IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 18, Issue 3 Ser. 1 (March 2024), PP 14-20
www.iosrjournals.org

Phytoremediation Study Of Potential Heavy Metal (Pb, Cd, Zn, Fe) Uptake And Translocation By Jute Plant (Corchorus Capsularis)

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Abstract
The potential of Corchorus capsularis, a jute plant species, in remediating heavy metals (Fe, Zn, Cd, and Pb) from contaminated soil was investigated through phytoremediation using a completely randomized design (CRD). The study assessed heavy metal contamination levels in both the soil and plant materials using Atomic Absorption Spectroscopy (240FS Varian AAS). Results were analyzed for the transfer factor (TF) and bio-concentration factor (BCF). Corchorus capsularis exhibited robust growth patterns in the presence of heavy metal pollution, with root and shoot lengths ranging from 2-4 cm and 9-11 cm, respectively, after 2 weeks, 3.0-5.5 cm and 10-15 cm after 4 weeks, and 6-7 cm and 17-20 cm after 8 weeks. The plant demonstrated a remarkable 95% overall growth in contaminated soil, highlighting its heavy metal tolerance capabilities. The transfer factor for the assessed metals increased steadily over the growth period, ranging from 0.44 to 0.68 for Fe, 0.24 to 0.54 for Zn, 0.44 to 0.65 for Cd, and 0.61 to 0.81 for Pb, indicating the plant's effective accumulation and translocation of absorbed metals from the soil. Corchorus capsularis exhibited substantial bioaccumulation of heavy metals in various plant components while maintaining a consistent growth rate exceeding 90%. This study offer significant perspectives on how multi-contaminant (heavy metals) can be sustainably remediated.
Keywords: *Heavy metal; Bioaccumulation; Mineral absorption; Transfer factor; Fibrous plant; Remediation*

Date of Submission: 18-03-2024 Date of Acceptance: 28-03-2024

I. Introduction

Heavy metal pollution has become a pressing global environmental concern [1]. Anthropogenic activities, such as mining, industrial effluent disposal, and waste disposal, have led to the introduction of heavy metals into ecosystems, disrupting natural biogeochemical cycles and causing persistent contamination [2]. Heavy metals, being non-biodegradable unlike organic matter, accumulate over time, posing threats to soil and water quality [3]. The need to address heavy metal pollution and its consequences is evident.

Phytoremediation, the use of plants to remediate contaminated soils, stands out as a promising approach in mitigating the impact of heavy metal pollution [4]. Research in this field has explored phytoremediation for both single and multiple heavy metal contaminants, acknowledging the versatile nature of this approach [1, 5, 6]

The jute plant (*Corchorus capsularis*) emerges as a compelling candidate for phytoremediation studies. Jute plants possess several key characteristics that make them an attractive choice for this research. Firstly, they are known for their hardy nature and adaptability to diverse soil conditions, including contaminated soils [7]. Secondly, jute plants exhibit rapid growth and have a robust root system, which can enhance the uptake and translocation of heavy metals [8]. Furthermore, jute fibers are of economic importance, providing an additional incentive for exploring their potential in phytoremediation [9].

In the context of previous research [3, 10, 11], our study aims to contribute to the existing knowledge by investigating the phytoremediation potential of the jute plant, *Corchorus capsularis*, a species that has received limited attention in the context of multi-contaminant heavy metal remediation. This study aims to assess the ability of *Corchorus capsularis* to absorb and accumulate multiple heavy metals, including lead (Pb), cadmium (Cd), zinc (Zn), and iron (Fe), from polluted soils. Employing a rigorously designed experimental framework, we evaluate the bioaccumulation efficiency and transfer factors of these heavy metals within the plant. The results will offer significant perspectives on how this particular variety of jute plant might be applied to tackle the problems caused by heavy metal pollution in various environmental contexts.

II. Materials And Methods

Collection of plant materials and soil samples

Jute seeds were obtained from Arochukwu in Okigwe Local Government Area of Imo State, Nigeria. Plant species were analyzed for heavy metal content before being used for the experiment. All reagents and chemicals used were of analytical grade. Aqueous solutions of the metals for pollution of soil were prepared using double-distilled water. Soil samples were collected from farms in the School of Agriculture and Agricultural Technology (SAAT) at the Federal University of Technology Owerri. Using a soil auger, topsoil was taken from a 15 cm depth after the sampling location had been cleared of debris. The samples were combined and homogenized to create a composite sample, which was then tested for the presence of heavy metals before being used.

Fig. 1: *Corchorus capsularis* plant growing on the heavy metal polluted soils.

Experimental Design

Nine seedling buckets were filled with a composite soil sample weighing 4 kg each. The buckets were placed in an improvised greenhouse and labeled A_w, A_j, B_w, B_j, C_w, C_j, D_w, D_j, and E respectively. Jute seeds were planted in each bucket according to its label and watered with 50 mL of deionized water at 8 hr intervals [12]. At an interval of 2 weeks starting with the A_w and A_j, 3 g of the soil and the plants were harvested, pretreated, and analyzed for their heavy metal concentrations. The soil sample in the different buckets was spiked with four different heavy metals 14 days after germination. Individual solutions of 0.5 M Zn, Cd, Pb, and Fe were prepared using respective metal salt compounds: Zinc Chloride ($ZnCl_2$), Cadmium Chloride ($CdCl_2$), Lead Nitrate {$Pb(NO_3)_2$}, and Iron sulfate ($FeSO_4$) respectively. About 50 mL of de-ionized water was sprayed into each seedling bucket twice weekly for the first two weeks, and then every other day as the seedlings increased in biomass. For about eight weeks, the plant buckets were kept in a shaded area where sunlight can readily enter.

Sample pre-treatment

The jute leaves and roots were carefully removed from the seedling containers and subjected to a double wash with distilled water, followed by air-drying. Thorough washing under a steady stream of water was conducted to eliminate any sand, dust particles, or organic contaminants present on the plants. Subsequently, each 3 g sample of composite soil and plant material underwent a 48-hour drying process at room temperature. This pretreatment procedure was systematically implemented for the harvested soil and plant samples, which were then meticulously stored in appropriately labeled plastic bags for subsequent analysis.

Heavy metals analyses

Stock solutions of the metals were used to pollute the soil and their concentrations were determined Spectrophotometrically using a 240FS Varian Atomic absorption spectrophotometer according to the procedure as adopted by [13] and modified.

Determination of the bioconcentration factor (BCF)

Heavy metal bioconcentration factor (BCF), also called accumulation factor AF [14] or transfer factor (TF) describes the transfer of metal from soil to the plant body. This can be calculated by dividing the concentration of the heavy metal in the plant (C_{plant}) by the corresponding concentration in the soil (C_{soil}) [15].

$$\text{Bioconcentration factor } (BCF) = \frac{C_{plant}}{C_{soil}}$$

Determination of the translocation factor (TF)

The plant's ability to move accumulated metal from its roots to shoots is measured by the translocation factor. It is calculated as follows [16].

$$\text{Translocation factor (TF)} = \frac{C_{shoot}}{C_{root}}$$

where C_{shoot} is the concentration of the metal in plant shoots and C_{root} is the concentration of the metal in the plant roots. A translocation factor value greater than 1 indicates the translocation of the metal from the root to the above-ground part [17]. According to [18], only plant species with both BCF and TF greater than 1 have the potential to be used for phytoextraction.

Determination of the Remediation/Metal uptake Rate

The rate at which the plant sample remediated or abstracted/accumulated heavy metal from the polluted soil was calculated as R = Amount of metal lost by the soil or gained by the plant expressed in percentage of the initial amount.

$$\text{Rate } (\%) = \frac{C^{nth\ week} - C^{0th\ week}}{C^{0th\ week}} \times \frac{100}{1}$$

Where $C^{nth\ week}$ and $C^{0th\ week}$ are concentrations of the heavy metals in the soil or plant sample at a time (weeks) = 'n' and '0' respectively.

III. Results And Discussion

Growth tolerance of jute *(Corchorus capsularis)* in the polluted soils

On harvesting jute from the various contaminated soils after 2 weeks, root and shoot lengths of the plants averagely varied between 2-4 cm and 9-11 cm respectively. After 4 weeks, the same lengths varied on average by 3-5.5 cm and 10-15 cm respectively from the same soils polluted with heavy metals. After the final week of growth (8 weeks), the same lengths varied between 6-7 cm and 17-20 cm respectively. Jute *(Corchorus capsularis)* attained about 95% overall growth in the polluted soil when compared to its growth in the control experiment. Hence, demonstrating the adaptive ability of *Corchorus capsularis* to withstand and tolerate the stress conditions of polluted soils is in line with one of the criteria to select a plant for phytoremediation. The growth rate of plant species in heavy metal-polluted soil was slow in the first 4 weeks of transplanting, but subsequently, rapid growth was observed in the last 4 weeks of the experiment [19]

Bioconcentration factor (BCF) and Transfer factor (TF) in *Corchorus capsularis* (jute)

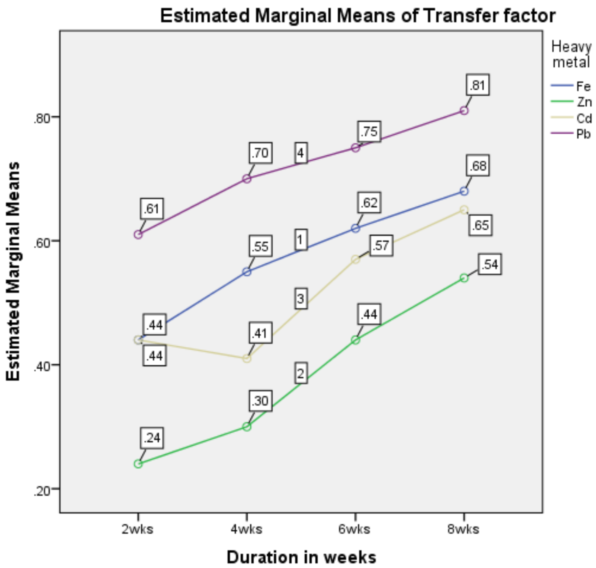

Fig. 2a: Variation of heavy metal transfer factor (TF) of *Corchorus capsularis* (Jute) with the period of growth

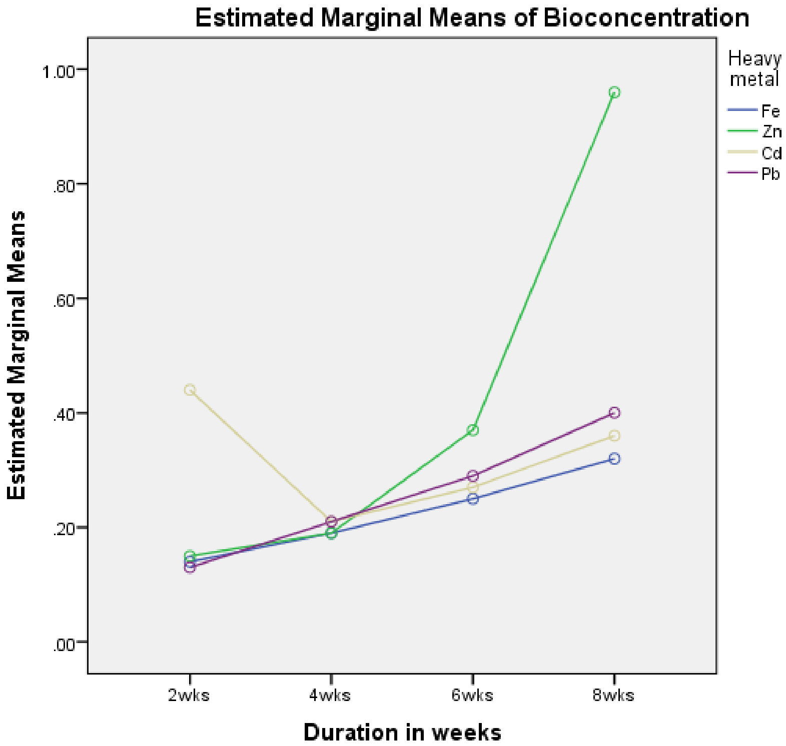

Fig. 2b: Variation of heavy metal bioconcentration factor (BCF) of *Corchorus capsularis* (Jute) with the period of growth

Bio-concentration factor, which measures the metal concentration (mg/kg) ratio of plant shoot to the soil [20], was determined for Fe, Zn, Cd, and Pb in the *Corchorus capsularis* plant. In all, the BCF obtained was << 1. However, the BCF values for each metal were time-dependent as an increase in weeks increased in BCF value close to 1. The highest BCF value was obtained in Zn (0.96), while Fe had the lowest BCF value (0.32). This further implies that *Corchorus capsularis* has a greater potential in remediating the concentration of Zn in the soil with the least potential of remediating Fe, Cd, and Pb respectively.

Transfer factor (TF) describes the migration of metal from the plant root to the plant parts [3, 21]. This could therefore be seen as an index of the potential of plant species to remediate contaminated soil of a specific metal [22]. Plants with TF of about one or more are suitable for phytoextraction [23]. The transfer factor for each of the metals assayed increased steadily throughout the growth period given ranging from 0.44 - 0.68, 0.24 - 0.54, 0.44 - 0.65, and 0.61 – 0.81 for Fe, Zn, Cd, and Pb respectively. In the first two weeks of growth, Pb recorded the highest TF (0.61) followed by Fe and Cd (0.44) and then Zn (0.24). For the rest of the growth period, the trend in increasing order was Zn < Cd < Fe < Pb. With the observed transfer factor being close to one [2] by the eight weeks of growth the plant sample could be adjudged good for fast and short-term phytoextractor of soil contaminated with Fe and Pb. Abstraction of Zn and Cd would require a longer period of growth. With the observation, it could be stated that TF varies with the stage of growth due to the different nutritional requirements in each stage of development.

Effect of the amount of different heavy metals removed by different parts of *Corchorus capsularis*

In Fig. 3 below, the estimated marginal means of the concentration of heavy metals trapped in the stem of *Corchorus capsularis* in each week showed that for the various weeks, iron was the most trapped heavy metal in the stem of the plant, followed by lead, cadmium and finally zinc as the least trapped. The upwards movement of each line shows that more heavy metals were trapped as the duration increased. The result of this particular study is in line with other literature as obtained in several studies [24, 25].

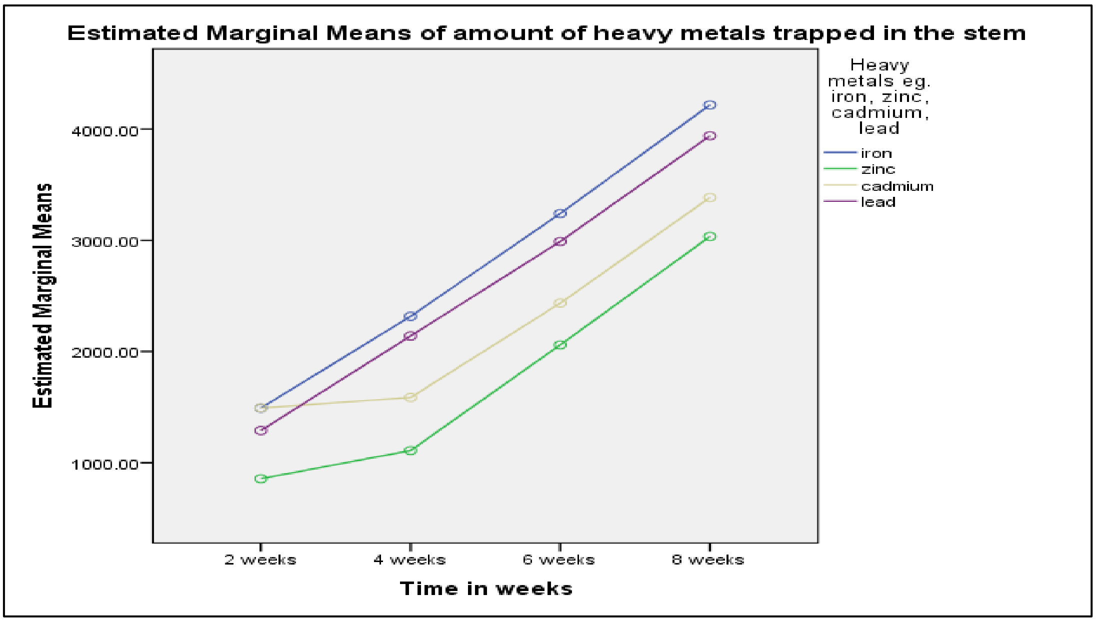

Fig. 3 Estimated marginal means of the concentration of heavy metals trapped in the stem of *Corchorus capsularis*

In Fig.4 below, the estimated marginal means of the number of heavy metals trapped in the root of the jute plant each week showed that for the various weeks, iron was also the most trapped heavy metal in the root of the jute, followed by zinc, cadmium and finally lead as the least trapped. Also, more heavy metals were trapped with time. This result agrees with [26, 27] in their assessment of the metals trapped in the root of some native plants.

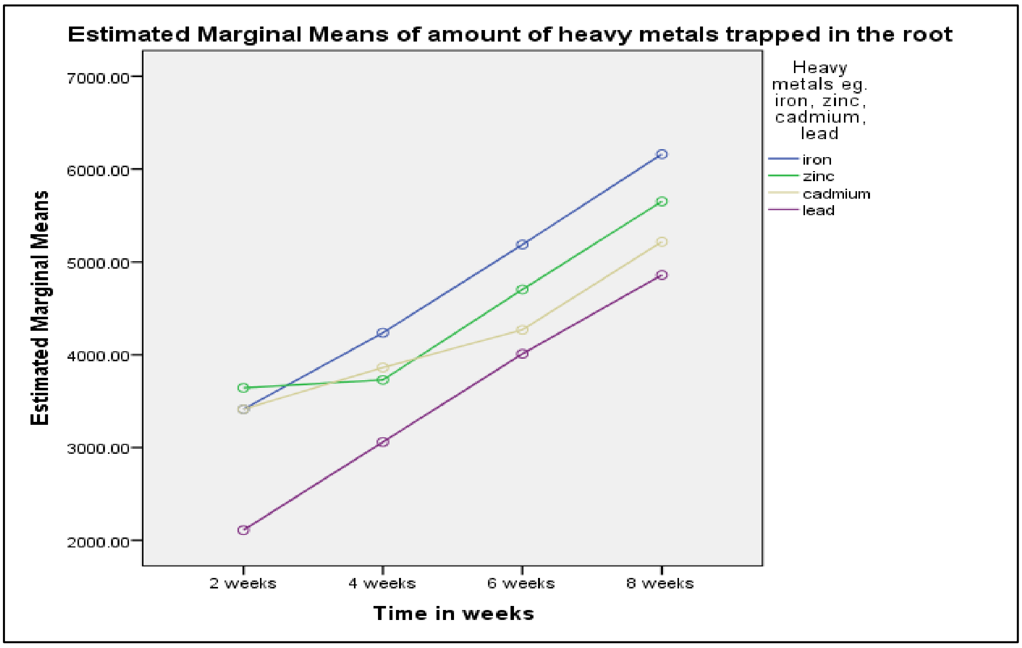

Fig. 4: Estimated marginal means of the number of heavy metals trapped in the root of *Corchorus capsularis*

Considering Fig. 5 below, the estimated marginal means of the number of heavy metals remaining in the soil each week showed that as the time (weeks) increased, the number of heavy metals in the soil reduced. Observe that there was a sharp decrease for the green line corresponding to zinc. This means that more zinc-heavy metals were removed by the jute plant with time. Previous investigations have also documented that phytoremediation is a time-dependent technique for proper uptake of the metals into the root of the plant species [28, 29] and this research, which is consistent with other studies, shows that the amount of remnant in the soil decreases over time. [7, 30]

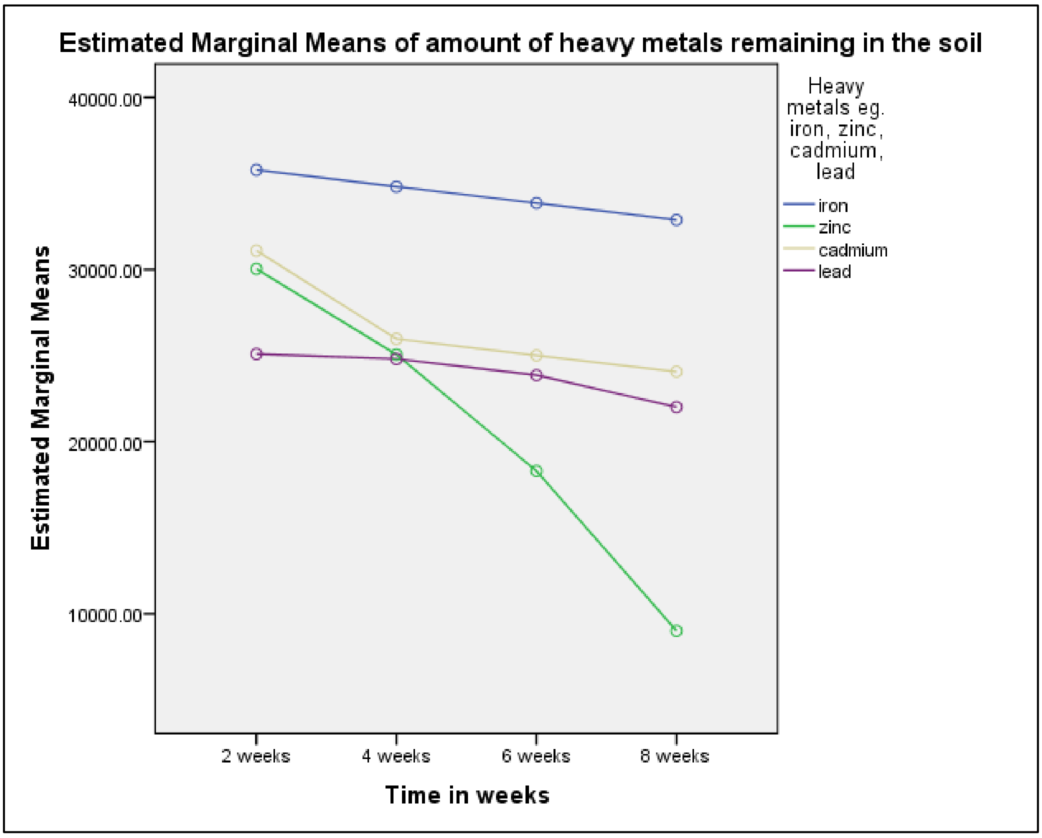

Fig. 5: Estimated marginal means of the number of heavy metals remaining in the soil

IV. Conclusion

Corchorus capsularis, a plant species, was able to retain an appreciable growth rate of 90 % on average in contrast to the control experiment while also accumulating heavy metals in various parts of its body from the heavy metal-contaminated soils. *Corchorus capsularis* is usually a good phytoextractor of Fe, Zn, Cd, and Pb, which can be attributed to the plant's long roots, as shown by the TF and BCF of the plant species. The TF and BCF have also shown that the plant species is a hyperaccumulator, raising the possibility that eating plant species from this heavy metal-polluted soil could be harmful to one's health. In a similar vein, it has been demonstrated that Cd abstraction in plants requires a longer time of growth; as a result, the plant species are not suitable for remediating the heavy metal (Cd) quickly.

The ability of *Corchorus capsularis* to function as phytoextractors for the remediation of soils contaminated with Fe, Zn, Cd, and Pb has been established. Utilizing the phytoremediation approach is a quick way to decontaminate soil. Also demonstrated is phytoremediation, an environmentally favorable but time-consuming method for restoring sound soil health. Future heavy metal phytoremediation and phytomining processes are anticipated to make use of the phytoextraction of heavy metals as an economically viable technology.

Acknowledgment

The authors wish to appreciate Mr. Augustine D. Terna for his constructive revision of the manuscript.

Statement and Declarations

Funding: If none, write: Not applicable
Conflict of Interest: If none, write: Not applicable.
Ethical approval: If none, write: Not applicable.
Informed consent: If none, write: Not applicable.

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