PHYTOEXTRACTION POTENTIAL OF *VETIVERIA ZIZANIOIDES* ON HEAVY METALS

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Abstract

Excessive release of heavy metals into the environment as a result of massive urbanization and industrialization has posed a great threat worldwide. In view of this, a more effective, sustainable, renewable and environmental friendliness technique is needful to curb the resulting environmental pollution. Several methods or technologies have been developed over the years for treating contaminated sites, but the kinetics of uptake of heavy metals which are necessary for the design of the treatment system have been largely neglected. This work therefore studies the uptake kinetics of three heavy metals (Lead, Zinc and Cadmium) by the plant *Vetiveria zizanioides* (vetiver) from contaminated soil. The model was based on bioaccumulation factors and half-life study of the heavy metals in the soil for a period of three months. From the result of the study, bioaccumulation factor (BAF) for Cadmium was found to be the minimum (0.2051mg/mg), followed by Lead (0.8265mg/mg) while that of Zinc was the maximum (0.9016 mg/mg). Also, the half- life was estimated to be 6.4 months for Zinc, 7.2 months for Lead and 29.64 months for Cadmium.

Keywords: Heavy metals, *Vetiveria zizanioides*, Bioaccumulation factors, Half-life, environment

Introduction

Heavy metals are one of the major categories of pollutants which are highly toxic, persistent and non-biodegradable (Olatunji *et al*., 2009). Due to mining, smelting, manufacturing, gas exhaust, energy and fuel production, fertilizer and pesticide application, and municipal waste generation, heavy metal contamination has significantly increased (Khan, 2009; Onweremadu and Duruigbo 2007; Remon, *et al*., 2005; Xinming, *et al*., 2005). The fundamental unit of the geosphere and biosphere is soil-plant system; this has therefore made pollutants in the soil to have great influence on the quality of crops. It also determines the quality of atmospheric and aquatic environment, and even the health of human beings via food chains (Aydin *et al.*, 2008). According to Kumar *et al.*, (1995), the basic research areas in bioremediation studies are cometabolism, bio-treatability, biotransformation kinetics, and modeling of biogeochemical processes. Phytoextraction is the use of plants to clean up or remediate sois contaminated with heavy metals and radioisotopes through concentration of pollutants in the above-ground plant tissues. "Hyperaccumulator" species can accumulate contaminants to thousands of times their normal required concentration from surrounding soils (Reeves, 2000). Vetiver grass is a versatile tool for environmental engineering, moreover it has been named the most versatile crop of the millennium (Maffei, 2002; Mucciarelli *et al.*, 1998).This grass has also been extensively used to control soil erosion and water conservation, especially on very steep slopes, due to its faster root growth, and broad root system. Vetiver length may reach up to 3 m just in one year (Lavania and Lavania, 2000). *Vetiveria zizanioides* can tolerate adverse soil conditions including high heavy metals toxicity and agrochemicals (Chen *et al.*, 2000). Several standard values (Threshold values) showing standard quantity of heavy metals in the soil have been suggested by several Environmental Protection Agencies across the globe; WHO, USEDA, FAO including FEPA (Federal Environmental Protection Agency) in Nigeria.

Table1 shows standard quantity of heavy metals in the soil as given by some environmental protection agencies.

Table 1: Standard Threshold Limit Values for Heavy Metals in the Soil (ppm).

Parameters	Stipulated Concentration Denmark (ppm)*	Stipulated Concentration WHO(ppm)**	Stipulated Concentration FEPA(ppm)***
Cadmium	5	10	3-6
Chromium	Not Fixed	Not Fixed	Not Fixed
Lead	40	70	250-500
Iron	Not Fixed	Not Fixed	Not Fixed
Zinc	500	200	300-600

Sources: (Ezigbo, 2011)

Sustainability of soil structure and fertility is of great interest in bioremediation studies, therefore phytoextraction is the best approach to removal of contaminant from the soil since it's an in-situ approach. Phytoextraction is a process of absorbing, concentrating and precipitating toxic metals and radionuclide from contaminated soils into the biomass (Ghosh and Singh, 2005). Two major strategies explored in phytoextraction are chelate assisted phytoextraction or induced phytoextraction, in which artificial chelates are added to increase the mobility and uptake of metal contaminant and continuous phytoextraction in which the removal of metal depends on the natural ability of the plant to remediate but only the number of plant growth repetitions are controlled (salt *et al.,* 1998). Hyperaccumulator species extracts large concentrations of heavy metals into their roots, translocate the heavy metals to the shoot above ground and produce a large quantity of plant biomass. Therefore, this study employs phytoremediation technique to investigate the phytoextraction potential of *Vetiveria zizanioides* on soil artificially contaminated with heavy metals.

Materials And Methods

Experimental Set-up

Treatment A: 5Kg of soil + 300mg Zinc + a tiller of Vetiver

Treatment B: 5Kg of soil + 300mg Lead + a tiller of Vetiver

Treatment C: 5Kg of soil+ 30mg Cadmium + a tiller of Vetiver

Treatment D: 5Kg of soil + a tiller of Vetiver (Control Experiment)

The soil used for the experiment was taken from agricultural garden of Ladoke Akintola University of Technology, Ogbomoso, Oyo state, Nigeria. The soil had a loamy-sandy texture with slightly acidic pH. Due to the potential risk of plant mortality in heavily contaminated soil, each treatment was replicated 9 times to make 40 pots in total. Starting with the date of the transplantation of vetiver to the pots, the experiment lasted 3 months. Destructive samplings were taken at 1 month intervals.

Treatment A-E (Contaminated Soil)

Specific quantities of each metals that is; 300mg Zn, 30mg Cd and 300mg Lead were obtained from their salts; $ZnCl_2$, $CdCl_2$ and $PbCl_2$. The soil and the metals were mixed thoroughly in each of the pots to facilitate proper distribution of the heavy metals in the soil. Each tiller of vetiver to be planted were cut to the same size (Shoot: 20 cm, Root: 10cm) and then stored in water for 2 days to improve their rooting ability (Rodriguez, 1997) before planting a tiller in each of the forty pots to initiate phytoextraction process. The experiment was carried out for a period of three months between April and July. Since water and oxygen availability are important for phytoremediation of contaminated soils, the plants were irrigated adequately (800 ml) 4 times a week.

Destructive Sampling

In course of the experiment, 3 destructive samplings were taken at 1 month intervals. During the monthly destructive sampling analysis, the whole soil is completely removed from the pot to ensure the roots are completely and carefully removed. The soil was checked for any detached root segments and thereafter the shoots were cut off the root systems and the tillers separated. Special observations like the number of tillers and their lengths were recorded, then both the roots and the shoots were oven dried at 60^0C, these and the soil samples were digested by dry ashing using HNO_3 and HCl (1:1).

Data Analysis

Bioaccumulation factors (BAF) for each plant-soil pair was calculated to obtain useful data using equation (1). BAF is the ratio of the heavy metals in the root and the shoot to the heavy metals in the soil.

$$BAF = \frac{Croot+Cshoot}{Csoil} \text{.............................} (1)$$

Croot =Dry weight of heavy metals concentration in the root (mg/kg);

Cshoot= Dry weight of heavy metal concentration in the shoot (mg/kg); and

Csoil =Dry weight of heavy metals concentration in the soil (mg/kg)

This model assumes that a certain mass of the contaminants (heavy metals) has been taken up into the plant since the beginning of its growth to the time of the harvest.

Uptake Kinetics

Time-dependent uptake kinetics is based on BAF values and this is equally useful in estimating the effectiveness of this phytoextraction approach. Derivation of the uptake kinetics model is based on uptake of heavy metals from the contaminated soil through destructive sampling and not the kinetics of physiological uptake of heavy metals into the plant. Also uptake rate is a continuous process though it may vary during the life of the plant, so the total mass of contaminant removed (influx mass) is determined by equation (2):

$$M_{influx} = C_{plant} \; x \; BM \text{...} (2)$$

M_{influx} = Mass of heavy metals in the above-ground plant (mg);

C_{plant}= Dry weight concentration of metals in the plant (mg/Kg); and

BM = Dry weight plant above the ground (kg).

The remaining heavy metals concentration in the soil at the time of plant harvesting is given by equation (3):

$$Cs(t+1) = Cs(t) - \frac{BF \; X \; BM}{Ds \; X \; Vs} Cs(t) \text{............................} (3)$$

Cs(t+1) = Heavy metals concentration in the soil after phytoextraction (mg/kg dry weight);

BAF = Bioaccumulation factor (mg/kg dry weight biota per mg/kg dry weight sediment);

BM = Dry weight above ground plant (kg);

Vs = Volume of underlying soil (3.846L); and

Ds = Dry density of heavy metals (assumed to be 1.3 kg/L); and

Cs(t) = heavy metals concentration in soil before phytoextraction (mg/kg dry weight).

Since this process is a continuous process throughout the life of the plant. The equation above can be rewritten as the following equation:

$$Cs(t+1) - Cs(t) = -\frac{BAF\ X\ BM}{Ds\ X\ Vs}\ Cs(t) \quad (4)$$

When differentiated it yields equation (5):

$$\frac{dCs}{dt} = -\frac{BAF\ X\ BM}{Ds\ x\ Vs}\ Cs\ (t) \quad (5)$$

At time $t = 0\ Cs(0) = C0$,

Eq. (5) can be rewritten as the equation below:

$$C_t = C_o\ x\ e^{-\frac{BAF\ X\ BM}{Ds\ x\ Vs}} \quad (6)$$

The above equation describes changes in the heavy metals concentrations during phytoextraction and destructive sampling of the above ground plant. Nonetheless, this expression fits the form of a standard exponential regression model:

$$Y = a\ e^{bX} \quad (7)$$

Predictive curves for the heavy metals uptake from the soil through phytoextraction and destructive sampling can therefore be constructed based on monthly BAF for each heavy metals.

Half-life study

The efficiency of phytoextraction and harvesting can be determined in terms of half life required for heavy metals removal from the soil. This is the time necessary for the heavy metals concentrations to be reduced to half the initial concentration. The half life due to phytoextraction and harvesting can be calculated by the following equation;

$$t_{1/2} = \frac{\ln\left(\frac{1}{2}\right) x\ Ds\ x\ Vs}{BF\ x\ BM} \quad (8)$$

Results And Discussion

Since the objective of this study is to determine the efficiency of phytoextraction as a less-destructive means of remediation, the above-ground BAF represent the ratio of heavy metals concentration in the plant at the time of each harvesting. The average values of BAF for each metal at each interval are given in Table 2 below;

Table 2: The Mean Bioaccumulation Factors (BAF) for Lead, Zinc and Cadmium

	30 Days	60 Days	90 Days
Lead	0.1498	0.5536	0.8266
Zinc	0.2274	0.6682	0.9016
Cadmium	0.2044	0.1828	0.2051

Uptake kinetics

The uptake kinetics studies how fast *Vetiveria zizanioides* uptakes the heavy metals from contaminated soil. Based on the data of heavy metals concentration with time, predictive curves depicting the removal of heavy metals from the soil through phytoextraction and harvesting was plotted. This is shown in figure1 below;

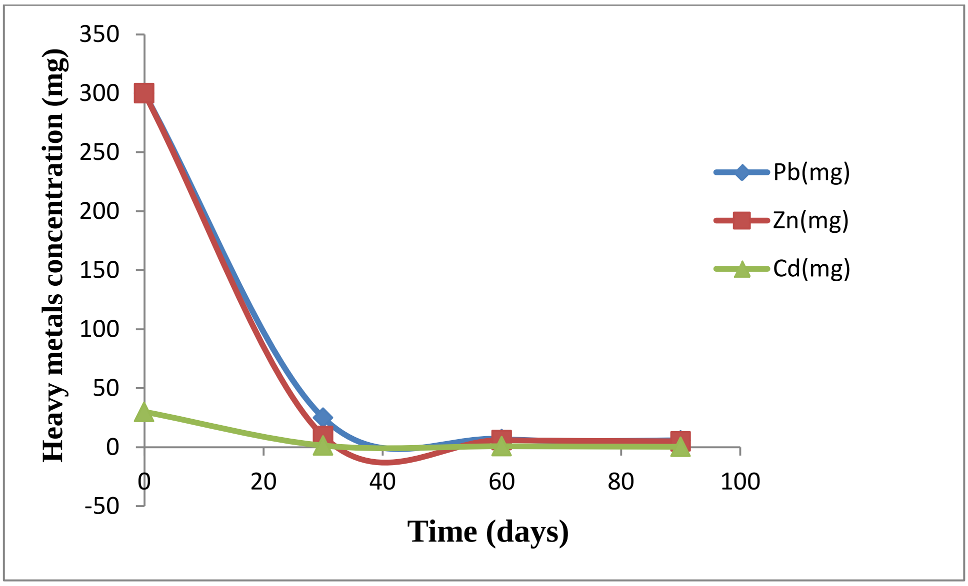

Fig.1: The plot of heavy metals concentration against Time

From the concentration time plot it is obvious that the ability of vetiver to extract heavy metals in the soil is plant-age dependent and it is more active for phytoextraction within the first sixty days (2 months).

Half-life study

The half-lifes for Pb, Zn and Cd calculated according to the available data at the completion of the third month are; 7.2, 6.4 and 29.64 months respectively. From these it is inferable that the half-life for Zinc is the shortest, followed by Lead while Cadmium is the longest.

Also from the available data heavy metals influx into the plant is not equivalent to the quantity of the contaminant in the plant and also more heavy metals are found in the above-ground shoot than in the root. From the concentration time plot it's obvious that the ability of vetiver to extract heavy metals in the soil is plant-age dependent and it is more active for phytoextraction within the first sixty days (2 months). The study also showed that there is more accumulation of the heavy metals in the above ground shoots than in the root. Also, it was discovered that an increase of plant density also showed further increase in the heavy metals depletion rate, because high root density usually improves ion uptake in soils (Baligar, 1985).

Conclusion

The study shows that phytoremediation is a means of bioremediation and the process is more effective within the first sixty days. The study also shows that much Zinc is bioaccumulated by vetiver in comparison with the remaining metals while the least accumulated metal was cadmium, likewise the half-life study revealed that it will take 7.2 months for lead to reduce to half its concentration in the soil likewise 6.4 months for Zn and 29.64 months for cadmium with initial concentrations of 300mg, for zinc, lead and cadmium respectively.

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