Phytoremediation Potentials of Selected Plants in Industrially Contaminated Soils

M. Waziri, U. Abdullahi, A. A. Audu, and Kalimullah

***Abstract*—Waste discharges into River Challawa in Kano, Nigeria is posing serious environmental hazards. The present study was therefore designed to examine the potentials of Jatropha (*Jatrophacurcas)*, Neem (*Azadirachtaindica*) and Baobab (*Adansoniadigitata*) for phytoremediation of some heavy metalsin the industrially contaminated soils of Challawain Kano, Nigeria. The plants were grown under hydroponic greenhouse conditions for thirteen weeks andlevels of metals in plants, soil and effluent water were determined using Atomic Absorption Spectrophotometer. The mean concentrations of the metals ranged from 4.33±0.02mg/kg Pb to 453.15 ±42.32mg/kg Feand 2.6 ± 0.01 mg/kg to 114.6 ± 23.24 mg/kg for plants grown in the contaminated and control soils respectively. The bioaccumulation factors (BAC>1) indicates metal contamination of the soils and thus can be used for their phytoextraction. The results suggests that the investigated plants are potentially useful for remediating heavy metals from Challawacont animated soils.**

***Index Terms*—Bioaccumulation factor, heavy metals, phytoextraction, phytoremediation, contaminated soils.**

I. Introduction

Phytoremediation is an environmentally friendly, safe and cheap technique used to eliminate pollutants from an environment. It is a technology which uses plants and microbes for there mediation of contaminated soils. It is a cost effective, long term, environmentally and aesthetically friendly method of immobilizing/stabilizing and transferring contaminants such asmetals, pesticides and chlorinated hydrocarbon without causing any disturbance to an area [1]-[4]. Basically, phytoremediation of contaminants is categorized under five major sub-groups phytoextraction, phytostabilisation, phytofiltration, phytovolatilisation, and phytodegradation [5], [6]. The idea of using metal accumulating plants to remove heavy metals and other compounds was first introduced more than 300 years ago [7]. Over the past decades, it has become a highly accepted means of detoxifying contaminated water and soil. The development of phytoremediation is being driven primarily by the high cost of other environment clean up techniques as well as a desire to use a "green" sustainable process. Metals contaminated soilscan be remediated by conventional and unconventional techniques but the in-situ techniques are favored over the ex-situ techniques, due to their low cost and reduced impact on the ecosystem.

Conventionally, the ex-situ technique of excavating contaminated soils and their burial in landfill sites is not an appropriate option because it merely shifts the contamination problem elsewhere [8]. The hazard associated with the transportation of contaminated soils makes it an undesirable option [9]. Most of these conventional remediation technologies are expensive to implement and cause disturbances to the already damaged environment [10], [11].

This paper presents the application of phytoremediation technology to the contaminated soils of the Challawa Industrial Estate whose effluents are connected in a channel and discharge in to river Challawa. The increasing discharge of industrial wastes in this river is posing serious danger to the soils, water resources and the health of people in the area [12]. The major problem of environmental concern, facing Kano city, is that of wastewater discharge from industries located within the metropolis. High levels of some physico-chemical pollution indicators studied from textiles and tanneries in the area showed higher pH, temperature, conductivity, turbidity, color, TSS, Oil and grease above the WHO [13] recommended levels [14], [15]. The concentrations of Cu, Zn, Mn, Pb, Cr and Ni were also reported to be significantly higher than the levels recommended by FAO, FEPA and the WHO/European Union limits [16]. This study was aimed at examining the phytoremediation potentials of Jatropha (*Jatrophacurcas)*, Neem (*Azadirachtaindica*) and Baobab (*Adansoniadigitata*) trees in removing Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn from industrially contaminatedsoils of the Challawa Estate located in Kano, Nigeria,using their bioaccumulation (BAC) [16] andtranslocation factors (TF) [17].

II. Materials and Methods

A. Sampling

Soil samples (15.00kg) were collected from the Challawa Industrial Estate along the effluent discharge channels in black polyethylene bags while the liquid effluent was collected in 25 liter container and transported to the laboratory. Control soil sample (15.00kg) was similarly collected from Barhim village, an area free from industrial activities. The seeds of Jatropha (*Jatrophacurcas)*, Baobab (*Adansoniadigitata*) and Neem (*Azadirachtaindica*) trees were obtained from the European Economic Community

Manuscript received August 7, 2015; revised December 25, 2015.

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(EEC) Nursery, Katsina. The soil samples were air-dried separately at room temperature in the laboratory.

B. Phytoremediation Studies

Plastics pots of 25cm and 30cm in diameter and height respectively were filled with 1.50 kg of the air-dried soil samples, the seeds were planted in the pots individually and allowed to germinate. Twenty (20) replicates of each plant, ten each for the control and the contaminated soils were prepared and placed in the Green-House area within the Biological Garden of Umaru Musa Yar'adua University, Katsina. The pots were watered daily with 500ml of the effluent water per pot. In order to prevent loss of soil nutrients and the essential elements out of the pots, plastic trays were placed under the pots and the drained-out water collected are recycled. Soil moisture content was adjusted regularly using distilled water. The survival rate and growth parameters of plants (height, number of leaves and biomass) of each plant were monitored daily for a period of thirteen weeks.

C. Sample Preparation

At the end of the experimentation period, the plants were harvested whole from each pot, placed in black plastic bags and taken to the laboratory. The soil sample in each pot was also collected in black plastic bags and taken to the laboratory. The plant samples were washed with distilled water to remove dirt and dust. The samples were then separated into portions of roots, stems, and leaves and air dried in the laboratory for three weeks. The dried samples were ground into fine powder using ceramic pestle and mortar and stored in stoppered plastic bottles, until used for acid digestion. Soil samples were also air-dried, ground to fine powder, sieved using a 2mm nylon sieve and stored in polythene bags, until used for acid digestion.

D. Soil pH Determination

The pH of the soil samples before planting and after harvest were measured using a calibrated SB20 pH meter and three replicated determinations were carried out on each sample based on the manufacturer's instruction for the pH meter.

E. Digestion of Effluent Water Samples

The effluent water sample digestions were carried out as described in standard methods (American Public Health Association, 1985) in which 50cm^3 of the sample was first treated with 20cm^3 concentrated HNO_3 and the mixture was heated to boiling on a hot plate. Heating continued until white fumes evolved. The digest was allowed to cool, filtered into 100cm^3 standard volumetric flask and made up to the mark with distilled water. A blank sample was prepared using same procedure but without sample.

F. Digestion of Plant Samples

Powdered samples (0.5g) of each part of the plant (leaves, stem, roots) were weighed into a 100cm^3 digestion flask and 5cm^3 of concentrated HNO_3 and 2cm^3 $HClO_4$ were added. The mixture was then heated on a hot plate at 95^{0}C until the digest became clear. The digest was diluted with de-ionised water, filtered into a 100cm^3 volumetric flask and then made up to the mark with more de-ionised water. A blank sample was prepared using same procedure but without sample.

G. Digestion of Soil Samples

The soil samples were digested using USEPA method [18], where 1.0g portion was weighed into a 100cm^3 beaker, followed by addition of 10.0 cm^3 of 1:1 HNO_3:H_2O. The mixture was then heated on hot plate at 105^{0}C for 1hr and allowed to cool to room temperature. This was followed by sequential addition of 5.0cm^3 of concentrated HNO_3, 1.0cm^3 of H_2O_2, and 5.0cm^3 of HCl. The resulting solution was filtered and diluted with de-ionized water to a final volume of 100cm^3 in a volumetric flask. A blank sample was prepared using same procedure but without sample.

H. Analysis of Samples

The concentration of heavy metals in the filtrates were determined using Atomic Absorption Spectrophotometer (Buck 210 VGP Model) equipped with a digital read-out system. Working standards were prepared, after serial dilution of 1000ppm metal stock solution in each case. Calibration curves were prepared for the elements individually. A blank reading was also taken and necessary corrections were made during the calculation of concentration of various elements.

I. Data Analysis

Analysis of variance for the growth parameters and heavy metals concentrations in the samples were computed by the Duncan's multiple range test DMRT (p=0.05) method [19]. The statistical variations were considered significant at p<0.05. Comparison using t-test was also used to detect any significant differences in metal concentrations between plants from polluted and unpolluted (control) sites.

III. Results and Discussion

A pictorial representation of the growth performance of the tested plants after one and three months of experiment are shown in Appendices 1-3, while the Plants growth performance, Plants biomass and Soil pH at the end of the three months experimentation period are shown in Table I.

TABLE I: Plants Growth Performance, Plants Biomass and Soil pH at the End of the Three Month Experimentation Period

Plant Samples	Treatment	3rd Month		Plant	Soil pH
		Biomass (g)			
		Shoot	No. of		
			Length (cm)	Leaves	
JatrophaCurcas	Contaminated Soil	13.00±3.74	9.30±1.83	18.82±1.86	5.37±0.06
JatrophaCurcas	Control Soil	11.43±2.03	6.80±1.62	14.72±9.51	7.12±0.02
Adansoniadigitata	Contaminated Soil	9.54±3.07	5.30±3.43	1.26±2.63	5.44±0.05
(Baobab tree)					
Adansoniadigitata	Control Soil	15.63±5.48	11.30±3.13	2.38±4.83	7.63±6.51
(Baobab tree)					
(*Azadirachtaindica*)	Contaminated Soil	15.71±3.99		10.00±1.92	1.18±2.91
(Neem tree)					5.56±0.06
(*Azadirachtaindica*)	Control Soil	5.06±7.50	4.30±9.49	0.23±8.20	8.04±0.02
(Neem tree)					

The soil pH values before planting and after harvest were

significantly different. The pH of the soils after harvest were lower compared to before planting in all treatments but the pH of the soil after harvest in the control treatments were slightly higher than pH before planting. The contaminated soil pH after harvest ranged from 5.37 to 5.56. The decrease in pH must have influenced the availability of metal cations and other ions in the soil which would have been effectively absorbed by the plants [20], [21]. The pH range obtained in this study were comparable to those reported by Brown, 2007 [22].

The growth parameters of *Jatrophacurcas* as shown in Table I were more affected by the contaminants in the soil and effluent water compared to the other two plants. In the first 3 to 4 weeks, the effects were negligible, but after three months, the effects of contamination on the growth parameters were pronounced. The *Jatrophacurcas* plants recorded an average shoot height (13.00±3.74 cm) in the contaminated soils compared to the shoot height (11.43±2.03 cm) in the control soil. It also had the highest biomass and higher number of dark-green colored leaves (9.30±1.83) in contaminated soil compared to the control which recorded lower number of leaves (6.80±1.62) with yellowish colors. Similar growth performance of *Jatrophacurcas* have been reported with variations in shoot heights which were attributed to the heavy metals toxicity and extreme infertility in the contaminated soils [23], [24].

The baobab seeds in contaminated soils germinated 3 days earlier than those of the control (Table I). This indicates that the plant adapted to the metal environment in the soil, prompting its fast germination. After three months, the number of leaves were 5.30±3.43 and dark-green in color while the shoot height was 9.54 ± 3.07cm for the plants from contaminated soil. The control site recorded higher number of yellowish colored leaves (11.0±0.13) and higher average shoot height (15.63±5.63cm). The growth parameters for Baobab in the contaminated soils were also lower than values recorded for *Jatrophacurcas* but are in agreement with values reported for some plants with high phytoremediation potentials [25].

The results indicate that the effluent water and the soil showed positive effects on the growth performance of Neem (*Azadirachtaindica*) tree (Table I). The seeds at both sites germinated the same time but after two weeks, a better growth performance of the seedling from the contaminated soil was recorded. In the third month, the contaminated site recorded higher average number of leaves (10.00±1.92) and shoot height (15.71±3.99cm) but lower values compared to the control siteand recorded values for the other studied plants. The plant biomass was also lower when compared to the other studied plants. Nazir*et al.*, 2013, reported that higher concentrations of heavy metals in growth media reduced the growth and biomass of their studied plants which are in agreement with our results [25]. Our results therefore signified that the Neem (*Azadirachtaindica*) trees toleratedand survived better in the contaminated soils.

The mean levels of Cr (2.47 ± 0.04 mg/l), Cu (2.50 ± 0.04 mg/l), Zn (3.09 ± 0.10 mg/l), Pb (1.62 ± 0.12 mg/l), Cd (1.82 ± 0.01mg/l) and Ni (1.86 ± 0.01mg/l) in the effluent water were found to be above the FEPA and WHO permissible limits [26], [27], but the levels of Mn (2.34 ± 0.01 mg/l) and Fe (10.0 ± 0.15 mg/l) were below the maximum permissible limits (Table II). Similar high concentrations of some heavy metals in the Challawa effluent water were reported [28].

When the levels of these metals in the Challawa soils and those of the control were compared, a general buildup of the metals in the Challawa soil ranging from about twice in the case of nickel to more than twenty times in the case of iron were noted. This buildup of the metals in the soil might be due to the continuous industrial activities within the estate. This means that metals such as Mn and Fe which were found to be within the tolerable limits will exceed the limits with time.

TABLE II: MEAN HEAVY METAL CONCENTRATIONS (MG/L) IN WATER EFFLUENTS COLLECTED FROM CHALLAWA INDUSTRIAL ESTATE AS COMPARED TO FEPA AND WHO STANDARD SPECIFICATION

Metals	Concentration (mg/L)	FEPA [21] mg/L	WHO [22]
Cd	1.82 ± 0.01	<1.0	-
Cr	2.47 ± 0.04	1.0	1.0
Cu	2.50 ± 0.04	1.0	0.5
Fe	10.00 ± 0.15	20.0	15.0
Mn	2.34 ± 0.01	5.0	-
Ni	1.86 ± 0.01	<1.0	-
Pb	1.62 ± 0.12	1.0	1.0
Zn	3.09 ± 0.10	15.0	1.0

The levels of heavy metals in the plant tissues (roots, leaves and shoot) in the tested plants and control are shown in Figs. 1-3.

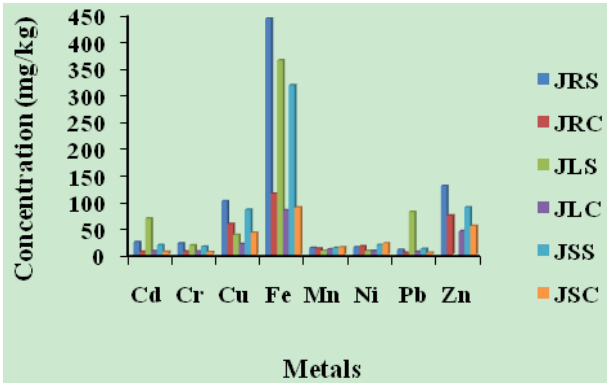

Fig. 1. Heavy Metal Concentrations in the Root, Leaves and Shoot of *Jatrophacurcas*in contaminated and control soils [J= *Jatrophacurcas*, R= Root, L=Leaves, S= Shoot, S= Contaminated soil, C= Control soil].

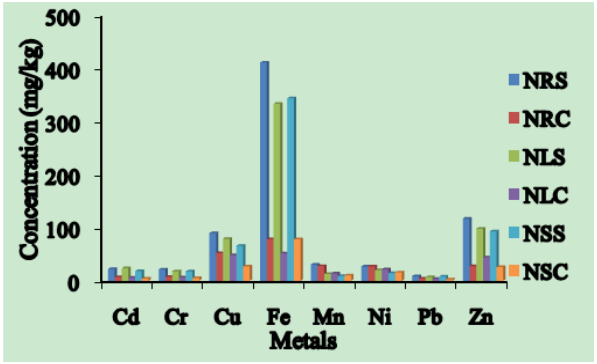

Fig. 2.Heavy Metal Concentrations in the Root, Leaves and Shoot of Neem (*Azadirachtaindica)* in contaminated and control soils [N= Neem (*Azadirachtaindica*, R= Root, L=Leaves, S= Shoot, S= Contaminated soil, C= Control soil].

The results indicate that the plant species accumulated different levels of Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn showing their tolerance for these metals. The roots of *Jatrophacurcas*

accumulated highest levels of Fe, Cu and Zn while the leaves contained highest levels of Fe, Cd and Pb compared to their levels in similar tissues of the control (Fig. 1). Similar variations of Cu, Fe, Al, Pb and Zn in *Jatrophacurcas* were reported [29], [30].

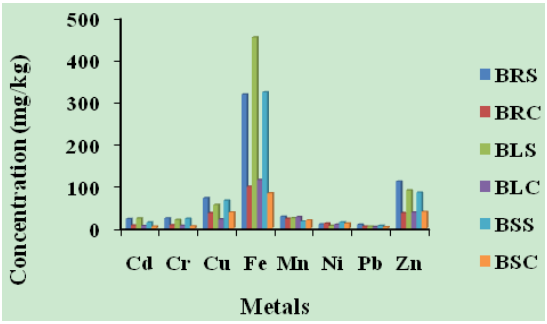

Fig. 3. Heavy Metal Concentrations in the Root, Leaves and Shoot of Baobab (*Adansoniadigitata*) in contaminated and control soils [B= Baobab (*Adansoniadigitata*), R= Root, L=Leaves, S= Shoot, S= Contaminated soil, C= Control soil].

The roots of Neem (*Azadirachtaindica*) accumulated higher levels of all the metals (Cd, Cu, Fe, Mn, Ni, Pb, and Zn) with high accumulation of Zn in the leaves and the roots accumulating highest levels of Cu and Ni (Fig. 2). Similarly Baobab (*Adansonia*digitata) tree roots accumulated highest levels of Mn while the leaves accumulated the highest level of Fe (Fig. 3).The capability of plants to grow well in soils with concentrations of heavy metals similar to the ones studied in the present study were reported [21], [23]-[25].

The results of the contamination factor CF showed that the levels found in the present study were in the sequence of Cd (7.76)> Cu (3.31)> Cr (2.34)>Pb (2.33)> Zn (2.26)> Fe (1.65)>Mn (1.07)> Ni (1.01) indicating very high contamination from Cd. The levels of contamination for Cu, Cr, Pb, and Zn could be considered as moderate while that for Fe, Mn and Ni as high [31].

The highest bioaccumulation factor (BAF) of all the metals examined in the tissues were in the following descending order; Pb(4.08)> Ni(3.35)> Cr(3.21)> Cu(3.09)> Fe(3.09)>Mn(3.08)> Cd(1.67)> Zn(1.64) for *Jatrophacurcas*; Mn(5.62)> Ni(4.37)> Cr(3.30)> Cu(2.90)> Fe(2.87)>Pb(2.62)> Zn(1.51) Cd(1.10) for Neem (*Azadirachtaindica*) tree and Mn(5.45)> Cr(3.86)> Fe(3.19)> Cu(2.26)> Ni(2.13)>Pb(1.43)> Zn(1.41)> Cd(1.11) for Baobab (*Adansoniadigitata*) tree. The BAF of all the metals determined were greater than one. The accumulation and distribution of heavy metals in these plants are important to assess their roles in remediation of heavy metals in soils. Therefore, the studied can be used as potential hyper-accumulators for these heavy metals [24], [29], [31].

The Baobab (*Adansoniadigitata*) has the highest translocation for Fe (2.44) and this is in good agreement with the sequence when the Fe levels in the tissues of the three plant species are compared. The sequence in Boabab (*Adansoniadigitata*) was Leaves > Shoots > Roots while for Neem (*Azadirachtaindica*) the order is Roots > Shoots > Leaves and Jatropha (*Jatrophacurcas)* is Roots > Leaves > Shoots. These observations were quite interesting as the only edible parts of Boabab consumedby people of Northern Nigeria in their food preparations are the leaves. The TF values for the contaminated sites were significantly (p<0.05) higher than the values in the control site.

The results showed high availability and distribution of metals in contaminated soils thus making all the three plant species as good accumulators of these metals based on TF > 1. Heavy metal tolerance with such TF values have been suggested for phytoaccumulation of contaminated soils [30] and thus these plant species can be used as potential phytoremediators for contaminated soils.

IV. Conclusion

In this study we examined the phytoremediation potentials of *Jatrophacurcas,*Neem (*Azadirachtaindica*) tree and Baobab (*Adansoniadigitata*) tree for removal of Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in contaminated soils. The parameters used in the assessment include; plant growth performance, plant biomass and soil pH. The results showed that the *Jatrophacurcas,*Neem (*Azadirachtaindica*) tree and Baobab (*Adansoniadigitata*) tree were suitable for the uptake, accumulation and storage of these metals from contaminated soils. The bioaccumulation and translocation factors were found to be greater than one in all cases, which indicate that the plants are good hyper-accumulators and have the potentials for remediation processes. These plants can therefore be considered suitable for growing in the industrially contaminated regions of Challawa estate. A massive plantation of these plants in and around the industrial estate to check the mobility of heavy metals into the ground water system in the Challawa area is therefore recommended.

Appendix

Graph 1 A. Growth of *Jatrophacurcas* i n contaminated and uncontaminated soil after one month.

Graph 1 B. Growth of *Jatrophacurcas* in contaminated and uncontaminated soil at final stage (after 3 months).

Graph 2 A. Growth of Baobab (*Adansoniadigitata*) tree in contaminated and uncontaminated soil after one month.

Graph 2 B. Growth of Baobab (*Adansoniadigitata)* tree in contaminated and uncontaminated soil at final stage (after 3 months).

Graph 3 A. Growth of Neem (*Azadirachtaindica)* tree in contaminated and uncontaminated soilafter one month.

Graph 3 B. Growth of Neem (*Azadirachtaindica)* tree in contaminated and uncontaminated soil at final stage (after 3 months).

Note: For each tested plant, the ten pots on the left are the contaminated treatments while the ten pots on the right are the control treatments.

ACKNOWLEDGMENT

The authors are grateful to the Village Head of the Challawa for his hospitality throughout the period of sampling. We are also indebted to Mallam Mustapha Kano of the Soil Science Department, Faculty of Agriculture, Bayero University, Kano for his technical assistance.

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