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Heavy metal uptake and phytoremediation potential of *Jatropha curcas* Linn in contaminated soils

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ABSTRACT

Jatropha curcas is a great plant for restoring nutrients in the soil and exhibits the ability to recover and reclaim contaminated soils. This study aimed at evaluating the phytoremediation capacity of *Jatropha curcas* (IAR JAT 044) for selected heavy metals (Cu, Cd, Pb and Zn). The treatments included three dumpsites (Sabo, Ori-Apata, Kakuri) and a control site in Samaru, Kaduna state. These were laid down in a Completely Randomized Design (CRD) repeated four times in a Screenhouse. The experiment was carried out for a period of three (3) months after transplanting. The selected heavy metals' concentrations of the dumpsites and control soils were initially determined before the establishment of the experiment. Likewise, the concentrations of the heavy metals were determined from the plant shoots and residual soils after harvest. Results of the initial concentration of the heavy metals before establishment of the experiment ranged as follows; Cu (36.35- 325.50), Zn (411.25- 2440.25), Cd (8.75-32.00) and Pb (36.35-249.75) in mg/kg which were significantly higher than the concentration after planting, which ranged as follows; Cu (3.75- 44.69), Zn (37.36- 37.36), Cd (0.6- 3.9) and Pb (11.59-43.19) in mg/kg respectively. The bioaccumulation factor for Cu (1.27-10.05), Zn (3.41-7.99), Cd (1.18-21.57) were higher in plants than soil indicating high uptake, while Pb (0.92-4.06) was lower in *Jatropha curcas* than soil of the control. Likewise, the translocation factor revealed ranges as follows; Cu 1.34-1.77, Zn 0.45-1.27, Cd 1.39-2.05 and Pb 1.48-2.39, which indicates the capability of plants to take up heavy metals in their roots and translocate them to above-ground parts in the study area. Hence, the study reveals *Jatropha curcas* (IAR JAT 044) as a potential heavy metal excluders and bioaccumulator that could be used for phytoremediation in the study area.

Keywords: *Jatropha curcas*; phytoremediation; soil contamination

INTRODUCTION

Heavy metal contamination is a major environmental crisis that affects the entire world. Heavy metals can be found in soils as precipitates or insoluble compounds such as oxides, carbonates, and hydroxides, as well as free metal ions, soluble metal complexes, exchangeable metal ions, and organically bound metals (Draszawka-Bołzan, 2015). Heavy metal pollution has increased alarmingly largely due to industrialization, intensive

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agricultural practices and other anthropogenic activities. Global food security is seriously threatened by heavy metal contamination in the soils, causing soil pollution. Soil pollution refers to the presence of toxic chemicals (pollutants or contaminants) in soil, in high concentrations enough to pose risk to human health and/or the ecosystem (Shaltami *et al*., 2020). Contamination of the biosphere by toxic metals has accelerated dramatically since the beginning of the industrial revolution and technological development (Abdu and Abdullahi, 2018). Environmental issues related to heavy metals contamination are becoming serious in developing countries due to an increase in geologic and anthropogenic activities. These activities increase the concentration of these elements to amounts that are harmful to the environment (Timothy and Williams, 2019). In recent times, the use of dumpsite wastes on agricultural soils has been on the increase because of its benefit as a source of fertilization due to the high cost of inorganic fertilizers. Rampant and illegal dumping of waste, originating from both industrial facilities and households, have also become a critical issue, threatening both environmental health and human well-being (Yakubu *et al*., 2007; Yakubu and Oyinlola, 2015). Some of the ways that toxic metals contaminate agricultural and inhabited lands and cause a number of health risks include runoff and the leaching of toxins from dumpsites (Naja and Volesky, 2017). Heavy metal contamination of agricultural soils may be ameliorated or reclaimed using different methods. Phytoremediation is one of such methods that uses plants to bioremediate contaminated soil, water, and air (Ashraf *et al*., 2019). Phytoremediation is an economically and environmentally favourable technique, which utilizes green plants to contain, sequester or detoxify contaminants from contaminated soil and water (Ashraf *et al*., 2019). *Jatropha currcas,* which belongs to the family Euphorbiaceae, has wide geographical spread and is a perennial shrub, and woody in nature. It is widely distributed in tropical and subtropical regions, especially in Africa and America. According to Sabandar *et al*. (2013) *Jatropha curcas* have been detailed for their therapeutic employment, chemical constituents, and biodiesel generation. *Jatropha curcas* is a great plant for restoring nutrients in the soil and has the ability to turn poorly-over used soil into great purposeful agricultural productivity and yields (Awalla, 2013). Hence, is this study was aimed to evaluate the phytoremediation capacity of *Jatropha curcas* for heavy metals using soil from dumpsites in Kaduna State, Nigeria, with specific objective of determining the heavy metals bioaccumulation and translocation factors of *Jatropha curcas* (IAR JAT 044).

MATERIALS AND METHODS

Study Area

The experiment was carried out using soil samples from Sabon Tasha (Latitude 10° 26’ 59.9” N and Longitude 7° 25’ 7.28” E), Ori-Apata (Latitude 10° 30’ 52.56” N and Longitude 7° 25’ 7.28” E), Kakuri (Latitude 10° 28’ 32.77” N and Longitude 7° 25’ 4. 51” E) and a fallow soil as control from Samaru (11° 11’ 10.86” N and Longitude 7° 36’ 53.28” E), using *Jatropha curcas* (JAT 044) as a phytoremediator. The pot experiment was conducted in the Screenhouse at the Department of Soil Science, Faculty of Agriculture, Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Samaru, Zaria with coordinate of Latitude (11° 9' 52' N) and Longitude (7° 37’ 58” E) and altitude of 682 m above the sea level. Coarse and other unwanted materials were removed from the soil samples. Samples from the dumpsite soils and control (Samaru) soil were air dried, sieved with 2 mm mesh, followed by routine soil analysis and determination of heavy metals;

Copper (Cu), Zinc (Zn), Cadmium (Cd), Lead (Pb), and using standard procedures. The total numbers of soils were four, each replicated four times in a Completely Randomized Design (CRD), giving a total number of 16 pots. Seeds of *Jatropha curcas* (IAR JAT 044) sourced from I.A.R Seed Unit, A.B.U, Zaria, was planted into a germination tray, seedlings of about 7 weeks after planting, and in good growth condition were transplanted into plastic pots containing 4 kg of dumpsite soils and control. The experiment was carried out for a period of three (3) months after transplanting. At harvest the leaf, stem and root samples were thoroughly washed using distilled water to remove all adhering soil particles and then oven dried to constant weights at 65^{o}C. The dried samples were ground and stored for analysis. Residual soil samples from each pot were also collected and stored for analysis.

Plant Tissue Analysis

Ground plant material of 1.0 g from each pot was weighed into a 125 ml Erienmeyer flask that was previously washed with acid and distilled water, 4 ml of perchloric acid 25 ml conc. HNO_3 and 2ml concentrated H_2SO_4 were added under a fume hood. The contents were mixed and heated gently at low to medium heat on a hot plate under perchloric fume hood and was continuously heated until dense white fumes appear (if any traces of carbon remain), the flask was allowed to cool, 1-2 ml concentrated HNO_3 was added and digest again to the fuming stage and were finally heated strongly (medium to high) for half a minute. After cooling, 40-50 ml distilled water was added and boiled for half a minute on the same plate at medium heat, the solution was cooled and filtered with Whatman No. 42 filter paper completely using a wash bottle into a 100 ml pyrex volumetric flask and were made up to mark with distilled water. The solution was stored for Cu, Cd, Pb and Zn determinations using atomic absorption spectrometry.

Soil Analysis

Soil samples of 5 g were weighed into 100ml plastic bottles, 50 ml of 0.1M HCl were added and shake for 30 minutes, then filter through No. 42 filter paper, heavy metals concentrations (Cu, Cd, Pb and Zn) were determined using atomic absorption spectrometer.

The phytoremediation potential of each *Jatropha curcas* was further assessed using the bioaccumulation factor and the translocation factors (Zhuang *et al*., 2007; Awotedu and Ogunbamowo, 2019). These are given by the equation:

$$Bioaccumulation\ factor\ (\text{BAF}) = \frac{\text{Croot}}{\text{Csoil}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Translocation\ factor\ (\text{TF}) = \frac{\text{Cshoot}}{\text{Croot}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Croot – concentration of heavy metals in the root
Cshoot – concentration of heavy metals in the shoot (stem and leaves)
Csoil – concentration of heavy metals in the soil

Data Collection

Plant height, stem girth and number of leaves were taken fortnightly at 2, 4, 6, 8, 10 and 12 weeks after transplanting.

Data Analysis

All the data were subjected to analysis of variance (ANOVA) and the means were ranked using least significant difference (LSD). All statistical analyses were performed using SAS 9.1 (SAS 2012).

RESULTS AND DISCUSSION

Table 1 presents the result of the routine soil analysis for both control and contaminated soil. The control soil was characterized as loam while the dumpsite soils were characterized as sandy loam, the pH of the control soil was slightly acidic while that of the contaminated soil was slightly basic in nature (Chude *et al*., 2012). The concentrations of organic carbon (OC) were high for the soils, except for Kakuri which was medium according to the ratings of USDSS (1993), total nitrogen content was low for the control soil, while it was high for the dumpsites soil, and available phosphorus in the control and dumpsite soils were high (USDSS, 1993). The results of the heavy metal concentration in both the control soil and dumpsites soils before transplanting are presented in Table 2. The concentrations of Cu, Cd and Zn in the control and dumpsite soils were all above the target value in soil while concentration Pb in control was below the target value and the concentration Pb in the dumpsites soil was above the target value as according to FAO (1994).

Table 1: Physical and chemical properties of the soils

Parameter	Unit	Control	Sabo	Ori-Apata	Kakuri
Clay	g kg^{-1}	140	140	120	100
Silt	g kg^{-1}	460	260	120	140
Sand	g kg^{-1}	400	600	760	760
Textural class		Loam	Sandy Loam	Sandy Loam	Sandy Loam
pH H_2O	pH 1:2.5	6.55	7.90	8.26	8.45
pH 0.01m $CaCl_2$	pH 1:2.50	5.45	7.10	7.26	8.08
EC	dS m^{-1}	0.120	0.450	0.700	0.800
OC	g kg^{-1}	19.95	34.91	21.82	14.34
TN	g kg^{-1}	1.23	2.08	4.00	2.19
AP	mg kg^{-1}	57.11	81.84	19.01	103.33
Ca	cmol kg^{-1}	9.72	12.97	16.89	14.41
Mg	cmol kg^{-1}	3.81	7.01	12.82	10.08
K	cmol kg^{-1}	0.32	0.77	1.74	1.53
Na	cmol kg^{-1}	0.64	1.65	2.61	2.09
H+Al	cmol kg^{-1}	0.40	0.10	0.10	0.10
CEC	cmol kg^{-1}	15.30	22.80	34.40	28.40
Fe	mg kg^{-1}	331.72	263.74	237.48	257.10
Mn	mg kg^{-1}	62.58	33.84	61.28	50.76

Table 2: Heavy metal concentration of the soils

Metal ($mgkg^{-1}$)	Control	Sabo	Ori-Apata	Kakuri	Tolerable limits (FAO)
Cu	99.75	207.50	245.75	325.50	100
Zn	411.25	1649.50	2440.25	2087.50	500
Cd	8.75	11.25	32.00	17.75	5
Pb	36.25	249.75	143.75	217.00	100

FAO = Food and Agriculture Organization

Heavy Metal Levels in Contaminated Soils before Planting and after Harvest

Table 3 presents the result of the heavy metals concentration in the pre-planting and post-harvest contaminated growth media. The result shows a reduced concentration of heavy metals in the post-planting growth media as compared with the pre-planting growth media (Control, Sabo, Ori-Apata and Kakuri). The reduction in Cu concentration ranged from 78.46%-90.59%, for Zn it ranged from 90.92%-98.47%, the concentration for Cd ranged from 87.81% -90.25% and for Pb it ranged from 68.12%-90.30%. Lead has the least accumulation of heavy metals in *Jatropha curcas* amongst the heavy metals considered in this study.

Heavy metal analysis of the soil samples from the dumpsite shows a higher level of contamination when compared with the control soil sample. The value of Cu, Zn and Pb for the control was within the tolerable limits and the dumpsite soils were above the tolerable limits for Cu, Zn and Pb. The value for Cd for the control and the dumpsite soils were above the tolerable limits for Cd in soil (FAO, 1994). This implies that dumpsites are sources of heavy metal contamination and proper management plans must be in place to mitigate its potential environmental impact. Phytoremediation offers one way to mitigate the environmental impacts of the high level of heavy metals in dumpsites. The concentration of heavy metals in the contaminated soil before planting and after harvesting were compared and it was observed that *Jatropha curcas* reduced the concentrations of heavy metal in the post-harvest soils (Table 4). From this study it was observed that Cu and Zn accumulation were significantly greater in the root than the stem and leaf of the plant while Cd and Pb were significantly higher in the stem than the leaf and root ($p<0.01$).

Table 3: Heavy metals before and after planting

Soil	Before				After			
	Cu	Zn	Cd	Pb	Cu	Zn	Cd	Pb
				mg kg^{-1}				
Control	99.75	411.25	8.75	36.25	3.75	37.36	0.6	11.59
Sabo	207.5	1649.5	11.25	249.75	44.69	52.12	0.98	43.19
Ori-Apata	245.75	2440.25	32	143.75	32.69	56.49	3.9	13.94
Kakuri	325.5	2440.25	17.75	217	30.64	54.49	1.73	36.06

Heavy Metal Uptake in Leaf, Stem and Root of *Jatropha curcas*

The roots showed the highest accumulation (73.68 mg kg^{-1}) followed by stem (48.25mg kg^{-1}) and the least (30.94 mg kg^{-1}) was in the leaf for Cu. The root has the highest accumulation (451.06 mg kg^{-1}) followed by leaf (113.13 mg kg^{-1}) and stem (109.38 mg kg^{-1}), the lowest accumulation was in stem (85.44 mg kg^{-1}) for Zn, The stem showed the highest accumulation (10.06 mg kg^{-1}) followed by stem the root (8.94 mg kg^{-1}) and (1.88 mg kg^{-1}) was in the leaf for Cd and The highest accumulation was in the stem (78.38 mg kg^{-1}) followed by the root (66.44 mg kg^{-1}) and the lowest accumulation was in the leaf (2.25 mg kg^{-1}).

This study shows that *Jatropha curcas* was able to accumulate heavy metals into the roots and shoots to a greater extent. This showed that the total root Cu concentration was higher than the stem, this result agrees with the findings of Awotedu and Ogunbamowo (2019) who also reported higher concentrations of copper in the root of *Jatropha curcas* raised in heavy metal dumpsite soil, than other parts of the plant and also in *Acacia mangium* raised on graded level of copper contaminated soils (Majid *et al*., 2011). Zn was found to be more in the root than in the stem, which is contrary with the study of Akintola *et al*. (2019) which shows that *Jatropha curcas* have more uptake of Zinc in the stem than in the root in heavy metals contaminated soil. *Jatropha curcas* leave absorbed more Zn than the stem for the dumpsite soils, while the control absorbed more Zn in the stem than the leave. Cadmium was found more in the stem than in the root, this study agrees with the finding of Abdullahi *et al*. (2017) that *Jatropha curcas* root can translocate Cd from the root to the shoot or leaf. This study also agrees with the study of Akintola *et al*. (2019) who observed that *Jatropha curcas* accumulated more Pb in the shoot than the roots for the dumpsite soil.

Table 4: Heavy metal concentration in plant parts of *Jatropha curcas*

	Concentration of Cu ($mg\ kg^{-1}$)			Concentration of Zn ($mg\ kg^{-1}$)			Concentration of Cd ($mg\ kg^{-1}$)			Concentration of Pb ($mg\ kg^{-1}$)		
Soil	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
Control	30.94^{c}	34.43^{c}	37.00^{c}	93.50^{b}	109.38^{a}	174.13^{b}	1.88^{c}	4.44^{c}	3.50^{c}	2.25^{c}	12.32^{c}	10.89^{c}
Sabo	43.50^{a}	35.81^{c}	56.19^{b}	102.13^{ab}	85.44^{b}	177.25^{b}	4.63^{b}	6.81^{b}	5.81^{b}	32.03^{b}	78.38^{a}	66.44^{a}
Ori-Apata	37.56^{b}	41.81^{b}	57.81^{b}	106.49^{ab}	94.06^{ab}	451.06^{a}	7.63^{a}	8.00^{b}	$4.63b^{c}$	36.22^{b}	48.39^{b}	46.27^{b}
Kakuri	47.13^{a}	48.25^{a}	73.68^{a}	113.13^{a}	86.81^{b}	222.69^{b}	8.06^{a}	10.06^{a}	8.94^{a}	55.84^{a}	68.08^{ab}	50.92^{b}
LOS	**	**	**	*	*	**	**	**	**	**	**	**
SE±	1.489	1.239	4.974	5.712	7.091	25.819	0.591	0.528	0.493	4.817	6.335	3.677

Means with the same letter are significantly the same while different letters are significant. NS = Not Significant

Bioaccumulation Factor and Translocation Factor

Table 5 shows the bioaccumulation factor (BAF) and translocation factor (TF) of the heavy metals (Cu, Zn, Cd and Pb) for the various soils (Control, Sabo, Ori-Apata and Kakuri). BAF for Cu 1.27-10.05, Zn 3.41-7.99, Cd 1.18 - 21.57 and Pb 0.92 - 4.06. TF for Cu 1.34 - 1.77, Zn 0.45 - 1.27, Cd 1.39 - 2.05 and Pb 1.48 - 2.39.

To evaluate the potential for phytoremediation of heavy metals in *Jatropha curcas*, the translocation factor and bioaccumulation factor also known as bioconcentration factor in certain literature were determined for each metal in *Jatropha curcas*. Plant species can be classified as either hyperaccumulators, which accumulate high concentrations of metals into their harvestable aerial parts, or metal excluders, which accumulate toxic metals from the soil to their roots but prevent their transport into the aerial parts of the plant, based on how well-adapted they are to heavy metals, as a result of their BAF and TF values (Malik *et al*., 2012), hence, these groups of plants will have a BAF >1 and TF <1 and therefore have low potential for extraction of metals but could be efficient for phytostabilization of heavy metals. In order for a plant to have the ability to do phytoremediation, it is necessary for both the translocation factor and the bioaccumulation factor to be greater than 1 (Rezvani and Zaefarian 2011), accordingly, effective metal transport from roots to shoots is therefore a crucial feature of metal hyperaccumulators (Zhao *et al*., 2006). Results from the bioaccumulation factor show that the BAF is greater than 1 for all the studied metals expect Pb in the control soil which suggest that *Jatropha curcas* has to absorb more metals in the root than that of the soil (Mattina *et al*., 2003; Liu *et al*., 2010). If TF value is less than one (<1), it indicates ineffective metal transfer, suggesting that this type of plant accumulates metals in the root and rhizomes more than in the shoot or leaf. The plant is considered capable of translocating metals from root to shoot when the TF is greater than one (>1). Results from the translocation factor show that TF is greater than 1 for all the metals studied except Zn suggesting that the plant indicates the translocation of the metal from root to above-ground part.

Table 5: Bioaccumulation and translocation factor

	Bioaccumulation factor				Translocation factor			
Soil	Cu	Zn	Cd	Pb	Cu	Zn	Cd	Pb
Control	10.05a	4.68b	21.57a	0.92b	1.77a	1.17a	1.39b	1.48b
Sabo	1.27b	3.41b	6.24b	1.54b	1.46ab	1.27a	1.56ab	1.67b
Ori-Apata	1.78b	7.99a	1.18b	4.06a	1.38b	0.45b	1.48b	1.83b
Kakuri	2.48b	4.09b	5.25b	1.42b	1.34b	0.95ab	2.05a	2.39a
LOS	**	**	**	**	*	*	*	*
SE±	0.396	0.506	6.477	0.492	0.124	0.202	0.174	0.164

Means with the same letter are significantly the same while different letters are significant. NS = Not Significant

CONCLUSION

Phytoremediation of the contaminated soils with heavy metals using non-edible plants like *Jatropha curcas* L offers an environmentally friendly and economical method for remediating contaminated soil. This study shows that soils from dumpsites are high in heavy metals, and when used as source of nutrients it can lead to contamination of agricultural soils. *Jatropha curcas* can effectively remove heavy metals such as Cu, Zn, Cd, and Pb. The significant reduction observed in concentrations of heavy metals in soils, when compared with after planting indicated their accumulation in the plant tissues. The bioaccumulation and translocation factors from this study show that *Jatropha curcas* can be used as phytoextraction of Cu, Cd and Pb and phytostabilization of Zn.

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