effectively from root to the shoot (Bu-Olayan and Thomas, 2014).

Phytoremediation performance was evaluated using the removal efficiency factor. The equation below was applied:

$$\text{Removal Efficiency (\%)} = \frac{C_0 - C}{C_0} \times 100$$

Where; C_o the primary metal concentration in the soil and C referred to the final concentration. The higher the amount of removal efficiency factor means the phytoremediation process was more effective.

3.5 Heavy metal concentration of plants in three months span

The table provides insights into the concentration of heavy metals, specifically lead and copper in the roots and shoots of vetiver and maize grown in soil from a former dumpsite over a three-month period (Table 4-5).

Data gathered showed that the concentration of lead in both shoots and roots revealed a decreasing trend over the three-month period. This suggests that vetiver is capable of initially accumulating lead from the soil, but the rate of accumulation decreases over time. The concentration of lead is consistently higher in the roots compared to the shoots. This indicates that vetiver tends to sequester lead in its root system, which is beneficial for phytostabilization as it prevents the translocation of lead to the above-ground parts of the plant.

The concentration of copper in the shoots decreases significantly over the three-month period. This suggests that the initial uptake of copper is high, but the plant's ability to translocate copper to the shoots diminishes over time. The concentration of copper in the roots shows a slight decrease from first to second month but then increases slightly in third month. This fluctuation could be due to various factors such as changes in soil chemistry, root growth dynamics, or microbial activity in the rhizosphere.

Similar to lead, the concentration of copper is significantly higher in the roots compared to the shoots. This indicates that vetiver is effective in accumulating copper in its root system, making it suitable for phytostabilization.

Table 4. Heavy metal concentration (μg/g) of roots and shoots of vetiver grown using former dumpsite soil in three months span

Months	Lead		Copper	
	Shoot	Root	Shoot	Root
1	3.02	7.89	40.45	187.03
2	1.76	4.07	30.65	156.14
3	1.43	3.16	19.18	163.19

Vetiver accumulates higher concentrations of copper compared to lead in both roots and shoots. Plant possesses a dense and deep fibrous root system significantly increasing the root-soil interface, enhancing its ability to absorb soluble metal ions such as copper. This suggests that the plant has a higher affinity for copper uptake from the soil. The higher accumulation of copper in the roots indicates that grass utilized in the research study can be particularly effective in stabilizing copper-contaminated soils.

The data in Table 5 provides insights into the concentration of heavy metals, specifically lead and copper in the roots and shoots of maize grown in soil from a former dumpsite over a three-month period.

Table 5. Heavy metal concentration (μg/g) of roots and shoots of maize grown using former dumpsite soil in three months span

Months	Lead		Copper	
	Shoot	Root	Shoot	Root
1	2.87	4.03	30.46	168.28
2	1.03	3.46	26.74	161.55
3	0.2	2.73	23.04	157.02

The concentration of lead in both shoots and roots decreases over the three-month period from 2.87 to 0.2 value in shoots and 4.03 to 2.73 value in roots. This suggests that maize initially accumulates lead from the soil, but the rate of accumulation decreases over time from 30.46 to 23.04 value in shoots and 168.28 to 157.02 value in roots. The concentration of lead is consistently higher in the roots compared to the shoots. This indicates that maize tends to sequester lead in its root system, which is beneficial for phytostabilization as it prevents the translocation of lead to the above-ground parts of the plant.

The concentration of copper in the shoots decreases over the three-month period. This suggests that the initial uptake of copper is high, but the plant's ability to translocate copper to the shoots diminishes over time. The concentration of copper in the roots shows a slight decrease over the three months. This indicates that while maize continues to accumulate copper in its roots, the rate of accumulation slows down over time. Similar to lead, the concentration of copper is significantly higher in the roots compared to the shoots. This indicates that maize is effective in accumulating copper in its root system, making it suitable for phytostabilization.

Maize has a well-developed fibrous root system with large surface area that enhances plant ability to absorb nutrients and trace elements from the soil. Plant root epidermis and cortex are structured to facilitate the movement of water and solutes, including copper ions, into the vascular system. Results showed that it accumulates higher concentrations of copper compared to lead in both roots and shoots. This suggests that the plant has a higher affinity for copper uptake from the soil. The higher accumulation of copper in the roots indicates that maize can be particularly effective in stabilizing copper-contaminated soils.

The observed trend in Figure 2(a-b), where lead concentration in vetiver shoots decreases from 3.02 μg/g in the first month to 1.43 μg/g in the third month, and in roots from 7.89 μg/g to 3.16 μg/g, suggests a declining uptake and translocation of lead over time. Pattern may be attributed to several physiological and environmental factors, including the plant's saturation threshold for lead, changes in bioavailability of lead in the soil, or the plant's adaptive detoxification mechanisms that limit further uptake to avoid toxicity.

Maintained higher value concentrations of lead in roots compared to shoots indicate that plant primarily functions as a phytostabilizer, sequestering lead in the root zone and minimizing movement to aerial parts. Result is consistent with findings that vetiver grass accumulated 107-911 mg/kg of lead in roots and only 8.3-180 mg/kg in shoots, even under high soil lead concentrations (Rotkittikhun et al., 2006).

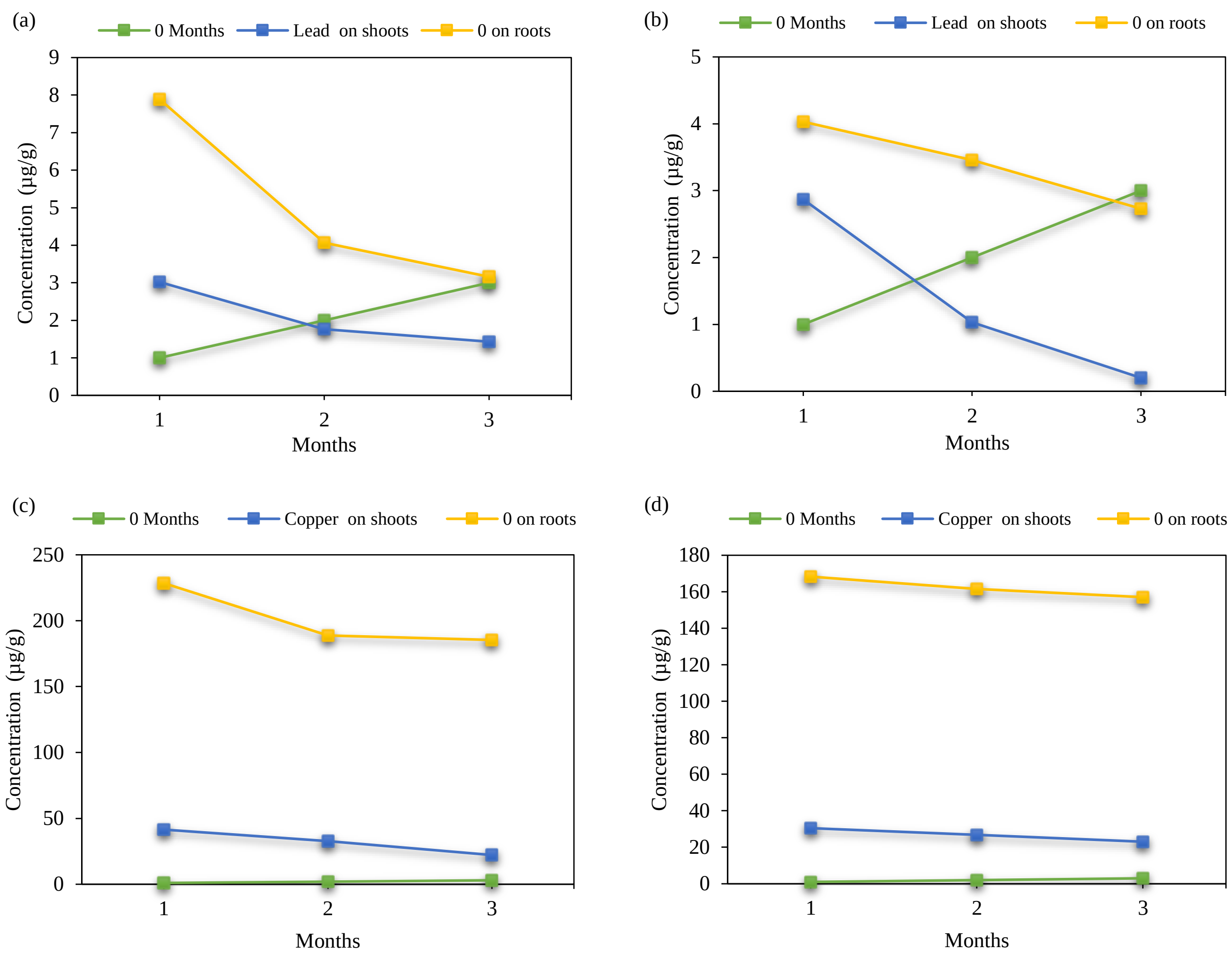

Figure 2. Heavy metal concentration in three months of vetiver and maize

Figure 2(c-d) presents Pb accumulation in maize over a three-month period. The concentration of lead in the shoots decreased markedly from 2.87 µg/g in the first month to 0.20 µg/g by the third month. Similar but less pronounced decline was observed in the roots, Pb levels dropped from 4.03 µg/g to 2.73 µg/g. Findings suggest that maize initially absorbs and translocate Pb efficiently, but its capacity to do so reduced over time, potentially it may due to physiological regulation or a reduction in the bioavailable fraction of Pb in the soil.

The consistently higher concentrations of lead in the roots compared to the shoots indicate that maize, like other cereal crops, tends to retain heavy metals in the root zone. Similar patterns have been reported that maize roots accumulated significantly more lead than shoots, with translocation factors typically below one (Sharma and Dubey, 2005).

3.6 Post analysis of the experimental soil

Soil post analysis was employed to assess how soil quality and contamination levels change over time, specifically in response to the utilization of hyperaccumulator species like maize and vetiver grass.

In the gathered data on post-analysis of the experimental soil, result revealed significant changes in heavy metal concentrations, particularly for Cu and Pb with the three-month phytoremediation period using maize and vetiver grass. The initial concentrations of Cu and Pb were 1,368 mg/kg and 38.1 mg/kg, respectively. After the experimental period, values decreased to 850 mg/kg for Cu and 20.5 mg/kg for Pb (Table 6). Reduction suggests effective uptake and accumulation of heavy metals by the experimental plants, supporting potential use in phytoremediation strategies.

Observable decrease in heavy metal concentrations was significant when compared to international safety thresholds. According to the World Health Organization (WHO), the acceptable limits for Cu and Pb in soil are 36 mg/kg and 85 mg/kg, respectively, for Dutch standards 3.5 mg/kg for Cu and 55 mg/kg for Pb. Although the post-analysis values remain above thresholds, the downward trend indicates progress toward safer soil conditions and highlights the potential of continued phytoremediation for long-term remediation (Du et al., 2022).

Table 6. Post Analysis of Physicochemical and Heavy metals Analysis of the Experimental Soil

Soil Characteristics	Value/Characterization	WHO/DUTCH Standards (mg/kg)	Method
Soil texture (%)			ASTM D 422-63 (2007) E2
Sand	44.60	40-50	
Silt	7.24	30-40	
Clay	48.16	20-30	
OM (%)	7.48		Walkley-Black (Colorimetric)
pH	7.8		
Pb (mg/kg)	20.5	85/55	Direct Air-Acetylene
Cu (mg/kg)	850	36/3.5	Flame AAS

Physicochemical properties namely soil texture and pH remained stable throughout the experiment, with a consistent pH of 7.48 and a soil texture dominated by clay (48.16%), followed by sand (44.6%) and silt (7.24%). Characteristics were favorable for heavy metal retention and plant growth, as clay-rich soils with neutral pH tend to immobilize metals and reduce their leaching potential. The stability of these parameters suggests that the remediation process did not adversely affect the soil's structural integrity or fertility.

3.7 Comparative removal efficiency of plants

Removal efficiency of plant species was determined to assess plants' ability to extract, accumulate, and reduce heavy metal concentrations on soil (Table 7).

Over a three-month phytoremediation period, a comparative analysis of vetiver and maize grown in dumpsite soil revealed notable differences in heavy metal removal efficiencies, particularly for Pb and Cu. Vetiver demonstrated a higher initial uptake of both metals, especially in root tissues. In the first month, vetiver roots accumulated 7.89 mg/kg of Pb and 187.03 mg/kg of Cu, while maize roots absorbed only 4.03 mg/kg of Pb and 168.28 mg/kg of Cu (Table 8).

However, maize exhibited a more pronounced reduction in metal concentrations over time, particularly for Pb. By the third month, Pb levels in maize shoots dropped from 2.87 mg/kg to just 0.2 mg/kg, indicating a removal efficiency of approximately 93%. In contrast, vetiver shoots showed a reduction from 3.02 mg/kg to 1.43 mg/kg, reflecting a lower efficiency of about 53%. For copper, vetiver still maintained higher uptake levels, but maize showed a steadier decline, suggesting a more consistent removal pattern.

Table 7. Removal efficiency of plants

Plant species	Shoots (mg/kg)				Roots (mg/kg)			
	Lead		Copper		Lead		Copper	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Vetiver	3.02	1.43	40.45	19.18	7.89	3.16	187.03	163.19
Maize	2.87	0.2	30.46	23.04	4.03	2.73	168.28	157.02

Table 8. Lead and copper removal efficiency

Plant species	Pb removal efficiency (%)	Cu removal efficiency (%)	Remarks
Vetiver			
Shoots	52.65	52.28	Highly efficient
Roots	52.58	52.58	Highly efficient
Maize			
Shoots	93.03	24.36	Highly efficient for Pb; less efficient for Cu
Roots	24.36	24.36	Highly efficient for Pb; less efficient for Cu

Philippine National Standard (PNS/BAFS 40:2014)

The findings were consistent with the work of (Otunola et al., 2023), emphasizing vetiver's strong phytoremediation potential due to its high biomass and tolerance to heavy metal stress. More so, maize was also recognized for its gradual and sustained metal uptake, making it suitable for long-term remediation strategies (Ali et al., 2013; Otunola et al., 2023). The complementary use of both species could enhance the overall efficiency of phytoremediation efforts in contaminated sites.

4. CONCLUSION

Vetiver grass was effective in absorbing and storing heavy metals from the soil with the roots acting as the primary site of accumulation. The initial concentration of Pb in the soil was 38.1 mg/kg, which decreased to 20.5 mg/kg by the end of the study, corresponding to a 46.19% reduction. Similarly, Cu levels declined from 1,368 mg/kg to 850 mg/kg, indicating a 37.87% reduction. These results highlight vetiver's strong phytoremediation potential, attributed to its extensive root system, high biomass production, and tolerance to heavy metal stress. The substantial accumulation of Pb and Cu in vetiver roots, particularly during the initial month, further supports its capacity for stabilizing and extracting contaminants from polluted soils. Pb and Cu concentrations in plant shoots and roots generally decrease over the three-month period of the study. Plant roots consistently show higher concentrations of lead and copper compared to plant shoots, indicating that the roots were more effective in absorbing and storing heavy metals. Vetiver grass in research study shows strong potential for phytoremediation, particularly for soils contaminated with Pb and Cu. Plant ability to accumulate higher concentrations of heavy metals makes the plant suitable candidate for soil remediation like areas of El Salvador City dumpsite area.

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AUTHOR CONTRIBUTIONS

Boter-Uayan, L.B.U.: Supervision, Conceptualization, Investigation, Methodology, Experiment, Validation, Formal Analysis, Visualization, Writing-Original and Revised Editing. Lacang, G.L.: Supervision, Visualization.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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