HYPERACCUMULATION AND MOBILITY OF HEAVY METALS IN VEGETABLE CROPS IN INDIA

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ABSTRACT

The heavy metals or trace elements play an important role in the metabolic pathways during the growth and development of plants, when available in appreciable concentration. The heavy metal concentration of Cadmium (Cd), Cobalt (Co), Copper (Cu), Iron (Fe), Nickel (Ni), Lead (Pb) and Zinc (Zn) was analyzed using Inductive Coupled Plasma Analyzer (ICPA) (Perkin-Elmer ICP Optima 3300 RL) in 18 vegetable crop plants and their parts along with their soil, collected from various agricultural fields around Anand province, Gujarat, India. The vegetables crop plants were Anthem (*Anthum graveolens*), Beat (*Brassica oleracea*), Bitter Gourd (*Momordica charantia*), Brinjal (*Solanum melongena*), Cauliflower (*Brassica oleracea* var. *botrytis*), Chilli (*Capsicum annum*), Coriander (*Coriandrum sativum*), Fenugreek (*Trigonella foenum-graceum*), Garlic (*Alium sativum*), *Coccinia indica*, Lufa (*Luffa acutangula*), Lady's Finger (*Abelmoschus esculentus*), Mint (*Mentha piperata*), Radish (*Raphanus sativum*), Spinach (*Spinacia oleracea*), Tomato (*Lycopersicum esculentum*), Vetches (*Cyamopsis soralioides*) and White Gourd (*Lagernaria vulgaris*). The Accumulation Factor (AF) and Mobility Index (MI) were calculated for assessment of mobility of heavy metals from soil to various plant parts: roots, stems and leaves through different levels: Level 1 (Soil-Roots), Level 2 (Roots-Stems) and Level 3 (Stems-Leaves) in studied vegetable crop plants. The results showed concentration dependent variables of heavy metal levels among vegetable crop plants. The lower and higher concentration gradient alongwith their mobility gradient was also determined. A perusal of data reflects that accumulation gradient of each crop plant component vary according to their nature, properties and podsol climate of a particular crop plant. The data on accumulation and mobility of heavy metals such as Cd, Co, Cu, Fe, Ni, Pb and Zn from soil to leaves through roots and stems, suggested that all the metals were highly mobile.

Key words: Vegetable crop plants, heavy metals, accumulation factor, mobility index

INTRODUCTION

The accumulation of metal ions by root systems is a key function in terrestrial plants, which exhibit extensive ramifications through soil. Distribution of heavy metals in plant body depends upon availability and concentration of heavy metals as well as particular plant species and its population (Punz and Seighardt, 1973). For instance, roots usually show higher heavy metal concentration than shoots, because they are the origin, which comes into contact with the toxic metals present in the soil (Breckle, 1991).

In recent past, Bunzl *et al.* (2001) investigated soil to plant transfer of heavy metals like, Cu, Pb and Zn by vegetables. Studies on heavy metal uptake reveled that vegetables grown at environmentally contaminated sites in Addis Ababa, Tanzania, could take up and accumulate metals at levels that are toxic to human health. Metal uptake differences by leafy vegetables are attributed to plant differences in tolerance to heavy metals (Itanna, 2002). Cadmium, copper and nickel levels in vegetables from industrial and residential areas of Lagos City, Nigeria was studied by Yusuf *et al.* (2002), which revealed that levels of Cd, Cu and Ni in different edible vegetables alongwith its soils on which they were grown were

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higher in industrial areas than those of the residential areas due to pollution. Trace element and heavy metal concentrations in fruits and vegetables of the Gediz River region were intensively studied by Delibacak *et al.* (2002). Also edible portions of five varieties of green vegetables *viz*. Amaranth, Chinese Cabbage, Cowpea leaves, Leafy Cabbage and Pumpkin leaves collected from several areas in Dar Es Salaam, Africa were analyzed for Pb, Cd, Cr, Zn, Ni and Cu. There was a direct positive correlation between Zn and Pb levels in soils with levels in vegetables. The relation was absent for other heavy metals (Othman *et al.* 2002).

In India, similar kind of study was undertaken. Somasundaram *et al.* (2003) conducted research on heavy metal content of plant samples of sewage-irrigated area of Coimbatore district, Karnataka. Leafy vegetables were found with very high levels of heavy metal contamination including Cd, Zn, Cu, Mn and Pb. A similar research conducted at Delhi on `Vegetables eating up vegetarians' found the presence of deadly heavy metals in vegetable samples collected across the capital (The Hindu, 2003).

Rana and Nirmal Kumar (1988) observed heavy metal concentration through Energy Dispersive Analysis of X-Rays (EDAX) in certain sediments in Central Gujarat and noticed that Fe content was found highest in sediment of Undeva region, followed by presence of Si and Al., and Nirmal Kumar *et al.* (1989) have also investigated elemental composition of certain aquatic plants by EDAX, and found high level of heavy metals such as Al, Si, Mn and Fe accumulated in *Vallisnaria spiralis*, *Hydrilla verticillata and Azolla pinnata*. Nirmal Kumar and Rita Kumar (1997) investigated elemental composition of certain economically important plants by EDAX, and encountered the greater accumulation of heavy metals like Fe, Cu and Zn in *Mangifera indica*, *Annona squamosa* and *Manilcara hexandra*, respectively. Nirmal Kumar *et al.* (2007, 2008) analysed concentrations of different heavy metals (Cd, Co, Cu, Ni, Pb, Zn) in market vegetables of Anand vegetable market, Anand town, Gujarat, India, and found that accumulation of heavy metals were higher in *Alium cepa* (Cd, Pb), *Brassica oleracea* var. *botrytis* (Co, Cu, Fe), *Cyamopsis soralioides* (Ni), *Cucumis sativus* (Zn). Leita *et al.* (1991), Prince *et al.* (2001) and Nivethitha *et al.* (2002) have emphasized utilization of heavy metal accumulating plants in reclamation of contaminated soil with heavy metals and assessment of heavy metal mobility in terrestrial ecosystem particularly trophic level of higher plants. However, scanty literature is available on the accumulation and mobility of heavy metals from soil to different vegetable crop plant components. Therefore, the present study was undertaken to visualize the trend of heavy metals in vegetable crop plants and their mobility in various vegetable crop plant components through soil gradient in Anand province, Gujarat, India.

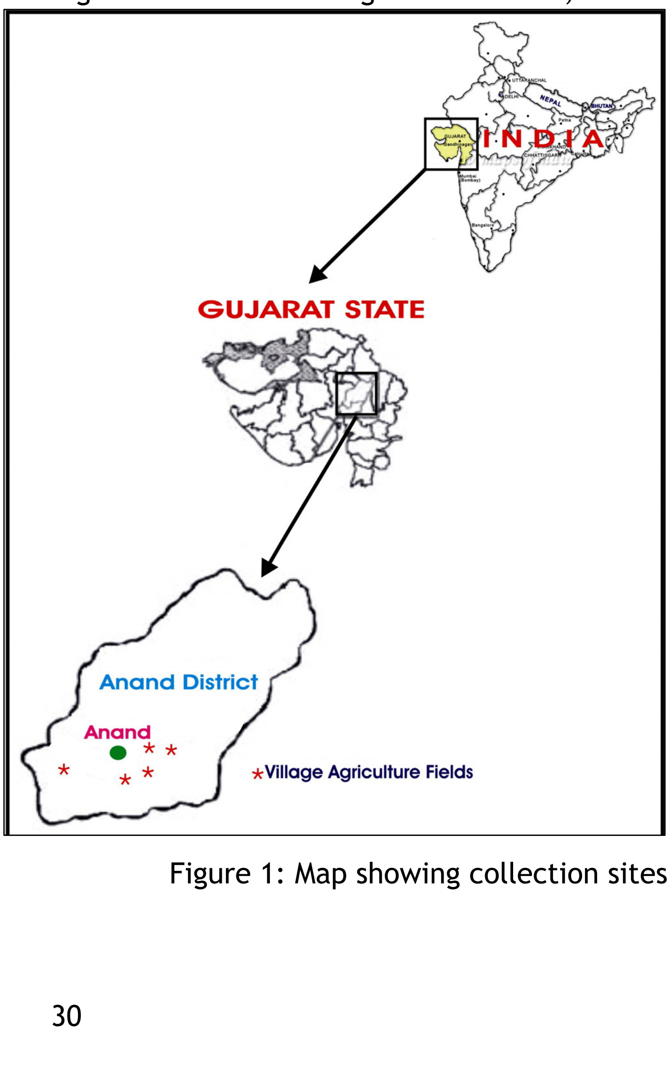

Figure 1: Map showing collection sites

MATERIALS AND METHODS

In the present study, 18 fresh vegetable crop plants were collected alongwith their soil from various agricultural fields around Anand province, Gujarat, India (Fig. 1) and brought to the laboratory. The common vegetable crop plants were *Abelmoschus esculentus*, *Alium sativum*, *Anthum graveolens*, *Brassica oleracea*, *Brassica oleracea var. botrytis*, *Capsicum annum*, *Coccinia indica*, *Coriandrum sativum*, *Cyamopsis soralioides*, *Lagernaria vulgaris*, *Luffa acutangula*, *Lycopersicum esculentum*, *Mentha piperata*, *Momordica charantia*, *Raphanus sativum*, *Solanum melongena*, *Spinacia oleracea* and *Trigonella foenum-graceum*. Rhizosphere soil samples for extractable element analysis were also collected from 0 to 20 cm depth from selected agricultural fields and extracted with DTPA (Di-ethylene Triamine Penta-acetic Acid), filtered through Whatman filter paper No. 42, and analyzed for element concentration (Lindsary and Norvell, 1978).

All vegetable crop plants were rinsed in double distilled water gently; moisture and water droplets were removed with the help of blotting papers; separated into roots, stems and leaves, and dried before grinding to fine powder. Approximately 0.5 gm of dry powder was weighed by electronic digital monopan balance (Shimadzu Co. BL 22 OH E-455000083, Japan), and digested with HNO_3, H_2SO_4 and H_2O_2 at the ratio of 2:6:6 as prescribed by Saison *et al.* (2004). Towards the end of digestion, the flasks were brought to near dryness. The solutions were made to 20 ml each in a measuring cylinder with double distilled water. The blanks were run with set; the samples were then ready for analysis in Industrial Coupled Plasma Analyzer (ICPA) (Perkin-Elmer ICP Optima 3300 Rl). The concentration of heavy metals such as Cd, Co, Cu, Fe, Ni, Pb and Zn were analyzed and calculated in $\mu g\ g^{-1}$ in duplicate samples.

As total heavy metal concentration of soils is poor indicator of metal availability for plant uptake, accumulation factor was calculated based on metal availability and its uptake by a particular plant (Brooks *et al.*, 1977). The whole experiment was divided into three categories: Level 1 (Soil-Roots), Level 2 (Roots-Stems) and Level 3 (Stems-Leaves).

Accumulation Factor for plants was calculated as:

$$\text{Accumulation Factor (AF)} = \frac{\text{Mean Plant Concentration } (\mu g\ g^{-1}) \text{ (Roots+Stems+Leaves)}}{\text{Mean Soil available } (\mu g\ g^{-1}) \text{ Concentration}}$$

Mobility Index (MI) was calculated for each level by using the formula:

$$\text{Mobility Index (MI)} = \frac{\text{Concentration of Metal } (\mu g\ g^{-1}) \text{ in the receiving level}}{\text{Concentration of Metal } (\mu g\ g^{-1}) \text{ in the source level}}$$

RESULTS AND DISCUSSION

Accumulation and mobility of heavy metals (Cd, Co, Cu, Fe, Ni, Pb and Zn) in vegetable crop plants as a function of concentration are presented in Table 1.

ACCUMULATION OF HEAVY METALS

During the present study, heavy metals such as Cd, Co, Pb, Ni, Cu, Zn and Fe were accumulated in particular crop plant components in a very high concentration. It was observed that high content of Cd was accumulated in roots of *C. sativum* (0.048), Co in *B. oleracea var. botrytis* roots (0.318), Pb in roots of *C. sativum* (0.401), Ni in *C. sativum* roots (1.63), Cu in *A. sativum* roots (2.10), Zn in roots of *C. sativum* (7.55) and highest concentration of Fe was found accumulated in roots of *C. sativum* (83.70). Heavy metals also accumulated in stems at different concentrations. Present study revealed that Cd content was found greater in stems of *C. annum* (0.021), Co in stems of *C. sativum* (0.076), Pb in *A. graveolens* stems (0.500), Ni (0.875) in *B. oleracea var. botrytis*, Cu (1.26) in stems of *M. piperata*, Zn (3.95) in stems of *A. graveolens* and maximum content of Fe was recorded in stems of *C. sativum* being 25.78. High content of Cd was accumulated being 0.015 in leaves of *A. esculentus*, Pb (0.325) in leaves of *R. sativum*, Co (0.387) in *C. sativum* leaves, Ni (1.50) in *M. charantia* leaves, Cu (1.78) in leaves of *C. sativum*, Zn (9.43) in leaves of *T. foenum-graceum* and high content of Fe was accumulated being 89.14 in *C. sativum* leaves. Thus higher accumulation factor of heavy metals in various plant components particularly in roots, stems and leaves could be found as Cd > Co > Pb > Ni > Cu > Zn > Fe (Table 1).

On the other hand, it was observed that heavy metals such as Cd, Co, Pb, Ni, Cu, Zn and Fe were present in a low concentration in particular crop plant component. The lowest concentration of Cd was found in roots of *B. oleracea var. botrytis* (0.003), Co content in *C. indica* roots (0.005), Pb in roots of *B. oleracea var. botrytis* (0.031), Ni in *C. indica* roots

(0.282), Cu in *R. sativum* roots (0.361), Zn in roots of *A. esculentus* (1.29) and low level of Fe was found in roots of *L. acutangula* (4.10). Stems also accumulated heavy metals upto certain concentration. Present findings revealed that Cd content was found lowest in stems of *M. charantia*, *C. indica* and *M. piperata*, Co in *A. esculentus*, Pb in *M. charantia*, Cu in *C. annum*, Ni in *A. sativum*, Zn in *L. acutangula* and Fe in *M. charantia* (2.01). Cd content was very low in leaves of *L. acutangula* (0.001), Co in *A. esculentus* leaves (0.004), Pb in leaves of *M. charantia* (0.042), Cu in leaves of *M. piperata* (0.058), Ni in *A. graveolens* leaves (0.199), Zn in leaves of *B. oleracea* (1.82) and low concentration of Fe was found in *A. sativum* leaves (5.62). Thus, poor accumulation factor of heavy metals in different crop plant components particularly in roots, stems and leaves could be shown as Cd > Co > Pb > Ni > Cu > Zn > Fe (Table 1).

In all vegetable crop plants, heavy metal content in plant components was found higher compared to available metal concentration in soil. Cd content was found lowest (0.14) in *M. charantia* and highest (4.27) in *L. vulgaris*. Low values of Co and Cu were observed in *C. indica* being 0.04 and 0.21, respectively, while high content of both the elements were recorded in *C. soralioides* being 3.59 and 2.66, respectively. Poor concentration of Fe was observed in *A. sativum* (0.02), and high Fe conent was noticed in *C. soralioides* (2.40). On the other hand, *S. oleracea* was found to contain low concentration (0.19) of Ni, while high content (1.25) of the same metal was registered in *C. sativum*. *M. charantia* exhibited low concentration of Pb and Zn being 0.22 and 0.15, respectively, while higher content (6.81) of Pb was found in *M. piperata* and low content was observed in *T. foenum-graceum* being 1.98. Thus heavy metal content (µg g^{-1}) in vegetable crop plants ranged from 0.14 to 3.69 (Cd), 0.04 to 0.42 (Co), 0.21 to 1.17 (Cu) and 0.02 to 0.40 (Fe), while in case of Ni, the concentration ranged from 0.39 to 1.25, Pb (0.22 to 6.81) and Zn (0.15 to 1.98).

In all vegetable crop plants, Cd content was higher in plant components compared to available Cd level in soil, which might be due to the high uptake and accumulation rate. Similar findings were noticed by Prince *et al.* (2001). Among all vegetable crop plants, Fe concentration was higher in all three-plant components, could be due to iron-rich soil (Nivethitha *et al.*, 2002; Nirmal Kumar *et al.*, 2007). Mechanism of metal accumulation was found significant in terms of accumulation factor of a particular plant component. Roots showed high accumulation of heavy metals (6.39), followed by moderate

Table 1: Accumulation and mobility indices of heavy metals in vegetable crop plants colleted from village farms around Anand province, Gujarat, India

Sr. No.	NAME OF THE PLANT ($\mu g\ g^{-1}$)	Cd*	Transport of Cd				Co*	Transport of Co				Cu*	Transport of Cu			
			S-R L1	R-S L2	S-L L3	AF		S-R L1	R-S L2	S-L L3	AF		S-R L1	R-S L2	S-L L3	AF
1.	*Anthum Graveolens*	0.006	0.023	0.020	0.008	2.82	0.329	0.100	0.064	0.021	0.19	1.359	0.910	0.947	0.239	0.51
	MI		3.90	0.85	0.39			0.30	0.64	0.32			0.67	1.04	0.25	
2.	*Brassica oleracea*	0.009	0.013	0.010	0.008	1.13	0.400	0.135	0.015	0.050	0.17	1.322	1.066	0.636	0.567	0.57
	MI		1.44	0.73	0.84			0.34	0.11	3.29			0.81	0.60	0.89	
3.	*Momordica charantia*	0.045	0.015	0.002	0.002	0.14	0.271	0.045	0.004	0.013	0.08	1.768	0.692	0.344	0.266	0.25
	MI		0.33	0.13	1.30			0.17	0.09	3.25			0.39	0.50	0.77	
4.	*Solanum melongena*	0.011	0.009	0.009	0.010	0.86	0.288	0.214	0.015	0.022	0.29	1.323	0.984	0.721	1.031	0.69
	MI		0.83	0.96	1.20			0.74	0.07	1.51			0.74	0.73	1.43	
5.	*Brassica oleracea var. botrytis*	0.007	0.003	0.008	0.008	0.93	0.324	0.318	0.051	0.022	0.40	1.089	1.424	0.450	0.369	0.69
	MI		0.45	2.61	0.99			0.98	0.16	0.43			1.31	0.32	0.82	
6.	*Capsicum annum*	0.008	0.014	0.021	0.006	1.72	0.400	0.124	0.010	0.047	0.15	1.396	0.944	0.139	0.236	0.32
	MI		1.75	1.52	0.28			0.31	0.08	4.60			0.68	0.15	1.69	
7.	*Coriandrum sativum*	0.007	0.048	0.019	0.013	3.69	0.578	0.258	0.076	0.387	0.42	1.267	1.724	0.965	1.777	1.17
	MI		6.63	0.40	0.69			0.45	0.29	5.13			1.36	0.56	1.84	
8.	*Trigonella foenum -gracum*	0.015	0.026	0.014	0.014	1.18	0.351	0.223	0.045	0.036	0.29	1.164	1.193	0.419	0.508	0.61
	MI		1.70	0.55	0.96			0.63	0.20	0.81			1.02	0.35	1.21	
9.	*Allium sativum*	0.007	0.016	0.007	0.007	1.51	0.483	0.189	0.047	0.019	0.18	1.711	2.102	0.186	0.545	0.55
	MI		2.48	0.40	1.04			0.39	0.25	0.40			1.23	0.09	2.93	

Sr. No.	NAME OF THE PLANT ($\mu g\ g^{-1}$)	Fe*	Transport of Fe				Ni*	Transport of Ni				Pb*	Transport of Pb				Zn*	Transport of Zn			
			S-R L1	R-S L2	S-L L3	AF		S-R L1	R-S L2	S-L L3	AF		S-R L1	R-S L2	S-L L3	AF		S-R L1	R-S L2	S-L L3	AF
1.	*Anthum Graveolens*	55.23	30.767	18.724	5.980	0.33	1.528	1.012	0.790	0.199	0.44	0.147	0.284	0.500	0.069	1.93	4.89	5.130	3.948	3.026	0.82
	MI		0.56	0.61	0.32			0.66	0.78	0.25			1.93	1.76	0.14			1.05	0.77	0.77	
2.	*Brassica oleracea*	265.05	36.630	8.838	15.160	0.08	0.809	0.664	0.389	0.351	0.58	0.155	0.160	0.143	0.101	0.87	5.16	3.477	1.970	1.816	0.47
	MI		0.14	0.24	1.72			0.82	0.59	0.90			1.03	0.90	0.70			0.67	0.57	0.92	
3.	*Momordica charantia*	128.63	18.055	2.009	13.041	0.09	0.702	0.705	0.230	1.496	1.15	0.291	0.123	0.031	0.042	0.22	28.41	6.518	1.192	4.659	0.15
	MI		0.14	0.11	6.49			1.00	0.33	6.50			0.42	0.25	1.35			0.23	0.18	3.91	
4.	*Solanum melongena*	71.99	75.670	5.344	5.670	0.40	0.581	0.609	0.750	0.501	1.07	0.083	0.262	0.189	0.203	2.62	13.53	2.892	2.666	4.732	0.25
	MI		1.05	0.07	1.06			1.05	1.23	0.67			3.14	0.72	1.07			0.21	0.92	1.77	
5.	*Brassica oleracea var. botrytis*	106.66	38.965	6.606	21.197	0.21	0.676	0.765	0.875	0.237	0.93	0.100	0.031	0.152	0.249	1.44	3.59	3.613	2.078	2.350	0.75
	MI		0.37	0.17	3.21			1.13	1.14	0.27			0.31	4.90	1.63			1.01	0.58	1.13	
6.	*Capsicum annum*	279.77	11.263	6.053	23.076	0.05	0.854	0.750	0.435	1.436	1.02	0.164	0.147	0.072	0.111	0.67	5.44	2.949	2.295	7.809	0.80
	MI		0.04	0.54	3.81			0.88	0.58	3.30			0.90	0.49	1.54			0.54	0.78	3.40	
7.	*Coriandrum sativum*	693.02	83.704	25.782	89.145	0.10	0.856	1.628	0.673	0.918	1.25	0.164	0.401	0.094	0.184	1.38	2.98	7.549	3.094	3.831	1.61
	MI		0.12	0.31	3.46			1.90	0.41	1.36			2.45	0.23	1.95			2.53	0.41	1.24	
8.	*Trigonella foenum -gracum*	351.87	75.155	11.695	20.261	0.10	0.556	0.962	0.339	0.386	1.01	0.184	0.212	0.163	0.273	1.17	3.14	5.292	3.940	9.430	1.98
	MI		0.21	0.16	1.73			1.73	0.35	1.14			1.15	0.77	1.68			1.68	0.74	2.39	
9.	*Allium sativum*	643.88	26.177	15.411	5.622	0.02	0.735	0.820	0.197	0.357	0.62	0.196	0.315	0.137	0.147	1.02	2.81	4.052	3.766	2.459	1.22
	MI		0.04	0.59	0.36			1.12	0.24	1.81			1.61	0.43	1.07			1.44	0.93	0.65	

* Concentration of heavy metal in soil, S-R: Soil to Root, R-S: Root to Stem, S-L: Stem to Leaf, L1: Level 1, L2: Level 2, L3: Level 3, AF: Accumulation Factor, *MI*: Mobility Index

\# All the values are expressed in $\mu g\ g^{-1}$

Table 1 continued...

Sr. No.	NAME OF THE PLANT	Cd*			Co*			Cu*						Ni*			Pb*			Zn*		
			Transport of Cd	AF		Transport of Co	AF		Transport of Cu	AF		Transport of Fe	AF		Transport of Ni	AF		Transport of Pb	AF		Transport of Zn	AF
	(µg g⁻¹)																					
		S-R	R-S	S-L	S-R	R-S	S-L	S-R	R-S	S-L	S-R	R-S	S-L	S-R	R-S	S-L	S-R	R-S	S-L	S-R	R-S	S-L	
		L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	
10.	*Coccinia indica*	0.005 0.005	0.002	0.003 0.75 0.313	0.005	0.016	0.014 0.04 1.845	0.408	0.323	0.456 0.21 49.53	7.265	11.093	25.137 0.29 0.775	0.282	0.378	0.359 0.44 0.229	0.108	0.105	0.148 0.53 3.21	1.541	1.728	2.212	0.57
	AI	1.14	0.40	1.44	0.02	3.34	0.88	0.22	0.79	1.41	0.15	1.53	2.27	0.36	1.34	0.95	0.47	0.98	1.40	0.48	1.12	1.28	
11.	*Luffa acutangula*	0.005 0.007	0.006	0.001 0.87 0.347	0.006	0.020	0.028 0.05 1.259	0.536	0.593	0.479 0.43 245.33	4.100	15.630	21.520 0.06 0.813	0.392	0.304	0.321 0.42 0.126	0.130	0.080	0.115 0.86 2.02	1.480	1.136	6.572	1.51
	AI	1.32	0.82	0.17	0.02	3.08	1.43	0.43	1.11	0.81	0.02	3.81	1.38	0.48	0.78	1.05	1.03	0.62	1.43	0.73	0.77	5.79	
12.	*Abelmoschus esculentus*	0.009 0.008	0.005	0.015 1.06 0.328	0.048	0.003	0.004 0.06 1.377	0.507	0.313	0.475 0.31 92.49	48.732	9.021	11.189 0.25 0.725	0.395	0.247	0.210 0.39 0.144	0.151	0.133	0.259 1.26 2.95	1.287	1.502	1.954	0.54
	AI	0.95	0.62	2.82	0.14	0.07	1.32	0.37	0.62	1.52	0.53	0.19	1.24	0.54	0.63	0.85	1.05	0.89	1.94	0.44	1.17	1.30	
13.	*Mentha piperata*	0.006 0.008	0.002	0.013 1.29 0.382	0.084	0.035	0.046 0.14 2.258	1.057	1.256	0.058 0.35 83.51	11.978	10.794	11.007 0.13 1.251	0.740	0.552	0.292 0.42 0.020	0.168	0.139	0.102 6.81 2.23	3.670	2.372	2.014	1.20
	AI	1.38	0.27	5.79	0.22	0.41	1.33	0.47	1.19	0.05	0.14	0.90	1.02	0.59	0.75	0.53	8.39	0.83	0.73	1.64	0.65	0.85	
14.	*Raphanus sativum*	0.010 0.011	0.014	0.015 1.30 0.314	0.037	0.005	0.033 0.08 0.972	0.361	0.210	0.467 0.36 348.48	10.613	9.198	49.175 0.07 0.369	0.320	0.338	0.346 0.91 0.175	0.162	0.300	0.325 1.50 2.15	2.745	1.680	2.545	1.08
	AI	1.09	1.28	1.02	0.12	0.14	6.21	0.37	0.58	2.22	0.03	0.87	5.35	0.87	1.06	1.03	0.93	1.85	1.09	1.28	0.61	1.52	
15.	*Spinacia oleracea*	0.006 0.013	0.010	0.014 2.05 1.032	0.147	0.065	0.062 0.09 1.763	1.210	1.132	0.606 0.56 1263.55	28.097	21.798	117.999 0.04 1.779	0.405	0.322	0.279 0.19 0.203	0.127	0.113	0.150 0.64 4.76	3.606	3.594	4.515	0.82
	AI	2.17	0.77	1.38	0.14	0.44	0.95	0.69	0.94	0.54	0.02	0.78	5.41	0.23	0.80	0.87	0.62	0.89	1.32	0.76	1.00	1.26	
16.	*Lycopersicum esculentum*	0.010 0.018	0.013	0.011 1.40 0.651	0.319	0.015	0.073 0.21 2.769	2.308	0.800	1.226 0.52 246.32	131.225	23.205	26.163 0.24 1.896	0.944	0.323	0.570 0.32 0.335	0.256	0.105	0.217 0.57 9.82	8.992	4.378	2.650	0.54
	AI	1.78	0.74	0.82	0.49	0.05	4.77	0.83	0.35	1.53	0.53	0.18	1.13	0.50	0.34	1.76	0.76	0.41	2.06	0.92	0.49	0.61	
17.	*Cyamopsis soralioides*	0.003 0.012	0.008	0.004 2.77 0.010	0.077	0.015	0.017 3.59 0.429	1.905	0.851	0.664 2.66 10.24	38.658	6.173	28.808 2.40 0.380	0.516	0.446	0.322 1.13 0.256	0.071	0.088	0.131 0.38 1.72	2.288	1.660	2.100	1.17
	AI	4.11	0.67	0.52	7.55	0.20	1.15	4.44	0.45	0.78	3.77	0.16	4.67	1.36	0.86	0.72	0.28	1.24	1.49	1.33	0.73	1.27	
18.	*Lagenaria vulgaris*	0.009 0.005	0.006	0.104 4.27 0.393	0.096	0.017	0.038 0.13 1.444	0.933	0.659	0.217 0.42 380.10	18.922	10.705	13.652 0.04 0.944	0.705	0.540	0.333 0.56 0.141	0.094	0.100	1.420 3.82 4.64	2.658	2.062	7.721	0.89
	AI	0.61	1.15	16.55	0.24	0.18	2.26	0.65	0.71	0.33	0.05	0.57	1.28	0.75	0.77	0.62	0.67	1.06	14.21	0.57	0.78	3.74	
	Mean	0.010 0.014	0.010	0.014 1.65 0.400	0.135	0.029	0.052 0.36 1.47	1.126	0.608	0.566 0.62 295.32	38.665	12.115	27.989 0.27 0.902	0.701	0.452	0.495 0.71 0.173	0.178	0.147	0.236 1.54 5.75	3.874	2.503	4.022	0.91
		1.89	0.83	2.12	0.74	0.54	2.22	0.93	0.61	1.17	0.44	0.65	2.55	0.89	0.72	1.37	1.51	1.07	2.05	0.97	0.73	1.88	

accumulation in leaves (4.77) and the poor content (2.27) in stems. This indicated higher rate of mobility of metals from soil to roots in a particular plant, moderate from stems to leaves, and low from roots to stems. Thus, the present results were well-corroborated with the observations of Hunter *et al.*, (1987a, 1987b, 1987c).

Moreover, the vegetable crop plants such as *M. charantia* and *C. soralioides* were found to be hypo-accumulative and hyper-accumulative, respectively, in nature. Presence of heavy metals such as Cd, Pb and Zn was detected in lowest concentration in *M. charantia*, while *C. soralioides* was found to accumulate Co, Cu and Fe in high content. Therefore, *C. soralioides* could be used to decontaminate heavy metals from polluted soils in view of its ability to accumulate various heavy metals several folds higher than their available level within the soil. Therefore, it is recommended that such verities of vegetable crop plants could be effectively used to decontaminate heavy metal polluted soil due to its capability to establish and proliferate in soil podsol (Nivethitha *et al.*, 2002).

MOBILITY OF HEAVY METALS

Mobility Index (MI) showed biomobility and transport of heavy metals through different levels: Level 1 (Soil-Roots), Level 2 (Roots-Stems) and Level 3 (Stems-Leaves) in vegetable crop plants, which becomes functional to understand the transport mechanism of heavy metals in plant components, such as roots, stems and leaves. Present findings revealed that Level 1 (Soil-Roots) registered high mobility rate of Ni and Zn in *C. sativum* being 1.90 and 2.53, respectively, Fe (3.77) and Cu (4.44) in *C. soralioides*, Cd in *C. sativum* (6.63), Co in *C. soralioides* (7.55) and Pb in *M. piperata* being 8.39. In case of Level 2 (Roots-Stems), greater mobility rate of Zn was achieved in *A. esculentus* (1.17); Cu in *M. piperata* (1.19), Ni in *L. acutangula* (1.34), Cd in *B. oleracea var. botrytis* (2.61), Co in *C. indica* (3.34), Fe in *L. acutangula* (3.81) and low mobility rate of Pb was encountered in *B. oleracea var. botrytis* being 4.90. Thus higher mobility gradient of heavy metals among various levels can be expressed as Co > Fe > Zn > Cu > Ni > Pb > Cd (Table 1).

Present study also showed that some metals exhibited low mobility rate from one part to other part in particular vegetable crop plant. Low mobility of metals was encountered in Level 1 (Soil-Roots): low mobility of Co and Fe in *C. indica* and *L. acutangula* (0.002), respectively, Zn in *S. melongena* (0.21), Cu in *C. indica* (0.22), Ni in *S. oleracea* (0.23), Pb in *C. soralioides* (0.28) and low transfer of Cd was recorded in *M charantia* (0.33). In case of Level 2 (Roots-Stems), low mobility rate of Co was achieved in *L. esculentum* (0.05), Fe in *S. melongena* (0.07), Cu in *A. sativum* (0.09), Cd (0.13) and Zn (0.18) in *M. charantia*, Pb in *C. sativum* (0.23) and low mobility of Ni was registered in *A. sativum* (0.24). Moreover, level 3 (Stems-Leaves) showed low mobility of Cu in *M. piperata* (0.05), Pb in *A. graveolens* (0.14), Cd in *L. acutangula* (0.17), Ni (0.25), Co (0.32) and Fe (0.32) in *A. graveolens* and Zn in *L. esculentum* (0.61). Thus, lower mobility rate gradient of heavy metals through different plant components can be expressed as Co > Fe > Zn > Cu > Ni > Pb > Cd (Table 1).

Rate of mobility was found higher in Cd (1.61), followed by Pb (1.54), Fe (1.21), Zn (1.19), Co (1.17) and lowest in Ni (0.99) and Cu (0.90). Mobility of metals at different levels varied among various plant parts. Mobility factor was ranged from 0.44 to 1.89 in Level 1 (Soil-Roots), 0.54 to 1.07 in Level 2 (Roots-Stems) and 1.17 to 2.55 in Level 3 (Stems-Leaves) (Table 1). Thus mobility gradient of heavy metals in plant components could be drawn as Cd > Pb > Fe > Zn > Co > Ni > Cu. Similarly, metal transport mechanism was found significant in terms of mobility of a particular metal content from source to receiving level. High mobility was observed at different levels, which is established by the fact that very low content of heavy metals are transported from roots to stems (Level 2) being only 0.73. Gradual increase in transport of metal content was observed in Level 1

(Soil-Roots) with 1.05, while highest content of metals are transported through Level 3 (Stems- Leaves) being 1.90. This might be due to the fact that Cd is more readily available than other metals in surface soil horizons, which corroborated the findings of Hunter *et al*. (1987a, 1987b, 1987c).

Thus concentration of heavy metals was found moderate in roots could be due to increased mobility of heavy metals from soil to roots indicated the tendency of roots to accumulate good amount of metals from soil and transfer a little to above ground biomass. These results are in conformation with the findings of Jarvis *et al*. (1976) and Leita *et al*. (1993), who noticed moderate accumulation of heavy metals in root system. It reveals that sometimes roots act as barriers to transfer the toxic metals through soil-plant system (Jones and Clement, 1972). Jarvis and Robson (1982) reported that most of the accumulated Cu was retained within roots even when plants showed Cu deficiency symptoms.

CONCLUSION

1. Higher accumulation factor of heavy metals in various plant components particularly in roots, stems and leaves was found in the order Cd > Co > Pb > Ni > Cu > Zn > Fe.

2. Vegetable crop plants like *C. soralioides*, *B. oleracea var. botrytis*, *C. annum*, *A. graveolens* and *M. piperata* were found to be hyper-accumulative, whereas, *C. indica*, *A. esculentus* and *L. acutangula* were hypo-accumulative.

3. *C. soralioides* could be used to decontaminate the heavy metal polluted soils.

4. Greater mobility rate was observed in vegetable crop plants such as *C. sativum*, *C. soralioides*, *M. piperata* and *C. indica*, while poor mobility in *S. melongena*, *S. oleracea* and *L. esculentum*.

5. Mobility of heavy metals such as Cd, Co, Cu, Fe, Ni, Pb and Zn from soil to leaves suggested that all these metals were highly mobile from soil to plant components.

6. Comparing transfer potential of metals among various plant components, these metals markedly exceeded in Level 3 (Stems-Leaves), followed by a gradual decline in Level 1 (Soil-Roots) and Level 2 (Roots-Stems).

ACKNOWLEDGEMENTS

Authors are thankful to “Charotar Ratna” and “Shalin Manav Ratna” Dr. C.L. Patel, Chairman, Charutar Vidya Mandal (CVM), Vallabh Vidynagar, Gujarat, India, for being a constant source of inspiration, initiation and motivation to carry out this small piece of work, without whose support this work would not have been possible. Thanks are also due to Dr. Gokul Patel and Mr. Tiwari for their assistance in sample analysis using Industrial Coupled Plasma Analyzer (ICPA) at Sophisticated Instrumentation Center for Applied Research and Testing (SICART), Vallabh Vidynagar, Gujarat, India.

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