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Phytoremediation Potential of *Ricinus communis* L. (Castor Oil Plant) in Northern Nigeria

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Authors' contributions

This work was carried out by author ZIY under the supervision of authors EBA, CEG and SOI. All authors read and approved the final manuscript.

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ABSTRACT

This research work is a field experiment carried out to evaluate the phytoremediation potential of *Ricinus communis* L (castor oil plant) in Zaria town of northern Nigeria. The sandy loam field (pH 6.78) used in the experiment was contaminated with Cd, Co, Ni and Pb from a metal dumpsite. A solution of 5 mmol/kg ethylenediamine-tetraacetic acid (EDTA) was applied on a portion of the field. The harvested plant and the soil collected from the experimental and control sites were analysed using atomic absorption spectrophotometer to determine the concentrations of Cd, Co, Ni and Pb in different parts of the plant and the soil treated and untreated with EDTA. The physicochemical parameters of the soils - pH, moisture content, particle size, cation exchange capacity (CEC) and organic matter (OM) were determined. The concentrations of the metals in the different parts of the plant harvested from the experimental site were higher than those from the control soil. The statistical analysis using One-way ANOVA Duncan grouping, showed that there is a significant difference ($P < 0.05$) between the concentrations of the studied metals in the soil and that of the plant tissues at the dumpsite. Also the metal levels in plant harvested from the soil treated with EDTA were higher than those from untreated soil and the increases for the studied metals in the entire plant were by the following factors: Cd – 1.9, Co – 1.8, Cu – 1.5, Ni – 8.8, Pb – 2.1 and Zn – 1.4. The Bioaccumulation factor (BF) and Translocation factor (TF) for the metals studied varied. *Ricinus communis* L (castor oil plant) was found to have good phytoremediation potential for soil contaminated with heavy metals.

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1. INTRODUCTION

Phytoremediation is an in situ, cost-effective potential strategy for cleanup of sites contaminated with trace metals. Selection of plant materials is an important factor for successful field phytoremediation [1]. Phytoremediation takes the advantage of the unique and selective uptake capabilities of plant root systems, together with the translocation, bioaccumulation, and contaminant degradation abilities of the entire plant body. The method is comprised of phytoextraction, phytostabilization, phytovolatilization, phytodegradation and phytofiltration. However, only phytoextraction that can effectively remove contaminants from contaminated soils by hyperaccumulators is the most promising for commercial application [2]. The terms phytoremediation and phytoextraction are sometimes incorrectly used as synonyms, but phytoremediation is a concept while phytoextraction is a specific cleanup technology. Plant roots can remove metals from contaminated soils/sediments and transport them to leaves and stems for harvesting and disposal or metal recovery through smelting processes without destroying the soil structure and fertility. It is best suited for the remediation of diffusely polluted areas, where pollutants occur only at relatively low concentration and superficially. This can be an effective remediation method at a variety of sites and on numerous contaminants. The success of the phytoextraction process, whereby pollutants are effectively removed from soil, is dependent on an adequate yield of plants and/or the efficient transfer of contaminants from the roots of the plants into their aerial parts [3,4].

Successful phytoextraction depends not only on metal concentrations in shoots but also on high biomass production. Selection of plant species is based on high tolerance and accumulation rate for several metals, adaptation to local climates, high biomass, depth root structure, growth rate, ease of planting and maintenance, and ability to take up large quantities of water through the roots [5,6]. Artificial chelates such as ethylenediamine-tetraacetic acid (EDTA) can be added to the soil to increase heavy metals bioavailability thus enhancing plant uptake and translocation of heavy metals from roots to the aerial parts [7].

The *Ricinus communis (*castor oil plant) is a species of flowering plant in the spurge family, Euphorbiaceae. It is a fast-growing, suckering perennial shrub that can reach the size of a small tree (around 12 meters or 39 feet), but it is not cold hardy. The plant spreads over sandy soil areas, creek banks and gullies. It is often abundant along watercourses and floodplains, disturbed or waste land and roadsides with high tolerance for growth under harsh environmental conditions, such as low rainfall and heat. It is an appropriate plant to be used as indicator plant for Cd and tolerant for Pb in contaminated solution and it can be potentially used for phytoremediation of contaminated areas. *Ricinus communis* was found more tolerant to salinity and drought in presence of Cd, and it can produce twelve fold higher biomass in terms of fresh weight and dry weight [8]. Olivares et al. [9] looked at the potential of *Ricinus communis* to remediate sites polluted with mine tailings containing high concentrations of Cu, Zn, Mn, Pb and Cd and as an energy crop. The plant species has attracted considerable attention because of its ability to grow in heavily polluted soil together with its capacity for metal ion accumulation. The possibilities of easily growing *Ricinus cummunis* in different climate and using its biomas in biofuel industries can make heavy metals contaminated soils productive, and although slowly, restore them at the same time [10].

The climate of Zaria (11°07’ 51” N; 7°43’ 43” E) is typically of the climate conditions in the northern part of Nigeria that exhibit only two different seasons, a short wet season and a prolong dry season. Temperature during the day remains constantly high while humidity is relatively low throughout the year, with little or no cloud cover. There are wide diurnal ranges in temperature (between nights and days) particularly in the very hot months. The mean monthly temperatures during the day exceed 36℃ while the mean monthly temperatures at night fall, mostly to below 22℃. In the north, a single wet/raining season is between June and September.

The aim of this study is to evaluate the phytoremediation potential of *Ricinus communis* L (castor oil plant) harvested from a sandy loamy field contaminated with cadmium (Cd), cobalt (Co), nickel (Ni) and lead (Pb) 50 m away from a scrap metal dumpsite in Zaria town of northern Nigeria.

2. MATERIALS AND METHODS

2.1 Experimental Design

An experimental area of 6 m x 4 m was selected at the experimental and control sites and divided into two parts (3 m x 2 m) where the *Ricinus communis* L plant was grown. The seedlings of the plant were obtained from farmlands not contaminated, transported to the field and planted in the designated field plot 50 m from scrap metal dumpsite with spacing of 20 cm x 20 cm as described by Zhuang et al. [11]. The plant was allowed to grow naturally under natural agro-climatic conditions and exposed to natural day and night temperatures, with neither fertilization nor optimum irrigation so as to assess the feasibility of the remediation process. Weeds were controlled by mechanical method. After 10 weeks when the plant must have achieved maximum biomass production, a single dose of 5 mmol/kg EDTA (Na_2-EDTA) was applied to the soil of one part of the plot. Seven days after the application of the EDTA solution, the plant was harvested and the associated soil samples were collected.

2.2 Sample Collection

Whole plant samples were collected from experimental site, while soil samples (150 g) were collected from the surface to 20 cm deep around each plant root zone, using hand trowel and then mixed together. Background soil (150 g) and plant samples of *Ricinus communis* were also obtained as control from an area 5 km distance away from the contaminated area. The collection was done by dividing the experimental and control sites each into four quadrants, five plant samples and soil samples were collected from each quadrant in a diagonal basis following the methods of Nuonom et al. [12]. Triplicate samples of both soil and plant were collected.

2.3 Sample Treatment and Analysis

The collected soil samples were air-dried at room temperature for 3 days, while the shoots and roots of the plant samples were washed, separated and air dried. The soil samples were ground and sieved (500 µm sieve) and then dried in an oven at 65 ± 1℃ for 16 hrs, following which it was kept in clean polythene bags for further analysis.

One gram of each of the soil and plant samples was digested separately with 10 cm^3 of aqua regia (a mixture of 3 parts concentrated $HClO_4$ to 1 part concentrated HNO_3) on a hot plate in a fume cupboard, until a clear solution was obtained. Distilled water was added periodically to avoid drying up of the digest. To the hot solution, 30 cm^3 of distilled water was then added and filtered through a Whatman No. 42 filter paper into a 50 cm^3 standard volumetric flask and then made up to the mark with distilled water [13].

Cadmium, cobalt, copper, nickel, lead and zinc concentrations in the plant and soil samples were determined using a D100XB4J atomic absorption spectrometer, with the analyses being done in triplicate.

The bioaccumulation factor (BF) and the translocation factor (TF) were calculated to determine the degree of metal accumulation in the plant.

$$BF = \frac{\text{Concentration of metal in plant}}{\text{Concentration of metal in soil}}$$

$$TF = \frac{\text{Concentration of metal in plant shoot}}{\text{Concentration of metal in plant root}}$$

Triplicates of the data obtained were subjected to one-way ANOVA using SPSS 20 software.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Parameters of the Soil before Planting

Table 1 shows the results of the physicochemical parameters of the soil analysed. The pH of soil affect the bioavailability of metals in the soil solution. Bioavailability of metals in soils decrease above pH 5.5–6 [14]. The percentage organic matter (% OM) 4.02±0.06 but still higher than values found in soils of the Nigerian savannah which range from 0.8 to 2.9% [15,16]. Cation exchange capacity (CEC) 10.20±0.15 $cmol/kg^{-1}$, normal CEC ranges in soils would be from < 3 cmol/kg, for sandy soils low in OM, to > 25 cmol/kg for soils high in certain types of clay or organic matter (OM). Soil OM will develop a greater CEC at near-neutral pH than under acidic conditions [17].

The mean concentration of the studied metals in the soil at the study area (experimental soil) were higher than the control and also higher than the standard regulatory limits [18] as reported by Akpoveta et al. [19] (Fig. 1). Using one-way ANOVA, there was a significant difference ($P < 0.05$) between the metal level at the experimental site and the control. This implies that the dumping of scrap metals on the soil has contributed significantly to the heavy metals contamination of the soil and can be of health risk since crops are planted on nearby farmlands.

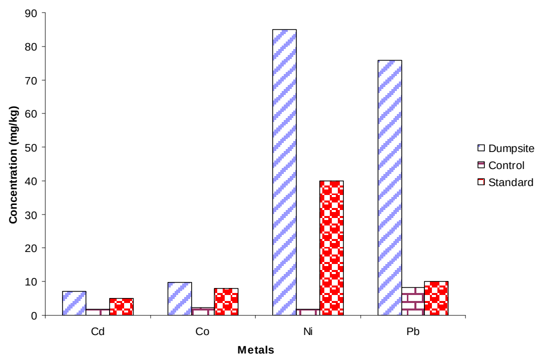

Fig. 1. Concentration of studied metals in the soil near the dumpsite and control before planting

Single Contamination Index (CI) was employed to evaluate the real quantitative information of key pollution multiples which is one of the current methods used in evaluation of the degree of heavy metal pollution in soil.

Calculation for Single Contamination Index:

$$P = C/S$$

Where P =contamination index, C = concentration of metal and S = background value.

The single method cannot express accurately the comprehensive impact caused by each kind of heavy metals. The Nemero Index method takes not only the extreme value but also the environmental quality index based on weighted multi-factors. The method can reflect the degree of soil pollution caused by various heavy metals pollutants [20].

Nemero Pollution Index:

$$P_i = \sqrt{[(P_{jmax})^2 + (P_{jave.})^2]/2}$$

where P_i = the comprehensive Pollution Index, P_{jmax} = corresponding maximum value in the single factor pollution index and $P_{jave.}$ = the corresponding average value in the single factor pollution index.

The dumpsite was slightly polluted with Cd and Co, but heavily polluted with Pb and Ni (Table 2). Therefore, phyto-remediation could be an effective and affordable method for the heavy metals remediation [21].

3.2 Metal Concentrations in Different Parts of *Ricinus communis* Plant

The metal concentrations in different parts of *Ricinus communis* plant harvested from experimental site and the control are presented in Fig. 2. The result indicated that there is a variation in the metal levels in the leaves, stems and roots of the plant. The concentration of metal in leaves are: Pb - 21.20±0.04 mg/kg, Ni - 12.40±0.05 mg/kg, Co - 8.00±0.05 mg/kg and Cd - 2.30±0.02 mg/kg; the stems: Pb - 21.70±0.04 mg/kg, Ni - 12.80±0.06 mg/kg, Co - 6.80±0.05 mg/kg and Cd - 2.00±0.01 mg/kg; the roots: Pb - 20.60±0.03 mg/kg, Ni - 7.80±0.03 mg/kg, Co - 5.60±0.03 mg/kg, Cd - 2.10±0.02 mg/kg. The statistical analysis using One-way ANOVA Duncan grouping, showed that there is a significant difference ($P < 0.05$) between the concentrations of the studied metals in the soil and that of the plant tissues at the dumpsite. This implies that the metal content in the plant was as the result of the metal uptake by the plant from the soil.

Bioaccumulation factor (BF), defined as the ratio of chemical concentration in a plant to its concentration in the soil, is used to measure the effectiveness of a plant in concentrating pollutant into the plant, while transfer factor (TF), the quotient of contaminant concentration in shoots to roots, which is used to measure the effectiveness of a plant in transferring a chemical from roots to shoots [2]. The BF values for Cd and Ni were greater than 1, while that of Pb and Co were less than 1 (Fig. 3). All the metals studied have their TF greater than 1. The BF and TF were in the order: Ni > Cd > Co > Pb and Ni > Cd > Co ≈ Pb respectively.

Plants extract most of their nutrients from top soil by roots penetrating the subsoil, and from upward migration of dissolved pollutants to the rooting zone above [22]. It has been reported that the plant has high tolerance to wide range of soil pH from 3.3 to 12.5 without soil amendment, and highly tolerant to growing medium high in acidity, alkalinity, salinity [23]. The experimental results for the soil pH was 6.78. Generally cationic metals are more soluble at lower pH levels, so increasing the pH to 6.5 or higher makes them less available to plants and therefore less likely to be incorporated in their tissues and ingested by humans.

Table 1. Physicochemical parameters of the soil before planting

Physicochemical parameters	Experimental	Control
Particle size(%): Clay	15	11
Silt	7	18
sand	78	71
Soil texture	Sandy loamy	Sandy loamy
Soil pH	6.78±0.02	7.50±0.03
Moisture content (%)	4.50±0.03	4.00±0.02
Organic matter (%)	4.02±0.06	4.87±0.05
Cation exchange capacity ($cmol/kg^{-1}$)	10.20±0.15	15.60±0.17
Cd	7.00±0.02 mg/kg	1.87±0.01 mg/kg
Co	9.90±0.05 mg/kg	2.37±0.04 mg/kg
Ni	84.93±0.07 mg/kg	6.50±0.02 mg/kg
Pb	75.90±0.04 mg/kg	8.23±0.03 mg/kg

Table 2. The grade standard of the nemero pollution index for soil before planting

	I $P \leq 0.7$ clean	II $0.7 < P \leq 1$ warning	III $1 < P \leq 2$ slight	IV $2 < P \leq 3$ heavy	V $P > 3$ very heavy
Dumpsite	-	-	Cd, Co	-	Ni, Pb
Control	Cd, Co, Ni	Pb	-	-	-

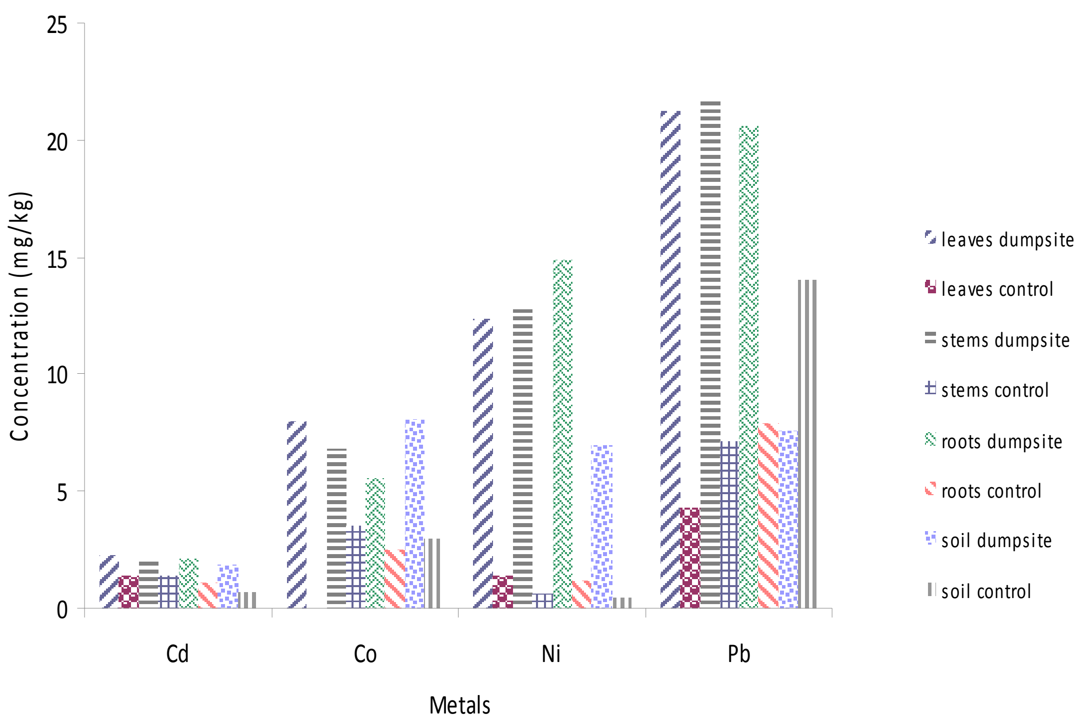

Fig. 2. Concentration of metals in different parts of *Ricinus communis* plant and soil

Table 3. Concentration of metals (mg/kg) in different parts of *Ricinus communis* plant

Metals	Without EDTA			With EDTA		
	Leaves	Stems	Roots	Leaves	Stems	Roots
Cd	2.30±0.02	2.00±0.01	2.10±0.02	3.30±0.03	3.70±0.0 2	2.90±0.03
Co	8.00±0.05	6.80±0.05	5.60±0.03	14.90±0.02	12.20±0 .02	11.70±0.05
Ni	12.40±0.05	12.80±0.06	7.80±0.03	276.00±0.12	64.4 0±0.09	14.90±0.10
Pb	21.20±0.04	21.70±0.04	20.60±0.03	45.70±0.03	44.50±0.05	44.50±0.02

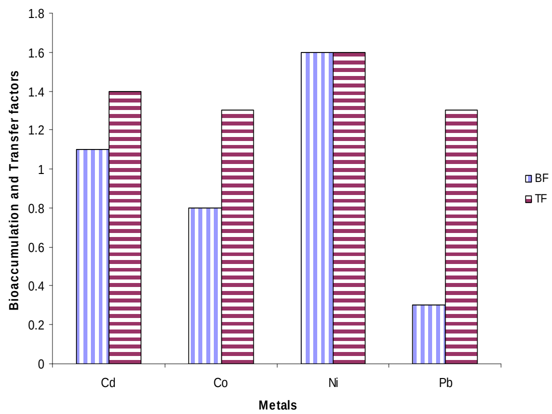

Fig. 3. Bioaccumulation and transfer factors for metals in *Ricinus communis* plant

Generally, Pb and Co were found to be less bioaccumulated. This is because Pb contamination in the environment exists as an insoluble form. It is one of the metals that is generally considered to be not very bioavailable. Lead (Pb) is notorious for its lack of soil mobility, primarily due to metal precipitation as insoluble phosphates, carbonates and hydroxides which have low solubilities in natural water [13]. Co was reported to be moderately bioavailable [24]. Influx from solutions containing Co^{2+} was reported to be inhibited by Cd^{2+}, Cu^{2+} and Zn^{2+}, but Mn^{2+} and Ni^{2+} had no significant effect [25]. Lower mobility of Co^{2+} in plants restricts its transport to the upper shoots from roots and its high levels can suppress the uptake of Cd by roots [26]. Cd normally occurs in low concentration in the soils [27].

3.3 The Effect of the Application of EDTA

The concentrations of the studied metals in different parts of *Ricinus communis* (Castor Oil) plant after the application of EDTA to the soil at the dumpsite indicated that, in the leaves Cd - 3.30±0.03 mg/kg, Co - 14.90±0.02 mg/kg, Ni - 276.00±0.12 mg/kg, Pb - 45.70±0.03 mg/kg; in the stems, Cd - 3.70±0.02 mg/kg, Co - 12.20±0.02 mg/kg, Ni - 64.40±0.09 mg/kg, Pb - 44.50±0.05 mg/kg; in the roots, Cd - 2.90±0.03 mg/kg, Co - 11.70±0.05 mg/kg, Ni - 14.90±0.10 mg/kg, Pb - 44.50±0.02 mg/kg. Heavy metal concentration in shoots and roots of plant significantly increased when EDTA was applied to the soil (see above Table 3). It was observed that the increases for the studied metals in the entire plant were by the following factors: Cd – 1.9, Co – 1.8, Cu – 1.5, Ni – 8.8, Pb – 2.1 and Zn – 1.4. Huang et al. [28] and Blaylock et al. [29] were able to achieve rapid accumulation of Pb in plant shoots higher than 1% of shoot dry biomass with EDTA, the most commonly used chelating agent. Laboratory studies showed that EDTA is effective in removing heavy metals from contaminated soils, although extraction efficiency depends on many factors such as the bioavailability of heavy metals in soil, the strength of EDTA, electrolytes, pH and soil matrix [30]. Complexation of heavy metals by chelates could play an important role in controlling heavy metal solubility and concentration in soil, hence their phytoextraction. EDTA complex the soluble form of heavy metal facilitated the heavy metal removal from the soil via plant uptake. The results of this study demonstrated that EDTA is an efficient soil amendment in enhancing Co, Cd, Ni and Pb desorption from soil and in increasing their accumulation in plants. It is generally noted in the literature that EDTA has taken a predominant place in increasing metal removal efficiency [31].

4. CONCLUSION

The results of this research work showed that the concentrations of Cd, Co, Ni and Pb around the scrap metal dumpsite were higher than the control site which implies that the dumping of scrap-metals on these soils has contributed significantly to the heavy metals contamination of the soils and can be of health risk since crops are planted on nearby farmlands. *Ricinus communis* L. (Castor oil plant) showed a significant higher absorption of Cd, Co, Ni and Pb at the experimental site compared to their individual control. It was also observed that treatment of the soil with EDTA enhanced the uptake of the studied metals in the plant by increasing the bioavailability of the metals in soil solution. The bioaccumulation and translocation factors for the studied metals by the test plant species are indications that this plant species has the potentials for phytoremediation under field conditions even on soils not treated with EDTA.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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