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Evaluation of the Uptake and Accumulation of Metals by Some Commonly Irrigated Vegetables in Soils Treated with Different Concentrations of these Metals

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Abstract: The uptake of some trace elements namely, chromium, nickel, cadmium and lead by some vegetables commonly irrigated were studied under glasshouse conditions. Experiments were conducted in plastic pots using some selected vegetables, lettuce (*Lactuca sativa*), okra (*Abelmoschus esculentus*) and pepper (*Capsicum annum*) grown on sandy loam soils treated with different concentrations of these metals. The treatments investigated include zero application (control), 10, 50 and 100 μg dm^{-3} metal applications. In general, each plant showed similar growth responses and tolerance but different metal uptake patterns in the same metal contaminated media for eight weeks. The enrichment factor of each metal in the different parts of the vegetables was highly varied. However, the fruits of pepper were more enriched with these metals than the okra fruits. Despite the concentration of metals used, the plants were still capable of controlling the metal uptake, no matter the concentration of metal solution applied to the soil.

Key words: Uptake, metals, vegetables

INTRODUCTION

Trace metals have a relevant role in the physiology of plants and animals being constituents of enzymes (coenzymes), membranes and organic complexes. However, most of them are needed only at significantly low levels (micro constituents) and the increase in their concentration above these levels can determine deleterious inhibition of cellular activities, mutagenic effects or at the very last the death of the organisms (Doncheva *et al*., 1996). Heavy metals are usually present in soils at very low amount and increase in their concentration can be determined by a number of natural and human activities. Agricultural practices like fertilizer application and treatment with pesticides also increase the concentration of heavy metals in the soils (Aiwonegbe and Ikhuoria, 2007) in particular fertilization with animal slurry and manure can significantly increase the concentration of some heavy metals in soils. It has been suggested that the pattern of metal distribution within the depth below soil surface is casually related to the pattern of distribution of organic matter (Ruhling and Tyler, 1973; Roberts, 1975). This, as well as the soil organic matter represents reservoirs of organic exchange sites on which cations may accumulate. Chelation is also important for those metals which tend to form stable complexes. In the same way mobile (dissolved) organic compounds increase the soil mobility of readily complex trace metal ions and easily leached from less readily complex metal ions (Tyler, 1978). Trace metals are distributed in the soil solution as free ions (M^{n+}) in form of inorganic and organic complexes. It is generally accepted that, in the short term, plant growth and metal uptake are related to free ion activities (Sparks, 1983; McBride, 1994).

The bioavailability of elements to plants is controlled by many factors associated with soil and climatic conditions, plants genotype and agronomic management, active/passive transfer processes, sequestration and speciation, redox states, type of plant root system and the response of plants to elements in relation to seasonal cycles (Misra and Chaturvedi, 2007). Release of heavy metals in soil as a result of industrial and anthropogenic activities are known to have potential impact on environmental quality and on human health via., ground water and surface water (Rulkens *et al*., 1998). Moreover, concentrations of heavy metals in soil may render plants nonproductive because of phytotoxicity and may cause bioaccumulation of heavy metals in animals and human exposure (Abdel-Sahab *et al*., 1994). Mench *et al*. (2006) and Vangronsveld *et al*. (1995) studied the effect of several soil amendments on the growth of some crops.

The study reported here aimed to establish whether vegetables studied have tolerance and whether there is a relationship between soil metal concentration and accumulation in the different plant tissues. Experiments were conducted to elucidate some heavy metal uptake

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(Cr, Ni, Cd and Pb) by vegetables irrigated by mostly polluted water during dry seasons in Zaria a Northern Nigerian City.

MATERIALS AND METHODS

Collection of soil and growth of vegetables: Soil samples were collected at a depth of 0-30 cm from a virgin area of Zaria (where there is little or no agricultural activity) in the month of March 2005. This period represented about two months to the commencement of the rainy season in this area. The soil samples were thoroughly mixed for homogeneity. Two kilograms each of the soil was weighed into plastic pots and soaked with distilled water and allowed to stand for three days.

The vegetables lettuce, okra and pepper were improved varieties obtained from an agro-allied shop in Zaria, Nigeria. Seeds of these vegetables were germinated at an average daily temperature of 30°C and seedlings grown for two weeks in the Biological Garden of Federal College of Education, Zaria. Uniform seedling were selected and transplanted into the plastic pots. These plants were then allowed to grow in a well aerated glasshouse located in the Department of Biological Sciences, Ahmadu Bello University, Zaria, with sunshine of approximately 10 h per day, night temperatures of approximately 23°C and relative humidity of 60%. There were 48 pots altogether, 16 for each vegetable. The pots were arranged in a randomized block design and watered daily in the glasshouse.

After the plants were adjudged to have stabilized, different solutions containing 10, 50 and 100 $\mu g\ dm^{-3}$ of nickel, chromium and lead as nitrates were applied at the rate of 15 cm^3 of each solution at alternate days until 1000 cm^3 solution was used. These levels of metal treatment were selected on the basis of results of pilot experiments. Days in which test solutions were not used, distilled water (20 cm^3) was used to water the plants and this continued for eight weeks.

When the test plants (lettuce, okra and pepper) were adjudged to be matured at the end of the eighth week, they were gently uprooted and separated into the roots, leaves and fruits regions using a sharp stainless steel knife. Each plant was washed with distilled water and oven-dried in a ventilated oven at 80°C to constant weight. The different parts were ground into powder and stored in airtight plastic containers.

Analysis of soil samples: Sample oxidation was by wet digestion method described by Allen *et al.* (1974), followed by elemental analysis using Atomic Absorption Spectrophotometer (PYE UNICAM Model SP 969) at National Research Institute for Chemical Technology, Zaria, Nigeria. Other physicochemical analysis of the soil were carried out using standard methods described by Allen *et al.* (1974).

Elemental analysis of plant samples: Dried and finely ground sample was weighed (1 g) into a 100 cm^3 Kjeldahl flask and 15 cm^3 of HNO_3 (sp. g. 1.42) was added and heated for 10 min at 60°C on a heating mantle. Hydrochloric acid (5 cm^3, 38% v/v) was added and the temperature gradually increased to 100°C to reduce the volume of the acid to about 2 cm^3. The solution was cooled and 10 cm^3 of distilled water was added and boiled for about 5 min. The metals were determined using atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

Metals in the environment have been found to undergo chemical transformations that help determine bioavailability and toxicity (Adeniyi, 1996; Misra and Chaturvedi, 2007). Some plants can withstand extreme environmental conditions, including the presence of toxic heavy metal contaminants, such as Zn, Pb and Cd (Ye *et al.*, 1997). However, it is not clear whether some plants have the capacity to evolve metal tolerance when growing in metal-contaminated soil or whether they have an innate metal tolerance even when growing on relatively uncontaminated sites. Most experimental studies of heavy metal tolerance confirm the fundamental tenet that populations surviving in metal contaminated habitats are differentiated from normal populations of the same species by possessing genetically-based tolerances (Page *et al.*, 1981). From an ecotoxicological standpoint, it could be argued that transfer of metals into shoot, leaves and fruit is an undesirable property, as metals so accumulated could pass into the food chain via., herbivores and detritus feeders.

Table 1: Physicochemical characteristics of the soil used for study

Parameters measured	Values
pH (H_2O)	6.10
pH (0.01 M $CaCl_2$)	5.20
Total N_2 (%)	0.21
Organic matter (%)	3.32
Cation Exchange Capacity (CEC)	17.2
Exchangeable ions ($\mu g\ g^{-1}$)	
Lead	0.098
Nickel	0.005
Cadmium	0.022
Chromium	0.340
Particle size distribution (%) corrected to 20°C	
Sand	20
Silt	46
Clay	20
Textual class	Loam
Colour	Dull brown

Table 2: Metal concentration in different parts of lettuce

	Metal ions			
Conc. ($\mu g\ g^{-1}$)	Pb	Ni	Cd	Cr
Leaves				
Control	0.029	0.064	0.009	0.016
10	0.411	1.188	0.029	0.915
50	37.10	6.692	0.045	0.711
100	39.53	19.62	0.141	0.839
Roots				
Control	0.103	0.111	0.006	0.212
10	18.06	5.867	0.030	0.323
50	34.56	23.44	0.113	0.342
100	35.07	17.90	0.137	0.022

Table 3: Metal concentration in different parts of okra

	Metal ions			
Conc. ($\mu g\ g^{-1}$)	Pb	Ni	Cd	Cr
Leaves				
Control	0.097	0.009	0.002	0.008
10	0.267	0.039	0.002	0.001
50	0.261	0.139	0.004	0.010
100	0.348	0.089	0.002	0.003
Fruits				
Control	0.053	0.007	0.002	0.008
10	0.263	0.029	0.001	0.016
50	0.222	0.032	0.005	0.012
100	0.319	0.033	0.005	0.001
Roots				
Control	0.007	0.003	0.004	0.012
10	0.192	0.043	0.001	0.006
50	0.187	0.060	0.002	0.004
100	0.283	0.066	0.001	0.004

Table 4: Metal concentration in different parts of pepper

	Metal ions			
Conc. ($\mu g\ g^{-1}$)	Pb	Ni	Cd	Cr
Leaves				
Control	0.018	0.011	0.001	0.017
10	0.188	0.022	0.011	0.017
50	0.239	0.052	0.012	0.011
100	0.411	0.062	0.014	0.003
Fruits				
Control	0.104	0.055	0.001	0.012
10	1.610	2.685	0.037	0.151
50	8.960	4.396	0.031	0.418
100	25.74	7.792	0.043	0.767
Roots				
Control	0.128	0.040	0.001	0.007
10	0.130	0.660	0.005	0.011
50	0.180	0.110	0.001	0.002
100	0.250	0.081	0.004	0.033

The physiological characteristics of the soil used for this investigation is shown in Table 1. The soil is sandy loam and not too rich in organic matter. The pH is close to being neutral with metal ion concentration not exceeding those found in typical soils of this region (Elaigwu *et al*., 2007).

The vegetables did not show any visible sign of physiological disorder and the growth rates for higher concentrations of metal were comparable to the control, suggesting that they tolerated the metals up to a concentration of 100 $\mu g\ dm^{-3}$ (Table 2-4).

Trace metals associated with leaves, roots and fruits originate from two sources, the growth medium of the plant and the atmosphere. Uptake of metal ions by plant roots from the growth medium can be active (metabolic) or passive (non-metabolic) process (Heiwith and Smith, 1975; Haghiri, 1976). These metals are taken up from the soil by plant roots and passed to stems, leaves and fruits, which are eventually consumed by animals and humans. The concentrations of metals studied in these vegetables show different uptake and accumulation levels by the different vegetables. However, the concentrations of heavy metals were still below the maximum level allowed (Fuleky, 1991). The metals were accumulated to different extent by each plant as shown by the enrichment factors calculated and presented in Table 5-7. However, the concentration in the plants generally increased as the concentration in the soil was increased.

Lead is not essential for plant and it has been found that increased pH and organic matter in soil reduces Pb uptake by plants (Largerweff and Speltch, 1970). The accumulation of Pb in the different parts of all the vegetables studied increased as the concentration of applied metal in the soil increased. The enrichment factor for lead in the roots is lettuce>okra>pepper, in the leaves the order is lettuce>pepper>okra and in the fruits of pepper and okra the order is pepper>okra (Table 5-7). The lead was found to be more concentrated in the roots and leaves of lettuce and well dispersed in pepper and okra. Even though the roots of okra concentrated more Pb than pepper, this metal finds its way more easily to other parts of the pepper especially the fruit.

Cadmium is another nonessential element and its concentration in most agricultural soil is usually as a result of pollution from industries and mines (Page *et al*., 1981). The concentration of the metal in all the vegetables was generally low even at higher applied concentration to the soil. This may be attributed to the fact that cadmium is a nonessential element or because of the ability of Cd to form strong chloro-complexes in the soil, thus making the metal unavailable (Ajibola *et al*., 2002). The results suggest that the plants have a way of controlling the concentration of Cd it takes from the soil despite the fact that it has about the same ionic radius with calcium which is an essential metal (Cd = 0.97 Å; Ca = 0.99 Å). The enrichment factor (EF) shows this order in the accumulation of Cd in the root of the vegetables, lettuce>pepper>okra; in the leaves lettuce>pepper>okra and in the fruits of pepper and okra the order is pepper>okra (Table 5-7).

The uptake of Ni by the vegetables generally increased as the concentration applied metal to the soil

Table 5: Enrichment factors (Ef) for lettuce at different concentration of metal ions applied to soil

	Leaves				Roots			
Conc. (μg g^{-1})	Cr	Ni	Cd	Pb	Cr	Ni	Cd	Pb
Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	57.19	18.56	3.22	21.63	1.52	52.86	5.00	175.34
50	44.44	104.56	5.00	195.26	1.61	211.17	18.83	335.53
100	52.44	306.56	15.67	208.05	0.02	161.26	22.83	340.49

Table 6: Enrichment factors (Ef) for okra at different concentration of metal ions applied to soil

	Leaves				Root				Fruits			
Conc. (μg g^{-1})	Cr	Ni	Cd	Pb	Cr	Ni	Cd	Pb	Cr	Ni	Cd	Pb
Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	0.01	4.33	1.00	2.75	0.50	1.33	0.25	27.43	2.29	41.43	0.50	4.96
50	0.13	15.44	2.00	2.69	0.33	20.00	0.50	26.71	1.71	4.57	2.50	4.19
100	0.04	9.89	1.00	3.59	0.33	22.00	0.25	40.43	0.14	4.71	2.50	6.02

Table 7: Enrichment factors (Ef) for pepper at different concentration of metal ions applied to soil

	Leaves				Root				Fruits			
Conc. (μg g^{-1})	Cr	Ni	Cd	Pb	Cr	Ni	Cd	Pb	Cr	Ni	Cd	Pb
Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1.00	2.00	11.00	10.44	1.57	1.65	5.00	1.02	12.58	48.82	37.00	115.00
50	0.65	4.73	12.00	13.28	0.29	0.28	1.00	1.41	34.83	79.93	31.00	640.00
100	0.18	5.64	14.00	22.83	4.71	0.20	4.00	1.95	63.92	141.67	43.00	1838.57

increased. The enrichment factor for Ni in the root and leaves of the vegetables is lettuce>okra>pepper and the order for the fruits of pepper and okra follows the same trend as in Pb and Cd. It is only with Ni that there is a relationship between root uptake and accumulation in leaves.

The uptake of Cr by the vegetables was similar to that observed for Cd in terms of low uptake compared to the level of application (Nouri *et al*., 2001). Chromium availability in soil depends on several soil conditions such as pH and redox potential (Bartlett and Kimble, 1976). If Cr is in the soil, it can be taken up by the roots and accumulated and distributed within the plant. The uptake of Cr by the root was found to be pepper>lettuce>okra; the order for the leaves is lettuce>pepper>okra and for the fruit of pepper and okra it is pepper>okra. This trend in accumulation of Cr by leaves in similar to Pb, except for a lower concentration observed in all the vegetables irrespective of the metal concentration that was applied to the soil. Contrary to the report of Zhu *et al*. (1999) on some come reeds, Cr accumulated preferentially in the fruits of pepper and okra rather than the roots.

CONCLUSION

The concentration of the metals in lettuce, okra and pepper did not increase in proportion with the increase in concentration of solution applied to the plants. This suggests that the plants have a way of controlling metal uptake from the soil to the root and subsequent transport to the aerial parts of the plant. These results have shown that the concentration of these metals in the soil does not necessarily determine the concentration in the plant and each plant accumulates a metal to different extent. Finally, these vegetables can tolerate these metals at concentrations as high as 100 μg dm^{-3} in soil solutions.

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