Study on the Effectiveness of Phytoremediation in the Removal of Heavy Metals from Soil Using Corn

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ABSTRACT:

The research study aimed at determining the effectiveness of phytoremediation in the removal of heavy metals using corn. Soil sample collected at a depth of 20 cm were taken from Gidan Kwanu area of Niger state, Nigeria. The experiment consists of 12 treatments each containing 4 kg of soil including soil without concentrations of Zn, Fe and Pb to serve as the control. 3 pots each were contaminated with 2.5 g/dm3 concentration of Zn, Fe and Pb. The initial analysis of the soil indicates that the uncontaminated soil sample contained 1.55 mg/kg of Zn, 31 mg/kg of Fe and 0.13 mg/kg of Pb while the contaminated soil sample contained 15.33 mg/kg of Zn, 45.7 mg/kg of Fe and 4.16 mg/kg of Pb. 4 corn seeds were planted on each of the soil sample at a depth of 4cm and the setup was monitored properly in an isolated place. Samples were taken for analysis at 2 weeks interval in a period of 8 weeks. Results show that at the end of the 8 weeks, there was reduction in the concentration of the heavy metals in the soil and there was an increase in the level of heavy metals in the plant leaves and stems. The plants were tolerant of the heavy metals as they had a fast growth, therefore it was concluded that corn is a hyper accumulator and it is effective in the removal and detoxification of soil contaminated with heavy metals.

Keywords: *Phytoremediation, Heavy metals, Corn, Soil, Nigeria.*

I. INTRODUCTION

Farming, military and industrial activities are responsible for contamination of large areas of developed countries with high concentrations of heavy metals and organic pollutants (Peuke and Rennenberg, 2005). In addition to the negative effects of accumulation of heavy metals on ecosystems and other natural resources, they also pose a great danger to public health because pollutants can enter food chain through agricultural product or leach into drinking water (Peuke and Rennenberg, 2005). Soil located in Industrialized regions have been identified as the most affected area due to the heavy metals they used for production and manufacturing. Soil pollution spread to other parts of the natural environment because soil lies at the confluence of many natural systems (Mohammad *et al*., 2008). Many human diseases result from the buildup of toxic metals in soil, making remediation of these areas crucial in the protection of human health (Shaylor *et al.*, 2009). Risk reduction can be through a process of removal, degradation or containment of contaminants. In Nigeria and other developing countries in the world, farmers are commonly using untreated industrial and municipal wastewater for irrigation, particularly in the suburbs of large cities and in the vicinity of major industrial estates (Ghafoor *et al*., 2008). However long term application of heavy metals such as cadmium (Cd), chromium (Cr), Lead(Pb), and Zinc (Zn), in soil causes decline in soil microbial activity, soil and groundwater contamination, reduction in soil fertility and contamination of human food chain (Cynthia and David, 1997).

Current methods of soil remediation such as soil washing, mechanical separation, extraction and storage do not really solve the problem. Hence the need for alternative, cheap and efficient methods to clean up heavily contaminated industrial areas. The current remediation techniques of heavy metal from contaminated soil water are expensive, time consuming and environmentally destructive. Unlike organic compounds, metals cannot degrade and therefore effective cleanup requires their immobilization to reduce or remove toxicity. In recent years, scientist and engineers have started to generate cost effective technologies such as adsorbents. Plants are an effective means of removal of contaminants from soil (Wenzel *et al.*,1999). Phytoremediation is a general term for using plants to remove, degrade or contain soil pollutants such as heavy metals, pesticides, solvents, crude oil, polyaromatic hydrocarbon and landfill leacheates.

For instance wild flowers were recently used to degrade hydrocarbons from an oil spill in Kuwait (Brady and Weil, 1999). Phytoremediation is therefore an emerging technology for cleaning up of contaminated and is now a widely supported green technology which may provide an alternative to cleaning wastewater and contaminated soil. It is a cost effective, environmentally friendly and aesthetically pleasant nature and equal applicability for the removal of both organic and inorganic pollutants present in soil, water and air (Yu *et al*., 2001). Plants which can accumulate high concentration of metals in the harvestable biomass are termed hyperaccumulators. According to and Proctor (1990), the plants that can accumulate >100 mg Cd kg^{-1} or >500 mg Cr kg^{-1} in dry leaf tissue are termed hyperaccumulators. Reeves and Baker (2000) also identified hyperaccumulator plants for elements including Cd, Cr, Ni, Pb, Zn and (Hajar, 1997). However such plants are typically slow growing small and weedy plants that produce only limited amount of biomass and therefore takes significance time to decontaminate polluted sites (Cherian and Oliveira, 2005). Therefore fast growing tree species that guarantee high biomass yield have a tendency for higher heavy metal accumulation, a deep root system and a strong evapotranspiration system are preferred for phytoremediation over conventional hyperaccumulator (Sebastiani, et al., 2004).

A major factor influencing the efficiency of phytoremediation is the ability of plants to absorb large quantities of metal in a short period of time. Corn (Zea mays) planted on the contaminated soil had higher levels of heavy metals than the one planted on the uncontaminated soil. The difference indicates that they have been absorbed away from the contaminated soil (Kumar et al., 1995). Zea mays is thus a hyper accumulator of heavy metal, tolerant of the targeted metals and also had a fast growth rate (Cunningham, et al., 1995). This present study focus on evaluating the performance of corn as an hyperaccumulator in the removal of heavy metals from soil.

II. RESEARCH METHODOLOGY

Soil Sampling

Soil sample was collected from Gidan Kwanu area of Minna, Niger state, Nigeria at a depth of 20cm. Four fresh corn seeds were planted in pots containing 4 kg of the soil at a depth of 4 cm. The experiment consists of 4 treatments, each of these treatment were divided into 3 replicates to give a total of 12 pots. 3 pots without zinc, iron and lead to serve as control, 3 pots contaminated with 2.5 g/dm^3 concentration of Zinc, 3 pots contaminated with 2.5 g/dm^3 concentration of Iron and 3 pots contaminated with 2.5 g/dm^3 concentration of Lead. All the soil samples were taken for initial analysis. The set up was placed in Crop Production Departmental garden of Federal University Technology Minna, Nigeria and monitored properly. After 8 weeks of seed planting and germination, samples from the contaminated soil and the control were analyzed at two weeks interval for heavy metal content. At the end of the 8 weeks, the plants were uprooted and the stems and leaves were also analyzed for the heavy metal uptake.

Soil preparation

Soil preparation before analysis involves two major steps: soil pre-treatment and soil digestion.

Soil Pre-treatment

The soil samples were properly grounded using Agate mortar to enhance the oxidation of soil samples and it was passed through a 0.25 mm sieve mesh to obtain a fine particle.

Soil Digestion

There are various methods of digesting soil such as nitric acid digestion, nitric acid-sulphuric acid digestion, nitric acid-perchloric acid digestion, wet ashing digestion and microwave digestion. In this experiment the nitric acid-perchloric acid digestion was utilized. 0.5g of the finely grounded soil sample was accurately weighed using a digital weighing balance and placed in a 50ml beaker. 20ml of a mixture of nitric acid and perchloric acid in 1:1 molar ratio was poured into the soil in the beaker and the content was placed on a hot plate and heated gently at low temperature until dense white fumes of $HClO_3$ appears. The digested sample was allowed to cool before it was filtered into a 50ml standard volumetric flask which was made up to mark with distilled water and the sample ware placed in storage containers and taken for analysis using atomic absorption spectrometer.

Soil Analysis

The soil was analysed using an atomic absorption spectrometer (AAS). The Sample was aspirated into a flame, atomized and a light beam was directed through the flame into a monochromator and a detector measured the amount of light absorbed by the atomized element in the flame. The radiation was passed through a filter or monochromator which tuned the line of interest but screened the others. The photo detector then received the resonance line, diminished by simple absorption and finally the concentration was displayed.

Plate 1: Experimental Set up

III. RESULTS AND DISCUSSIONS

The study is focus on evaluating the effectiveness of corn as a phytoremediating agent in the removal of heavy metal from soil. The results of the study conducted in period of 8 weeks are presented in tables and figures. The concentrations of Zn, Fe and Pb over a period of 8 weeks at 2 weeks interval are presented in table 1- 5 while the results obtained on the leaves and stems after 8weeks are presented in table 6 and 7. The result of the percentage absorbance of the heavy metal in the leaves and stems of the plant at the end of the 8 week period are presented as Figure 1-4.

Table 1: Sample at Initial Stage

Treatments	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)
CONTROL	1.55	31	0.13
T1	14.9	47	4.16
T2	15.7	47.2	4.22
T3	16	42.9	4.09

Table 2: Sample at 2nd Week

Treatments	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)
CONTROL	0.70	14.30	0.11
T1	12.33	25.78	3.17
T2	13.16	34.80	3.10
T3	11.59	36.11	3.11

Table 3: Sample at the 4th Week

Treatment	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)
CONTROL	0.36	11.04	0.10
T1	9.05	18.02	1.65
T2	10.17	20.24	1.42
T3	9.24	19.26	1.73

Table 4: Sample at the 6th Week

Treatment	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)
CONTROL	0.25	8.56	0.06
T1	4.79	13.56	1.17
T2	5.12	14.02	0.98
T3	4.24	15.73	1.32

Table 5: Sample at the 8th Week

Treatment	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)
CONTROL	0.22	8.13	0.03
T1	4.33	8.88	0.91
T2	4.59	12.24	0.77
T3	3.99	13.51	1.02

Table 6: Results of Levels of Heavy Metal in Leaves of the Corn after 8 Weeks

Treatment	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)
CONTROL	0.32	4.34	0.02
T1	1.94	6.12	0.62
T2	1.91	6.18	0.54
T3	1.85	7.26	0.57

Table 7: Results of Levels of Heavy Metal in Stems of the Corn after 8 Weeks

Treatment	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)
CONTROL	0.39	4.57	0.03
T1	2.27	7.75	0.71
T2	1.98	8.26	0.67
T3	2.06	8.85	0.59

Percentage Absorbance in Leaves and Stems

The percentage absorbance of Zn, Fe and Pb into the plants and stems of the corn planted on both the control and contaminated soil was calculated after 8 weeks.
The results are as follows:

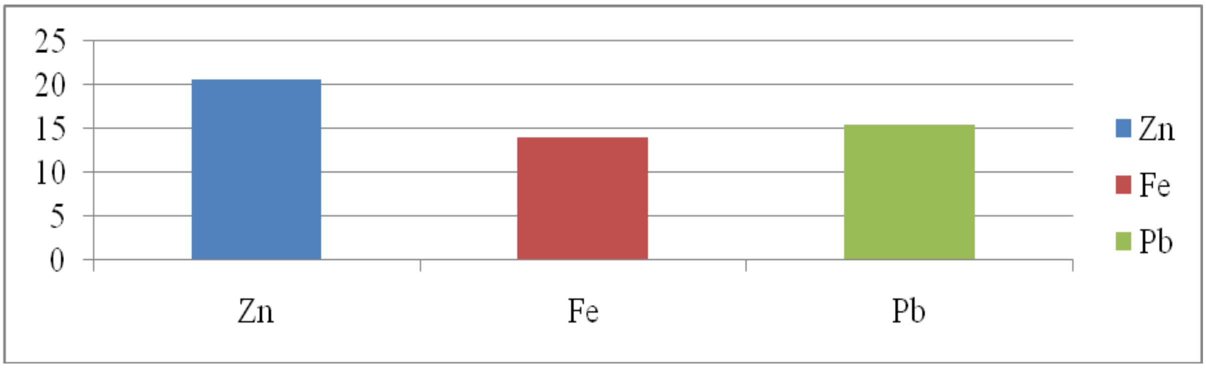

Figure 1: Percentage Absorbance of Heavy Metals in leaves of Corn on Controlled soil sample after 8 weeks

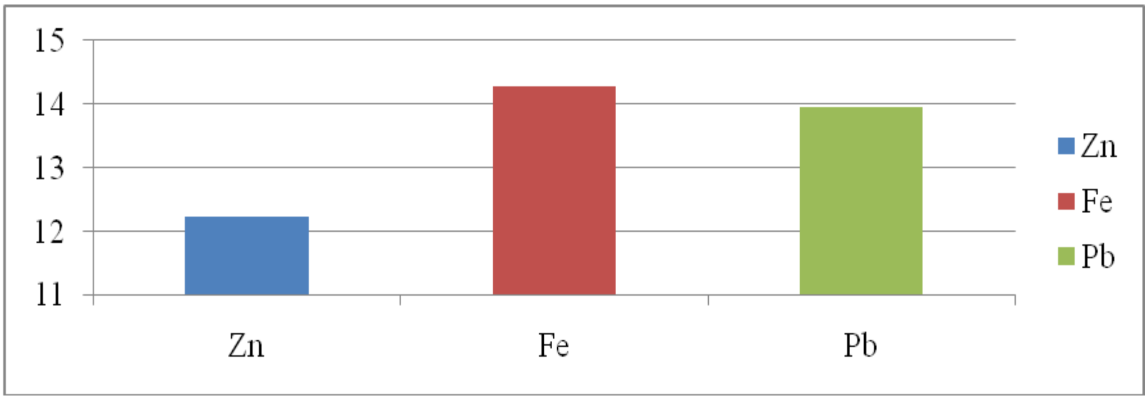

Figure 2: Percentage Absorbance of Heavy Metals in leaves of Corn on Contaminated soil sample after 8 weeks

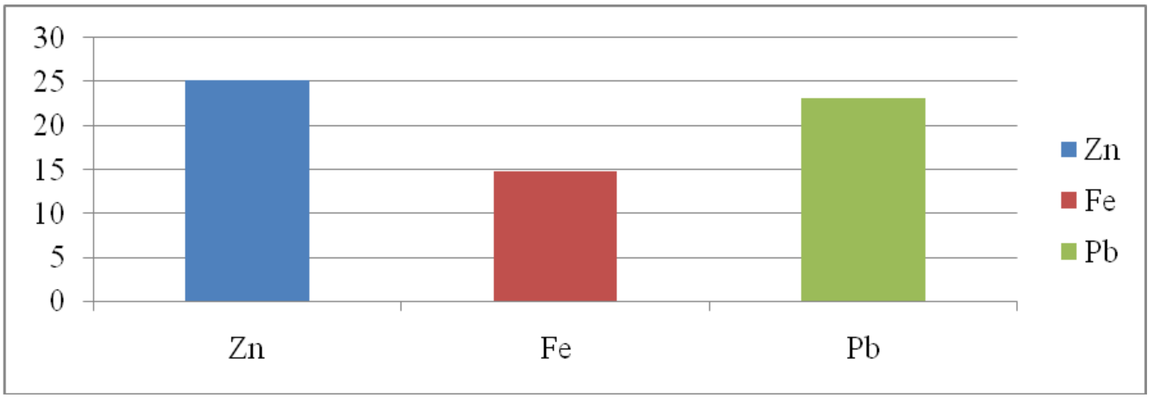

Figure 3: Percentage Absorbance of Heavy Metals in Stems of Corn on Controlled soil sample after 8 weeks

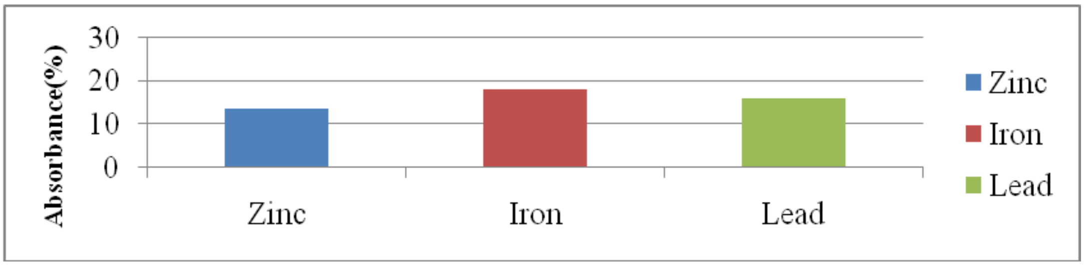

Figure 4: Percentage Absorbance of Heavy Metals in Stems of Corn on Contaminated soil sample after 8 weeks

Discussion of Results

Table 1 to 5 shows the level of heavy metals concentration found in the control and contaminated soil samples in 2 weeks interval in a space of 8 weeks. Table 6 and 7 shows the level of heavy metal in the stem and leave of the harvested plant sample. Figure 1 to 4 shows the comparative reduction in the level of heavy metals in soil over the study period of 12 weeks.Table 1 shows the average concentration of Zn, Fe and Pb at the initial stage was 1.55 mg/kg, 31 mg/kg and 0.13 mg/kg respectively which shows their level in a soil that is not contaminated and from the result it can be deduce that iron has a high concentration in an uncontaminated soil. Also, the average concentration of Zn, Fe and Pb at the initial stage in the contaminated soil was 15.53 mg/kg, 45.7 mg/kg and 4.16 mg/kg respectively which is considerably high for a contaminated soil. Table 2 shows the result of the sample at the end of the 2nd week of experiment.

The concentration of Zn, Fe and Pb in the uncontaminated soil is 0.7 mg/kg, 14.3 mg/kg and 0.11 mg/kg respectively and their average levels in the contaminated soil are 12.36 mg/kg, 32.23 mg/kg and 3.12 mg/kg respectively. These indicate a comparative reduction of the heavy metals ion both the controlled and contaminated soil which can be attributed to the transport of the heavy metal into the roots of the plant. Table 3 shows the result of the sample at the end of the 4th week of experiment. The concentration of Zn, Fe and Pb in the uncontaminated soil is 0.36 mg/kg, 11.04 mg/kg and 0.10 mg/kg respectively and their average levels in the contaminated soil are 9.48 mg/kg, 19.17 mg/kg and 4.18 mg/kg respectively. These also indicates a comparative reduction of the heavy metals in both the controlled and contaminated soil which show more amount of the heavy metals have been absorbed in the corn(Zea Mays). Table 4 shows the result of the sample at the end of the 6th week of experiment. The concentration of Zn, Fe and Pb in the uncontaminated soil is 0.25 mg/kg, 8.56 mg/kg and 0.06 mg/kg respectively and their average levels in the contaminated soil are 4.72 mg/kg, 14.44 mg/kg and 1.16 mg/kg respectively.

These also indicates a comparative reduction of the heavy metals in both the controlled and contaminated soil which show more amount of the heavy metals have been absorbed in the corn (Zea Mays).Table 5 shows the result of the sample at the end of the 8th week of experiment. The concentration of Zn, Fe and Pb in the uncontaminated soil is 0.22 mg/kg, 8.13 mg/kg and 0.03 mg/kg respectively and their average levels in the contaminated soil are 4.30 mg/kg, 11.54 mg/kg and 0.9 mg/kg respectively. The result at the end of the 8th week also indicates a comparative reduction of the heavy metals in both the controlled and contaminated soil which show more amount of the heavy metals have been absorbed in the plant without affecting the development of the corn (Zea Mays). In summary, it can be deduced that the level of Zn, Fe and Pb in both the controlled and contaminated sample reduce over time of 8 weeks. From Figure 1, the percentage absorbance of Zn, Fe and Pb into the leaves of the plant is 20.65 %, 14.00 % and 15.38 % respectively of their initial concentration from the controlled soil sample into the leaves. In Figure 2, there was an uptake of 12.23 % Zn, 14.3 % Fe and 13.9 % Pb of the initial concentration from the contaminated soil sample into the leaves of the corn. From these results, it can be deduce that Zn has the highest absorption rate into the leaves from the controlled soil sample and Fe has the highest absorption rate into leaves of the contaminated soil sample.

From figure 3, there was an uptake of 25.16 % Zn, 14.74 % Fe and 23.08 % Pb of the initial concentration from the controlled soil sample into the stem of the plant. Also, in Figure 4 there was an uptake of 13.52 % Zn, 18.14 % Fe and a 15.87 % Pb of the initial concentration from the contaminated soil sample into the stem of the corn plant. From these results, it can be deduce that Zn has the highest absorbance rate into the stem from the controlled soil sample and Fe has the highest absorbance rate into the stem from the contaminated soil sample. The results also pointed out that the level of the heavy metals in the stem were more than their amount in the leaves which can be attributed to the further transportation of the heavy metals from the stem to the leaves. The highest removal of Zn concentration in the contaminated soil sample was in the sixth week period and the highest removal of Fe and Pb was in the Fourth week.

From all these result obtained, it shows there was a steady decrease in the levels of the heavy metals in both the controlled and contaminated soil sample and an increase in the levels of these heavy metals in the leaves and stem of the corn accompanied by their corresponding decrease in soil sample indicate that they are accumulating into the corn through its root. The increase in the levels of these heavy metals in the corn sample can be attributed to two major transport mechanisms: convection and diffusion. There is a transport of soluble metal ions from the soil solid to the root surface due to convection because as water is being lost by the leaves due to transpiration. There is need of replacement of these water from the soil, these water loss to the atmosphere create a concentration gradient thereby driving the diffusion of ions towards the depleted layer of the plant thereby creating a movement from the soil into the roots, stems and leaves. Some ions are absorbed by roots faster than the rate of the supply.

IV. CONCLUSION

From the results obtained in the cause of this study, it was deducted that there was an uptake of 25.16 % Zn, 14.74 % Fe and 23.08 % Pb of the initial concentration from the controlled soil sample and an uptake of 13.52 % Zn, 18.14 % Fe and a 15.87 % Pb of the initial concentration from the contaminated soil sample into the stem of the corn plant. Therefore it can be concluded that corn (Zea Mays) is a hyper accumulator of heavy metal, tolerant of the targeted metals and also had a fast growth rate and is a good phytoremediation agent.

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