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Full Length Research Paper

Concentration and bioavailability of cadmium by some plants

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A survey was carried out to evaluate the existing level of cadmium in three plant species within and around a refuse site at Ojota, Lagos State, Nigeria. Concentration ranged from background levels to levels well in excess of the maximum tolerable limit in agricultural soils. In the leaves, the least (highest in bracket) of cadmium concentration was 0.24 (4.99)mg/kg while in the roots, it was 0.39 (11.03)mg/kg. The apparent influence of anthropogenic inputs at the refuse site was reflected by the relatively higher concentrations than other sampling locations. The influence of some physico-chemical parameters such as pH and Soil organic matter on the relative mobility of cadmium and its redistribution amongst the different plant species was investigated and found to be generally consistent with findings and experimental observations of other workers. An initial evaluation is made of the potential of the species as indicator plants and that vegetables from refuse sites should be avoided and discouraged either as livestock or human feeds.

Key word: Bioavailability, cadmium, indicator plants, pollution, refuse.

INTRODUCTION

In recent years, metal accumulation in plants has been of environmental concern because their uptake from contaminated soils is a process by which metal can enter the food chain. Immense volume of literature has been published on plants as indicator of land heavy metals pollution (Djingova and Kuleff, 1986; Kabata–Pendias and Dudka, 1991; Czarnowka and Milewska, 2000). High levels of Pb (23 ppm), Cd (4.5 ppm) and Ni (2.7 ppm) have been reported in leaf vegetables grown in close proximity to the copper smelter (Little and Martins, 1974). Borauvka et al. (1997) collected and analysed samples of soil and plants in a polluted area in order to asses the mobility and accumulation of Cd, Pb and Zn in plants. Metals were found to accumulate in the roots and their mobility found in order Zn > Cd > Pb.

Concern about metal contamination of soils relates directly to the extent to which natural background levels are exceeded and to the ease with which the metals are mobilized and made bio-available. A lot of work has been done to find a method that can reliably estimate the bioavailability of metals to plants grown and at the same time evaluate the potential health risk of the element.

However, information concerning the effects on plants within a refuse site is rather limited. This may be due to improper awareness by environmental agents on the danger behind indiscriminate dumping of refuse materials. Understanding the transfer of contaminants through the food web is critical to predict the exposure of humans to contaminants and the possible health consequences of such exposure which will assist in making accurate risk assessment for seafood safety purposes. Unlike many organic contaminants, most metals cannot be eliminated from the environment by chemical or biological transformation. Although it may be possible to reduce the toxicity of certain metals by influencing their speciation, they do not degrade and are persistent in the environment.

Cadmium is a relatively rare element (0.2 mg/kg in the earth crust) and is not found in the pure state in nature. The average annual production of cadmium throughout the World increased from only 20 tonnes in the 1920s to about 12,000 tonnes in the period 1960 - 1969, 17,000 tonnes in 1970 - 1984; and since 1987 it has fluctuated around 20,000 tonnes (Friberg, 1986). Nowadays, cadmium-nickel battery manufacture consumes 55% of the cadmium output and it is expected that this application will expand with the increasing use of rechargeable

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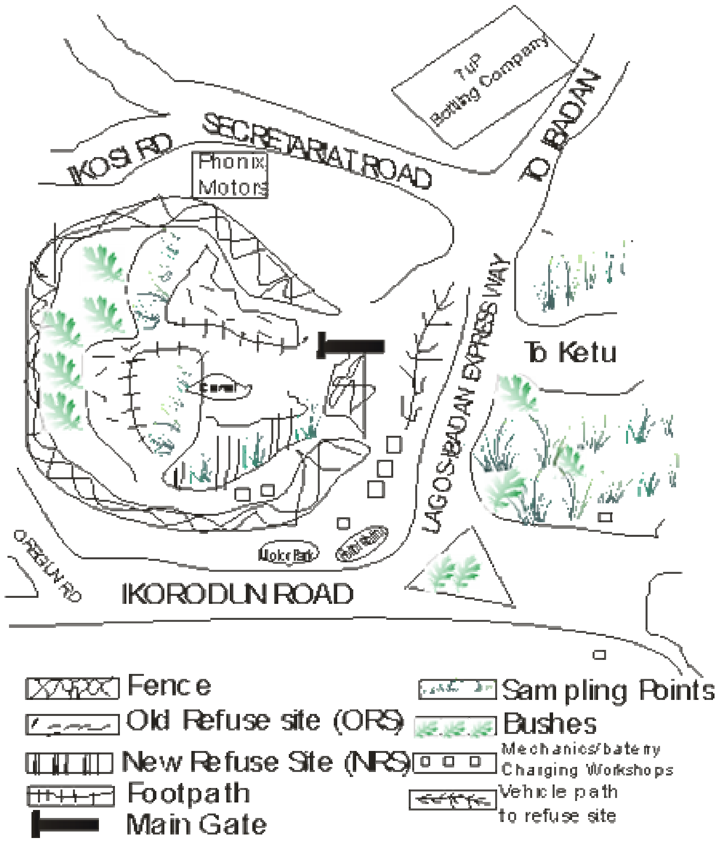

Figure 1. Schematic diagram of the sampling locations in Lagos State, Nigeria.

batteries and their potential use for electric values. For instance, the demand for cadmium in nickel-cadmium batteries moved from 3000 tonnes in 1980 to 9000 tonnes in 1990. This rapid growth has more than offset declining trends for pigments (20%), plating (8%) and stabilizers (10%). In many respects, cadmium has become a vital component of modern technology, with countless applications in the electronics, communications, power generation and aerospace industries (Staessen, 1994).

Metals availability and chemical reactivity in soils have been shown to depend on many factors, such as cation exchange, pH and plant species (Soon and Bates, 1982; Davies, 1992). Other authors have equally shown that soil pH, organic matter and organic carbon content to a greater extent affects, in particular, cadmium sorption by soils (He and Singh, 1993) and their availability in the soil (Chaney and Hornick, 1978).

The refuse site investigated for this present study is located at Ojota, Lagos State, Nigeria. This site is rich in cadmium-containing materials such as vehicle and metal parts, battery waste, dyes and pigment wastes, photographic and glass manufacturing waste and many others. Some of these wastes are capable of releasing toxic metals such as cadmium into the environment upon degradation and subsequently accumulate in plant body (Numberg, 1984). The ingestion of cadmium containing vegetables by humans and animals can lead to series of clinical manifestation such as emphysema of the lungs, bronchitis and cancer, high blood pressure, destruction of testicular tissue and red blood cells (Bowen, 1966; Bryce Smith, 1977).

The objective of the present study was, therefore, to determine the influence of refuse site and some soil properties on the distribution of cadmium and its degree of uptake by three different species of plants which serve as food for both human and animal consumption.

MATERIALS AND METHOD

Sampling and preservation

Five locations were investigated for cadmium in the present study using three (3) species of plants; *Panicum maximum* (PM); *Eupatorium odorata* (EO) and *Carica papaya* (CP). Two sites, the old refuse site (ORS) and the new refuse site (NRS) at Ojota, were principally of interest. Two other sites were considered with respect to the principal sites in order to investigate in addition to the pollution caused by the refuse site, the effect of traffic on the vegetation around the localities. They are 50 m and 100 m away from new refuse site. The last site is the Isheri area of Lagos, a pristine environment served as control. The area map of Lagos state showing the sampling locations is as indicated in Figure 1.

Soil and plant samples were collected on the same spot in duplicate and in random manner at each location, mixed up, in

Table 1. Plants total cadmium (mg kg^{-1} dry weight) and some soil physico-chemical properties.

Sample locations	Plant species	Physico-chemical parameters of the soil at sampling points			Plant metal concentration (mg kg^{-1} dry weight) *		% Cd uptake*
		pH	% organic Carbon	% organic matter	Leaves	Roots	
Old Refuse Site (ORS)	*C. papaya*	4.8	2.26	3.90	1.20 $\pm$ 0.40	6.45 $\pm$ 0.03	15.0
	E. odorata	5.3	2.28	3.94	1.40 $\pm$ 0.80	8.30 $\pm$ 0.02	14.4
	P. maximum	5.2	2.21	3.82	4.99 $\pm$ 0.01	11.03 $\pm$ 0.04	31.1
New Refuse Site (NRS)	*C. papaya*	4.3	2.16	3.74	1.90 $\pm$ 2.70	8.20 $\pm$ 7.10	18.0
	E. odorata	4.6	2.25	3.89	2.25$\pm$ 0.03	6.20 $\pm$ 0.20	26.6
	P. maximum	5.0	2.04	3.33	3.30$\pm$ 4.50	9.90 $\pm$ 4.30	25
50 m distance away from NRS	*C. papaya*	-	-	-	-	-	-
	E. odorata	5.1	1.30	2.25	2.03 $\pm$ 0.02	2.51 $\pm$ 0.03	44.7
	P. maximum	5.6	1.50	2.58	1.50 $\pm$ 0.05	2.27 $\pm$ 0.20	35.7
100 m distance away from NRS	*C. papaya*	-	-	-	-	-	-
	E. odorata	7.3	1.42	2.45	0.38 $\pm$ 0.01	0.40 $\pm$ 0.04	48.7
	P. maximum	6.7	1.54	2.66	0.47 $\pm$ 0.01	0.61 $\pm$ 0.01	43.5
Control Site	*C. papaya*	7.2	1.72	2.98	0.24 $\pm$ 0.07	0.39 $\pm$ 0.03	38.1
	E. odorata	7.4	1.50	2.60	0.27 $\pm$ 0.02	0.38 $\pm$ 0.04	41.5
	P. maximum	6.5	1.55	2.68	0.43 $\pm$ 0.01	0.56 $\pm$ 0.03	43.5

Values are mean of three replicates; mean ± S.D.

* % Cd leaf uptake $= \dfrac{[M_{leaves}]}{[M_{roots}]+[M_{leaves}]} \text{ x } 100\%$

Where [M] = concentration of metal.

--- = Samples not available.

order to get a fair representation at each site. Soils were collected at depth 0 to 15 cm. The samples (soils and plants) were stored in polythene bags and appropriately labeled in other to maintain the samples integrity

Chemical analysis

In the laboratory, the soil samples were dried at ambient temperature (22 – 25°C), crushed by hand in a porcelain mortar and sieved through a 0.5 mm screen. The pH (1:2.5 soil: water) was measured using Hanna pH 211 microprocessor pH meter. Organic carbon was determined using the Walkley and Black method wet combustion method (Nelson and Sommers, 1982)

The metal analysis in plants was similarly carried out. The plants were first manually cleaned with de-ionized water and then dried at 95°C in an oven. A sub sample of each plant was ground finely from which 5 g samples were weighed into 150 ml beaker followed by addition of 75 ml aqua-regia (HCl:HNO_3 in ratio 3:1). The beaker, with its content was digested at 90 - 95°C until a volume of 2 ml was reached. Then, 30 ml of 30% H_20_2 were added. The mixture was allowed to evaporate down to a volume of 6 ml after which 10 ml of 2 MHCl were added. Further heating reduced the volume to 6 ml. After cooling, the solution was filtered to remove small quantities of waxy (cerous) solids and deionized water was added to attain final volume of 50 ml. Blanks were similarly prepared by the same method (Rodriquez Flores and Rodriquez –Castellion, 1982). A recovery study was carried out using standard salt of the metal in order to estimate the efficiency of the digestion process. An average recovery of 82.5 ± 1.5% was obtained. The statistical relationship between the individual elements across the various plants (excluding the control site at Isheri) was determined by bivariate correlation using the Pearson and Spearman coefficient (r-values) in a two-tailed test ($p < 0.05$, $p < 0.01$). All data analysis was carried out using SPSS for windows 13.0 version.

RESULTS

The results obtained in this study are presented Table 1. The total metal concentrations of the plant samples showed a wide range of values, from minimum (0.24 mg kg^{-1}) in the leaf of *C. papaya* at the control site to a maximum (11.03 mg kg^{-1}) in the root of *P. maximum* at the old refuse site; a level considered to reflect anthropogenic impact and gross contamination with reference to the maximum tolerable level (0.6 ppm) of the metal in plants (Bowen, 1966). Detail of the average mean concentrations is presented in Table 2. Highest coefficient of variation (CV) across sampling locations were observed within the roots of *P. maximum (*CV: 89%) while the root of *C. papaya* recorded the least variation (CV: 17%).

Three sampling locations; Old Refuse Site (ORS), New Refuse Site (NRS) and 50 m distances away were identified with excessively high values above the tolerable levels irrespective of the plant involved This is, however, indicative of the bioaccumulative strength of these plants. *P. maximum* and *E. odorata*, almost show similar trend with better response to cadmium than *C. papaya*. As might be anticipated, there is a strong and

Table 2. Means# of Cd in (mg kg^{-1}) in various plants part.

	L-CP	L-EO	L-PM	R-CP	R-EO	R-PM
Mean ± S.D	1.55±0.49	1.52±0.84	2.57±1.99	7.34±1.24	4.35±3.56	5.95±5.27
CV (%)	32	55	77	17	82	89

#: Means without the control site. L : Leaves ; R : Roots CV: Coefficient of Variation

very clear relationship between the soil properties and metal contamination. The results equally revealed the impact of traffic and refuse materials on the soil properties which consequently affects the sorption of cadmium into the leaves.

DISCUSSION

Trace element are intrinsic in nature, in fact, many are essential micronutrients (copper, Iron, selenium, zinc, etc) and thus are important for functioning of plants and animals (Leland and Kuwubara, 1985). Cadmium is generally considered a nonessential trace element (Eisler, 1985). However, it is effectively absorbed by both root and leaf systems. Cadmium is likely to be concentrated in the protein fraction of plant (Raija, 1996). The above results have clearly shown that the three plant species can effectively be utilized as bio-indicator for cadmium monitoring. In this study, of particular interest are the refuse sites. The striking accumulation of cadmium in both leaves and roots to levels at least four (4) and ten (10) times, respectively, the greatest natural concentrations ever recorded (Bowen, 1966), is particularly disturbing. These values contrast sharply with the values obtained from other sampling locations. As expected, the high values can be associated with the various anthropogenic sources of cadmium containing materials (indicated above), which were being deposited on the sites. What are the consequences of this build up for human and ecosystem health? There is no general answer to this question because health effects depend sensitively on the precise exposure routes, not only for cadmium, but for the different forms of the metal. The physical and chemical state of the metal is all important for transport mechanisms, and also for bioavailability (Thomas and Williams, 2004).

Cadmium in food comes to a large extent from atomspheric cadmium as a result of foliar absorption or root uptake of cadmium deposited on soils. Foliar absorption is determined by dry or wet deposition rates of cadmium and uptake of cadmium by plants from soil is primarily controlled by the concentration of cadmium in soil solution. The transfer of cadmium from soil to the food-chain depends on a number of additional factors, such as the type of plant, the type and pH of the soil, and the zinc and organic matter content of the soil. These factors explain why a transfer of cadmium from soil to plants and humans has been demonstrated in some polluted areas of Europe (Staessen, 1994).

The different plants tissues exhibited to some extent different absorbing capacities, accumulation ratio and affinities for cadmium. The increase in metal content in certain plants part can be informative sublethal response, indicating increased metal availability and potential metal stress on the plant. Thus, the ability to regulate the internal metal levels is impaired. This might be sufficient to cause chronic toxicity or mortality particularly in grazing animals which are more or less dependent on these plants for survivor at these study area. The main metabolic feature of cadmium is an exceptionnally long biological half-life resulting in a virtually irreversible accumulation of the metal in the body throughout life. The difference in cadmium uptake can be related to the plants genetic characteristics and physiological state of development (He and Singh, 1993). Czarnowska and Milewska (2000) had reported cadmium concentration in the leaves of dandelion (*Taraxacum officinale*) in the range 0.65 – 1.55 mg/kg. These concentrations are quite in agreement with some of the data obtained in this study. Bioaccumulation of heavy metals in water, sediment and periwinkle (*Tympanotonns Fuscatus var radula*) from the Elechi Creek, Niger Delta, Nigeria, have also been re-ported (Davies et al., 2006).

The direct entry and re-entry of heavy metals like cadmium into the plant via the roots is regulated by many factors (Chlopecka et al., 1996). Some of these factors such as pH, a major soil factor controlling both total and relative uptake of Cd, organic matter and organic carbon content were investigated and were found to correlate as expected. The organic carbon (OC) content can be said to be low, being less than 3.0% as recommended by Loring and Rantala (1992). The Cd concentration generally decreases with increasing soil pH though the changes may be inconsistent in some plant.

The high concentration observed within three of the sampling locations; ORS, NRS and 50 m distances away from NRS can be associated with the acidic nature (pH < 5.2) of the soil, which could have risen mainly from industrial liquid waste regularly deposited indiscriminately on the site. The cadmium concentrations were found to decrease with increasing soil pH in agreement with literature (He and Singh, 1993). Again, the change may be inconsistent in some plant species. A highly correlated value (-0.82335) was obtained between the pH and root concentration across all the sampling location. In addition, there was a strong correlation (-0.86864) between the % cadmium uptake and soil organic matter.

The leaves Cd concentrations at the NRS were relative-

Table 3. Correlation in Cd concentrations between various parts of plants.

	L-CP	L-EO	L-PM	R-CP	R-EO	R-PM
L-CP	1	.577	.780	.987*	.824	.908*
L-EO	.410	1	.584	.585	.645	.627
L-PM	.564	.700	1	.865	.995**	.969**
R-CP	1.000*	.410	.564	1	.898*	.961**
R-EO	.564	.700	1.000*	.564	1	.984**
R-PM	.564	.700	1.000*	.564	1.000*	1

L : Leaves ; R : Roots,
* Significant at the 0.05 level (2-tiled).
** Significant at the 0.01 level (2-tailed).
Spearman and Pearson coefficients are shown above and below the diagonal line respectively

ly higher than those at the ORS, indicating a relatively higher Cd uptake. This can be associated with the relatively higher organic carbon and organic matter content of the soils at this location (ORS), which in general, to a greater extent affects Cd sorption by the soil (He and Singh, 1993) and its availability (Chaney and Hornick, 1978). However, Cd uptake was generally low at the Refuse Site (Old and New). This is based on the fact that Cd uptake in plants is sensitive to metabolic inhibition and that Cd and micronutrients such as Cu, Zn, Fe and possibly Mn which are reasonably present at the site in their various forms, have a common transport site (Cataldo et al., 1983). These findings indicate that Cd uptake into plants is supported by metabolically mediated transport process.

At 50 m distances away from NRS, the soils were found to be slightly acidic, thus increase in the percenttage of cadmium uptake. The striking increase in the leaves concentration at this site can be associated with the closeness of the site to the highway from which automobile tyres could readily release some amount of cadmium and other human activities such as battery charging, located around this site. The very low value of the soil organic matter and carbon content further contributed to the increased Cd uptake at this site and those of 100 m-distance location.

Soil at the 100 m and control locations lie between very slightly acidic and circum-neutral with fairly high value of organic matter content. Though, the accumulation of Cd at these sites was relatively low compare to other locations the percentage uptake was very high. This observation further shows that the control site so investigated typified a fairly perfect pollution free environment.

In general, the study showed for both leaves and roots a gradual decrease in Cd concentration the farther the distance for the NRS. Though *C. papaya* was not available at the 50 m and 100 m away, the pattern could not have changed when results of NRS and control are compared with other plant species. Table 3 shows correlation coefficient values of Cd between the various plants part. For example, it is clear that the leaves of both *C. papaya* and *P. maximum* co-vary with their respective roots. However, for *E. odorata* no correlation was observed. This may be due to foliar absorption in this plant which may not necessarily be translocated into the roots.

Conclusion

The presence of heavy metal like cadmium at any location represents one of the most important environmental hazards. Knowledge of the total concentration of this metal through plant analysis (as indicator) could be considered a starting point for evaluating the degree of pollution as investigated in the present study. Monitoring of cadmium in plant tissues is essential in order to prevent its excessive build up in human food chain as evidenced at the refuse sites and 50 m away where cadmium concentrations particularly in the leaves were mostly at critical levels as a result of anthropogenic inputs.

All environmental problems have a local origin, but may affect a much broader area. Several factors such as improper waste disposal/treatment, non-availability of special collection/dump site and lack of political will to put in place appropriate machinery/personnel required for good waste management have contributed to the deployrable state of the waste management sector in Lagos State and in Nigeria in general. Consequently, appropriate measures should be established to amend all these anomalies. Continued contaminants monitoring of the refuse sites and 50 m away is essential if the service is to ascertain the quality of habitants for resident, migratory animals and some individuals, who for the sake of livelihood have pitch their tent at these locations. Nevertheless, planting and collection of vegetable materials at the refuse sites and the 50 m away should be discouraged to avoid health hazard to consumers.

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