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Research Article

A Study of the Uptake of Heavy Metals by Plants near Metal-Scrap Dumpsite in Zaria, Nigeria

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The research work investigates the metal uptake of the plants *Lycopersicon esculentum* (tomato), *Rumex acetosa* (sorrel), and *Solanum melongena* (garden egg) collected from experimental sites and a control area in Zaria, Nigeria. The concentrations of Cd, Cu, Fe, Pb, Mn, and Zn in different parts of each of the plant species grown on the experimental and control soils were determined using atomic absorption spectrophotometry. The experimental levels of the metals were higher than those at the control site and the limits recommended by Food and Agricultural Organisation/World Health Organisation (FAO/WHO). *Solanum melongena* showed bioaccumulation factor (BF) and transfer factor (TF) greater than 1 for Cd, Pb, and Mn; *Rumex acetosa* showed BF and TF greater than 1 for Mn and Zn, and TF was greater than 1 for Cu and Fe; *Lycopersicon esculentum* had only the TF for Fe, Pb, Mn, and Zn greater than 1. This results implies that *Solanum melongena* and *Rumex acetosa* plants can be effectively used for phytoremediation of Cd, Pb, Mn, and Zn from the dumpsite. Pearson's correlation coefficient values (r) were greater than 0.75 for all the metals studied which indicated that the high metal level in the experimental soil was a result of the metal-scrap.

1. Introduction

Heavy metals constitute a group of metals and metalloids with atomic density greater than 4 g/cm^3 or 5 times or more greater than water [1]. The toxicity of heavy metals is a problem of increasing significance for ecological, nutritional, and environmental reasons.

It is evident that, among others, manufacturing activities involving the disposal of metal containing materials into the biosphere may soon trigger a silent epidemic of environmental metal poisoning [2]. Toxic metals cannot be biodegraded. They have long half-life in the environment and biological system; hence, they pose an environmental problem [3, 4].

Despite the best attempts at waste avoidance, reduction, reuse, and recovery, landfill and disposal of metal still constitute a principal focus by environmental scientist. It has been observed that the larger the urban area, the lower the quality of the environment. So solid waste disposal and management have reached a critical stage in major towns and cities of Nigeria [5].

Environmental restoration of metal-polluted soils using a plant-based technology has attracted increasing interest in the last two decades. Phytoremediation has been developed as a cost effective and environmentally friendly remediation method of contaminated soils. It is an economically attractive approach to decontaminate soils polluted by heavy metals. Because of its relatively low costs, phytoremediation poses a viable approach to cleaning up soils [6–10]. The use of plants to extract and translocate metals to their harvestable parts (phytoextraction) is aimed at reducing the concentration of metals in contaminated soils to regulatory levels within a reasonable time frame [11]. Some plant species have developed tolerance towards metals and others (hyperaccumulators) are characterised by their ability to accumulate high quantities of metals in their tissues [12]. Hyperaccumulators are plants that achieve a plant-to-soil metal-concentration ratio (bioaccumulation factor) and shoot-to-root metal-concentration ratio

(transfer factor) greater than one. The accumulation of these metals may vary from plant to plant and soil to soil. The metal availability to plants depends on total concentration of metals in the soil and the forms in which they occur, pH, organic carbon, cation-exchange capacity, stage of growth of plants, and microorganisms around the root zone [13, 14]. If these factors are constant, the uptake of a metal by different plant species may be compared.

Gaskiya metal dumpsite occupies an estimated capacity of 20 m × 6 m, and several crops such as *Lycopersicon esculentum* (tomatoes), *Rumex acetosa* (sorrel), and *Solanum melongena* (garden egg) are grown on the soil near the dumpsite.

The dumping of metal scraps at Gaskiya in Zaria, Nigeria (11°07′ 51″ N; 7°43′ 43″ E), implies that there might be more or less pollution of the soil.

The aim of this study is to compare the uptake of some metals by *Lycopersicon esculentum* (tomatoes), *Rumex acetosa* (sorrel), and *Solanum melongena* (garden egg) grown on the soil near a metal-scrap dumpsite in order to determine the bioaccumulation factor (BF) and transfer factor (TF), hence, the plants phytoremediation potentials.

2. Materials and Methods

2.1. Sample Collection. Whole plant sample of *Lycopersicon esculentum* (tomato), *Rumex acetosa* (sorrel), and *Solanum melongena* (garden egg) was collected 50 m from Gaskiya metal-scrap dumpsite, while soil samples (150 g) were collected from the surface to a depth of 15 cm around each plant root zone, using hand trowel, and then mixed together. Background soil (150 g) and plant samples were also obtained as control from a farmland that is at a distance of 5 km away from the dumpsite. The collection was done by dividing the experimental and control sites each into four quadrants; five plant samples or soil samples were collected from each quadrant in a diagonal basis following the methods of Nuonom et al. [15].

2.2. Sample Treatment. The collected soil samples were air-dried at room temperature for 3 days, while the shoots and roots of the plants were washed, separated, and air-dried. The soils were ground and sieved (500 μm sieve), dried in an oven at 65 ± 1°C for 16 hrs and then kept in clean polythene bags for further analysis.

One gramme of each of the soil and plant samples was digested separately with 10 cm^3 of aqua regia (a mixture of 3 parts concentrated HCl 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 number 41 filter paper into a 50 cm^3 standard volumetric flask and the solution made up to the mark with distilled water [16].

Cadmium, copper, iron, lead, manganese, and zinc were analysed in the plant and soil samples using a UNICAM 969 atomic absorption spectrometer [16], with the analyses being done in triplicate.

Pearson' correlation coefficient (r) was calculated between metal levels in soil and plant samples for individual metals using the following formula:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{\left[n\sum x^2 - \left(\sum x\right)^2\right]\left[n\sum y^2 - \left(\sum y\right)^2\right]}}, \quad (1)$$

where x and y were the two variables, plant samples and soil sample, respectively, while n is for the pairs of observed values of the these variables [16].

The bioaccumulation factor (BF) and the transfer factor (TF) were calculated to determine the degree of metal accumulation in the plants grown at the farm site close to the metal-scrap dumpsite [17]. Consider

$$\text{BF} = \frac{\text{Concentration of metal in plant}}{\text{Concentration of metal in soil}};$$
$$\text{TF} = \frac{\text{Concentration of metal in plant shoot}}{\text{Concentration of metal in plant root}}. \quad (2)$$

3. Results and Discussion

3.1. Metal Contents in Different Parts of the Plants. In *Solanum melongena* plant (Figure 1(a)), there was generally an increase in the level of the metals in the shoot compared to the root (except Zn). The total metals in the soil follow the ranking Fe > Zn > Pb > Mn > Cu > Cd. The uptake of Cd in roots is via a system involved in the transport of another essential divalent micronutrient possibly Zn^{2+}. Cadmium is a chemical analogue of Zn and plants may not be able to differentiate between the two ions [18]. The bioaccumulation factor (BF) and the transfer factor (TF) for the heavy metal build-up in the plant tissues (Figure 1(b)) indicted that the BF and TF for Cd (2.33, 1.16), Pb (1.32, 1.93), and Mn (1.04, 2.00), respectively, were found to be greater than 1. The BF for Cu (0.42) and Fe (0.08) were found to be less than 1, but the TF 1.98 for Cu and 1.61 for Fe, respectively, were greater than 1. The BF and TF of Zn were both less than 1 (0.62, 0.96). This indicates that the plant roots are able to solubilize and take up the metals from very low levels in the soil, even from nearly insoluble precipitates. The TF is an essential indicator that allows the assessment of mobility of heavy metals in plants [19]. This result implicates *Solanum melongena* plant as a bioaccumulator of Fe, Zn, and Pb and indicates that it can function as hyperaccumulator for Cd, Cu, Fe, Pb, and Mn [20]. These findings agreed with study carried out by Mukut and Arundhuti [21], Stefan and Todor [22], and Bulent and Kubilay [23].

In *Rumex acetosa* plant, from the experimental site (Figure 2(a)), it was observed that the concentrations of Cu (35.65 mg/kg), Fe (2008 mg/kg), Mn (52.90 mg/kg), and Zn (120.83 mg/kg) were higher in the shoot than in the experimental root (28.90 mg/kg, 1916.50 mg/kg, 33.60 mg/kg, and 59.95 mg/kg, resp.). The metals were translocated from the root to the above plant tissue [24, 25]. In Figure 2(b), the BF and TF for only Mn (1.41, 1.57) and Zn (2.02, 1.15), respectively, were greater than 1, which indicates that *Rumex acetosa* plant can function as hyperaccumulator for Zn and Mn.

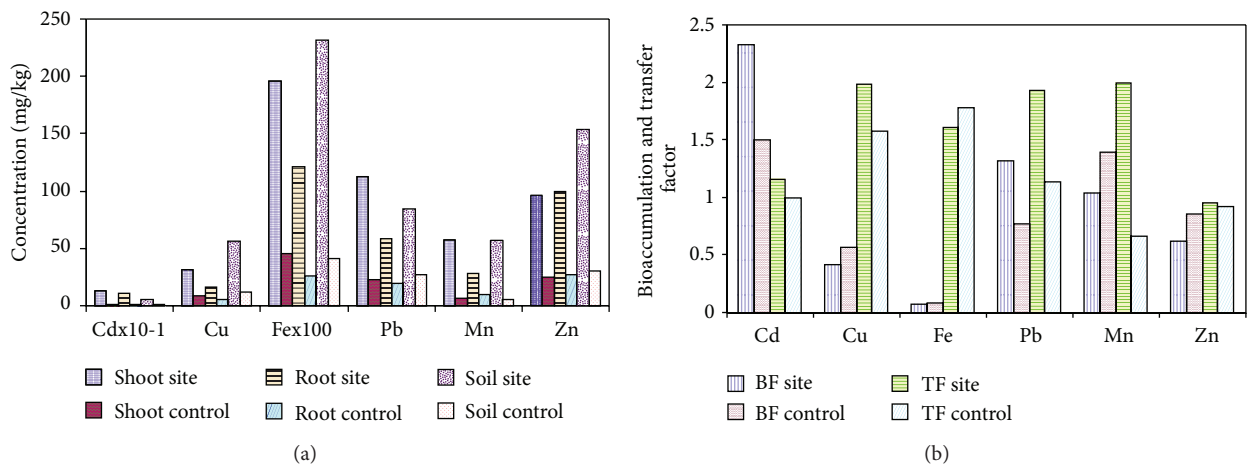

Figure 1: (a) Concentration of metals in *Solanum melongena* and the soil. (b) Bioaccumulation and transfer factors for *Solanum melongena*. BF: bioaccumulation factor; TF: transfer factor.

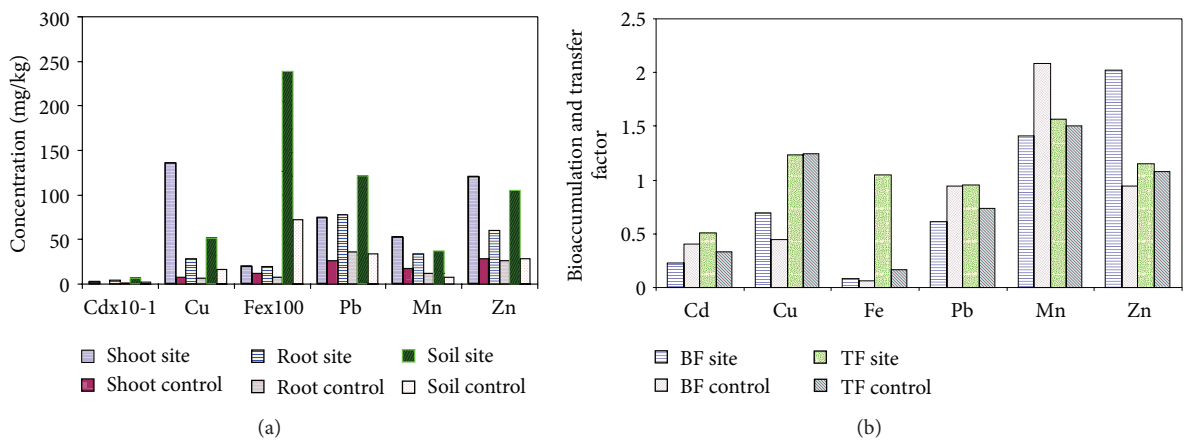

Figure 2: (a) Concentration of metals in *Rumex acetosa* plant and the soil. (b) Bioaccumulation and transfer factors for *Rumex acetosa* plant. BF: bioaccumulation factor; TF: transfer factor.

For *Lycopersicon esculentum* the concentrations of Cd (0.28 μg/g) and Cu (66.00 μg/g) in the experimental shoot were lower than those in their root (0.30 μg/g and 68.95 μg/g, resp.), but those of Pb (82.38 μg/g), Fe (1474.50 μg/g), Mn (19.38 μg/g), and Zn (175.90 μg/g) were higher than in the root (62.30 μg/g, 502.50 μg/g, 18.15 μg/g, and 117.80 μg/g, resp.). The BF for all the metals studied were less than 1, which implies that *Lycopersicon esculentum* plant is not a bioaccumulator of Cd, Cu, Fe, Pb, Mn, and Zn [21].

It was observed that the BF and TF for Cd in *Rumex acetosa* plant were 0.23 and 0.51 as depicted in Figure 2(b) and for *Lycopersicon esculentum* plant the values were 0.56 and 0.93 as shown in Figure 3(b) and were all less than 1. This means that these plants are not good bioaccumulators of Cd.

The levels of these heavy metals in the plant and soil samples were generally higher than those of the control counterparts and also above the limits set by the Joint Food and Agricultural Organisation and World Health Organization [26]. The recommended limits are as follows: Cd—0.1 mg/kg; Cu—10 mg/kg; Fe—0.3 mg/kg; Pb—0.05 mg/kg; Mn—0.3 mg/kg; and Zn—5–15 mg/kg. The coefficient of correlation (r) values between the metal levels in soil and plant from Pearson's correlation coefficient is presented in Table 1. A strong positive correlation for all the metals studied, Cd (r = 0.792), Cu (r = 0.965), Fe (r = 0.932), Pb (r = 823), Mn (r = 0.875), and Zn (r = 0.985), was observed. This indicated that this metal level in the soil is the major factor governing the heavy metal contents in the plants studied.

4. Conclusion

The soils and plants near the scrap metal dumpsite were found to be enriched with Cd, Cu, Fe, Pb, Mn, and Zn. So, the planting on the land close to the metal-scrap dumpsite at Gaskiya, Zaria, should be discouraged. The environmental agency should enforce the law prohibiting the use of metal-scrap dumpsites for farming activities. *Solanum melongena* showed BF and TF greater than 1 for Cd (2.33, 1.16), Cu (1.61, 1.98), Pb (1.32, 1.93), and Mn (1.04, 2.0); *Rumex acetosa* on the other hand had BF and TF greater than 1 for Mn (1.41, 1.57) and Zn (2.02, 1.15), and TF was greater than 1 for Cu (1.23) and

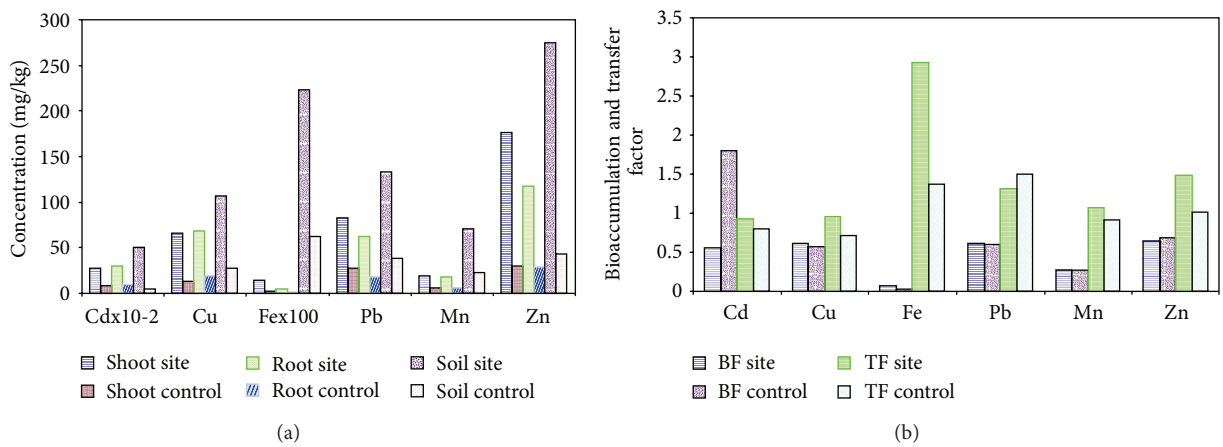

Figure 3: (a) Concentration of metals in *Lycopersicon esculentum* plant and the soil. (b) Bioaccumulation and transfer factors for *Lycopersicon esculentum* plant. BF: bioaccumulation factor; TF: transfer factor.

Table 1: Pearson's correlation coefficient (r) values for metal level between soil and plant.

	Correlation coefficient					
	Cd	Cu	Fe	Pb	Mn	Zn
Soil and plant	−0.220	0.965	0.332	0.823	−0.375	0.985

Fe (1.05); *Lycopersicon esculentum* plant had only the TF for Fe (2.93), Pb (1.32), Mn (1.07), and Zn (1.47) being greater than 1. Therefore, *Solanum melongena* and *Rumex acetosa* plants can be used as hyperaccumulators for phytoremediation of Cd, Cu, Pb, Mn, and Zn.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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