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ASSESSING HEAVY METAL HYPER-ACCUMULATION AND MOBILITY IN SELECTED VEGETABLE CROPS: A CASE STUDY OF ORGANIC FARM, GUJARAT, INDIA

J.I. Nirmal Kumar, Hiren Soni*, Rita N. Kumar and Ira Bhatt**
Department of Environmental Science & Technology (EST), Institute of Science & Technology for Advanced Studies & Research (ISTAR), Vallabh Vidyanagar-388 120, Gujarat
*****Ashok and Rita Patel Institute of Integrated Study and Research in Biotechnology and Allied Sciences (ARIBAS), New Vallabh Vidyanagar-388 121, Gujarat
******Department of Biosciences & Environmental Sciences, N.V. Patel College of Pure and Applied Sciences, Vallabh Vidyanagar-388 120, Gujarat

ABSTRACT

The heavy metals play an important role in the metabolic pathways during the growth and development of plants, when available in required concentration. The heavy metal concentration of cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), nickel (Ni), lead (Pb) and zinc (Zn) was analysed using Inductive Coupled Plasma Analyser (ICPA) in 20 vegetable crop plants and their parts along with the soil, collected from Shivam organic farm, Valasan, Anand, Gujarat, India. The vegetables selected for the present investigation were *Abelmoschus esculentus, Allium sativa, A. cepa, Anethum graveolens, Brassica oleracea, B. oleracea, Capsicum annum, Coccinia indica, Coriandrum sativum, Cucumis sativus, Cyamopsis psoralioides, Lagenaria vulgaris, Luffa acutangula, Lycopersicon esculentum, Mentha piperata, Momordica charantia, Raphanus sativus, Solanum melongena, Spinacia oleracea* and *Trigonella foenum-graceum*. The concentration of heavy metals of vegetable crop plants, grown in organic farm, falls within the prescribed limit except Fe. The Accumulation Factor (AF) and Mobility Index (MI) were calculated for the assessment of accumulation and mobility of heavy metals from soil to various plant parts, i.e., roots, stems and leaves through different levels: Level 1 (soil-root), Level 2 (roots-stem) and Level 3 (stem-leaf) in the plants. The accumulation factor (AF) for Cd, Co and Pb metals was found greater in plant parts as compared to available levels in soil. On the other hand, the concentration of Cu, Fe, Ni and Zn was lower in plant parts than the soil. The mobility index (MI) of heavy metal in plant parts was found to be greater compared to available metal concentration in soil. The results showed concentration dependent variables of heavy metal levels among vegetable crop plants. The lower and higher concentration gradient along with their mobility gradient was also determined. A perusal of data reflects that accumulation gradient of each plant component vary according to nature, properties and podsol climate of a particular plant. The data on accumulation factor and mobility index of the heavy metals from soil to leaves suggest that all the metals are highly mobile in the soil.

INTRODUCTION

Organic farming is about building a sustainable, healthy and productive future for every aspect of our planet, i.e., the soil, water supply, animals and humans. Organic foods have higher nutrient and mineral level than non-organic food. They have considerably low level of heavy metals and fewer pesticide residues, especially in fruits and vegetables (Organic Gardening Almanac, 2003). Organic farming helps in better soil management such as crop rotation, cover crops and composting to enrich the soil and increase the concentration of vitamins and minerals in the plants. Though organic farming has a tremendous scope in India, there exist a number of bottlenecks for farmers who are interested in organic farming and for the industry who want to process and export organic food products

(Chaturvedi & Nagpal 2001). Scanty literature is available on accumulation factor and mobility index of heavy metals in vegetables (Leita et al. 1991).

Prince et al. (2001) and Nivethitha et al. (2002) have worked out utilization of heavy metal accumulating plants in reclamation of contaminated soil. Some studies on distribution and characterization of heavy metals in vegetable crop plants from the fields around Anand, Gujarat as well as common edible vegetables sold in market were also carried out (Nirmal Kumar et al. 2004). However, the mobility of heavy metals from soil to specific plant parts is needed to be investigated in vegetables grown in organic farms. Therefore, the present study was undertaken to carry out heavy metal content in vegetable crops and their mobility among various plant parts through soil gradient.

Earlier, Rana & Nirmal Kumar (1988) observed heavy metal concentration through Energy Dispersive Analysis of X-Rays in certain sediments in central Gujarat and noticed that Fe content was highest in sediment of Undeva region, followed by presence of Si and Al. 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 in *Vallisnaria spiralis*, *Hydrilla verticillata* and *Azolla pinnata*. Nirmal Kumar & Rita Kumar (1997) investigated elemental composition of certain economically important plants and found greater accumulation of Fe, Cu and Zn in *Mangifera indica*, *Annona squamosa* and *Manilcara hexandra*. Nirmal Kumar et al. (2007) analysed heavy metals in market vegetables of Anand and found that accumulation of heavy metals was higher in *Alium cepa* (Cd, Pb), *Brassica oleracea* var. botrytis (Co, Cu, Fe), *Cyamopsis soralioides* (Ni) and *Cucumis sativus* (Zn).

MATERIALS AND METHODS

In the present study, 20 fresh vegetable crop plants were collected separately along with their soil from Shivam Organic Farm, Valasan near Vallabh Vidyanagar in Gujarat where vegetable crops are grown using only vermicompost without addition of chemical fertilizers. The common vegetables were *Abelmoschus esculentus* (L.) Moench. (lady's finger), *Allium sativa* L. (garlic), *A. cepa* L. (onion), *Anethum graveolens* L. (anthem), *Brassica oleracea* L. (beat), *B. oleracea* L. var. botrytis (cauliflower), *Capsicum annum* L. (chilli), *Coccinia indica* W. & A., *Coriandrum sativum* L. (coriander), *Cucumis sativus* L. (cucumber), *Cyamopsis psoralioides* DC. (vetches), *Lagenaria vulgaris* Ser. (white gourd), *Luffa acutangula* (L.) Roxb. (lufa), *Lycopersicon esculentum* Mill. (tomato), *Mentha piperata* L. (mint), *Momordica charantia* L. (bitter gourd), *Raphanus sativus* L. (radish), *Solanum melongena* L. (brinjal), *Spinacia oleracea* L. (spinach) and *Trigonella foenum-graceum* L. (fenugreek). Rhizosphere soil samples for extractable element analysis were also collected from 0 to 20 cm depth from selected agricultural fields and extracted with DTPA (diethylene triamine pentaacetic acid), filtered through Whatman filter paper No. 42 and analysed for elemental concentration.

All vegetable crop plants were rinsed with double distilled water; moisture and water droplets were removed with the help of blotting papers; and separated into roots, stems and leaves. Approximately 0.5 g of dry powder was weighed and digested with HNO_3, H_2SO_4 and H_2O_2 in 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 with double distilled water. The blanks were run with the sets; the samples were then ready for analysis in Industrial Coupled Plasma Analyser (ICPA) (Perkin-Elmer ICP Optima 3300 Rl). The concentration of heavy metals such as Cd, Co, Cu, Fe, Ni, Pb and Zn was estimated and calculated in μg/g 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. The whole experiment was divided into three categories: Level 1 (soil-root), Level 2 (roots-stem) and Level 3 (stems-leave). Mobility Index (MI) was calculated for each level; the mean value was also elaborated with root square (R^2) value ($y = 0.0009x + 1.2223$; $R^2 = 0.0001$).

Accumulation factor for plants was calculated as:

$$\text{Accumulation Factor (AF)} = \frac{\text{Mean plant concentration } (\mu g/g) \text{ (roots + stems + leaves)}}{\text{Mean soil available } (\mu g/g) \text{ concentration}}$$

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

$$\text{Mobility Index (MI)} = \frac{\text{Concentration of metal } (\mu g/g) \text{ in the receiving level}}{\text{Concentration of metal } (\mu g/g) \text{ in the source level}}$$

RESULTS AND DISCUSSION

Accumulation Factor: Accumulation factor and mobility index of heavy metals such as Cd, Co, Cu, Fe, Ni, Pb and Zn in vegetable crop plants are presented in Table 1. Accumulation factor was calculated for the assessment of accumulation capacity of heavy metals by soil and different plant parts, i.e., roots, stems and leaves, which showed concentration dependent variables of heavy metal levels among vegetable crop plants. It was observed that high content of Cd was accumulated in roots of ***C. sativum*** (0.036), whereas Pb content in ***M. charantia*** (0.300), Co (0.709), Ni (1.242) and Cu (2.441) in ***L. esculentum*** and Zn in ***C. sativum*** (31.221) were registered. The greater concentration of Fe was achieved in roots of ***L. esculentum*** (826.09). Present results showed that Cd content was maximum in stems of ***C. sativum*** (0.040), Co in ***S. melongena*** (0.047), Pb in ***C. sativum*** (0.348), Ni in ***S. oleracea*** (0.787), Cu in ***C. sativum*** (1.017), Zn in ***S. melongena*** (9.803) and Fe in ***C. sativus*** (37.690). High content of Cd was encountered in leaves of ***R. sativum*** (0.015), whereas accumulation of Co content in ***M. piperata*** (0.049), Pb in ***M. charantia*** (0.266), Ni in ***C. soralioides*** (0.724), Cu in ***C. sativum*** (0.862), Zn in ***A. sepa*** (4.698) was observed. The highest content of Fe was recorded in ***S. oleracea*** leaves (43.07).

It was also observed that roots of ***C. indica*** have lowest content of Cd and Co, being 0.001 and 0.008 respectively, whereas Pb in ***L. esculentum*** (0.060), Cu in ***B. oleracea*** (0.063), Ni (0.065), Zn (0.736) and Fe in ***A. esculentus*** (2.610) were observed. Present findings revealed that stems of ***T. foenum-graceum*** contained lowest content of Co (0.001), Cd (0.002) in ***C. indica***, Pb in of ***L. esculentum*** (0.025), Cu in ***C. sativus*** (0.027), Ni in ***C. sativus*** (0.067), Zn in ***M. piperata*** (1.005) and Fe in ***R. sativum*** (6.32). Cd content was accumulated in a very low concentration in leaves of ***C. indica*** (0.001), Co in ***T. foenum-graceum*** (0.002), Pb in ***L. esculentum*** (0.014), Cu in ***S. oleracea*** (0.123), Ni in ***L. esculentum*** (0.128), and Zn and Fe in ***A. esculentus*** being 0.814 and 0.6.83 respectively. The concentration of heavy metals in vegetable crop plants grown with organic farming technique falls within the prescribed limit except Fe could be due to iron-rich nature of soil of the region (Nirmal Kumar et al. 2007). This may be due to the fact that Fe is more readily available than other metals in surface soil. Similar trend was observed by Bunzl et al. (2001) who have investigated soil to plant transfer ratio of heavy metals like Cu, Pb and Zn in vegetables grown in environmentally contaminated sites of Addis Ababa, Tanzania.

The accumulation factor in vegetable crop plants ranged from 0.51 to 5.76 (Cd), 0.03 to 2.48 (Co), 0.11 to 6.12 (Cu) and 0.02 to 2.24 (Fe), 0.23 to 2.34 (Ni), 0.30 to 3.08 (Pb) and 0.47 to 5.68 (Zn). Leafy vegetables like *Anthum graveolens*, *Coriandrum sativum*, *Trigonella foenum-graceum*, *Alium sativum*, *Mentha piperata*, *Alium sepa* and *Spinacia oleracea* were found with very high levels of Cd, Zn, Cu, Mn and Pb (Fig. 1). Similarly accumulation factors for Cd, Co and Pb metals were also found higher in plant parts compared with available level in soil. On the other hand, the concentration of Cu, Fe, Ni and Zn was lower in plant parts than the soil, which corroborated the observations of Prince et al. (2001). An indirect negative correlation between Pb and Zn levels in green leafy vegetables, viz. amaranth, Chinese cabbage, cowpea leaves, leafy cabbage and pumpkin, collected from several areas in Dar Es Salaam, Africa, was observed by Othman (2001), which is very well substantiated with the present findings.

Mobility Index: Mobility Index (MI) showed 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 exhibited that Level 1 (soil-roots) showed high mobility of Pb in *C. indica* (1.90), Co (5.45), Ni (5.60) and Fe (6.48) in *L. esculentum*, Cd in *S. oleracea* (9.20), Cu in *L. esculentum* (13.35) and Zn in *C. sativum* (14.17). In case of Level 2 (roots-stems), Co in *C. sativus* (1.40), Pb and Cd in *A. esculentus* being 3.232 and 3.794 respectively, Zn in *S. melongena* (3.93), Ni in *A. esculentus* (4.09), Cu in *B. oleracea* (5.52) and Fe in *A. esculentus* (6.85).

On the other hand, Fe content was found lowest in *R. sativum* (0.02), Co and Cu in *C. indica* and *A. esculentus* being 0.03 and 0.11 respectively, Ni in *C. indica* (0.23) Pb in *L. esculentum* (0.30), Zn in *M. piperata* (0.47), and Cd in *C. sativus* (0.51). The accumulation factor for different metals in vegetable crop plants ranged from 0.51 to 5.76 (Cd), 0.03 to 2.48 (Co), 0.11 to 6.12 (Cu) and 0.02 to 2.24 (Fe), while in case of Ni, concentration of heavy metal ranged from 0.23 to 2.34, Pb (0.30 to 3.08) and Zn (0.47 to 5.68). Among the metals, Zn showed maximum rate of mobility in different plant parts (1.46), followed by Cd (1.44), Cu (1.40), Ni (1.13), Pb (1.11) and Co and Fe with 1.065 and 0.884 respectively (Table 1, Figs. 2, 3).

Mobility index (MI) of metals at different levels varies among various plant parts. Mobility index was ranged from 0.009 to 0.370 in Level 1 (soil-roots), 0.022 to 0.420 in Level 2 (roots-stems) and 0.165 to 0.365 in Level 3 (stems-leaves). Similarly, metal transport mechanism was found significant in terms of mobility of a particular metal content from source to receiving level. High mobility index was observed at different levels, which is established by the fact that very low content of heavy metals is transported from roots to stems (Level 2), being only 0.149. Gradual increase in transport of metal content was observed in Level 1 (soil-roots) with 0.182, while highest content of metals is transported through Level 3 (stems-leaves) being 0.280.

Data on mobility index of various heavy metals from soil to leaves suggested that all the metals are mobile in soil with varied transfer rates. Comparing transfer potential of metals among various plant parts, these metals markedly exceeds in Level 3 (stems-leaves), followed by a gradual declining drift in Level 1 (soil-roots) and Level 2 (roots-stems). These results are significant and coinciding well with findings of Martin & Coughtrey (1975). Mobility index of heavy metals in various plant parts was found greater compared to available metal concentration in soil, which substantiated the findings of Breckle (1991). This proves that roots usually show higher heavy metal content than shoots, because they are absolutely origin and with direct contact with the soil.

Table 1 Accumulation factor and Mobility indices of heavy metals in vegetable crop plants colleted from Shivam Organic Farm, Valasan, Anand district, Gujarat, India

Sr. No.	Name of the Plant (mg L^{-1})	Cd*	Transport of Cd			AF	Co*	Transport of Co			AF	Cu*	Transport of Cu			AF	Fe*	Transport of Fe			AF	Ni*	Transport of Ni			AF	Pb*	Transport of Pb			AF	Zn*	Transport of Zn			AF
			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	
1	*Abelmoschus esculentus*	0.007	0.002	0.009	0.004	0.71	0.017	0.090	0.006	0.032	2.48	0.433	0.087	0.356	0.148	0.45	116.92	2.61	17.87	6.83	0.08	0.319	0.065	0.266	0.266	0.62	0.152	0.061	0.198	0.087	0.76	1.704	0.736	1.706	0.814	0.64
	MI		0.329	3.794	0.432			5.229	0.068	5.265			0.200	4.105	0.416			0.022	6.849	0.382			0.204	4.091	0.999			0.405	3.232	0.438			0.432	2.319	0.477	
2	*Alium sativum*	0.005	0.009	0.005	0.006	1.31	0.245	0.071	0.015	0.029	0.16	0.784	0.818	0.325	0.156	0.55	277.14	26.51	12.16	9.97	0.06	0.440	0.453	0.453	0.161	0.81	0.091	0.097	0.059	0.080	0.87	1.994	4.415	2.689	3.652	1.80
	MI		1.771	0.565	1.160			0.292	0.210	1.933			1.043	0.397	0.480			0.096	0.459	0.820			1.030	0.999	0.354			1.070	0.606	1.359			2.214	0.609	1.358	
3	*A. sepa*	0.005	0.005	0.009	0.005	1.24	0.164	0.086	0.039	0.031	0.32	0.394	0.525	0.326	0.455	1.10	179.86	18.03	18.72	12.25	0.09	0.241	0.410	0.291	0.234	1.29	0.100	0.100	0.105	0.068	0.91	2.293	11.823	2.271	4.698	2.73
	MI		0.920	1.957	0.556			0.526	0.452	0.801			1.331	0.621	1.395			0.100	1.038	0.654			1.703	0.710	0.804			1.000	1.050	0.648			5.156	0.192	2.069	
4	*Anthum graveolens*	0.007	0.010	0.008	0.008	1.16	0.264	0.040	0.016	0.008	0.08	1.026	0.590	0.389	0.446	0.46	323.05	28.88	12.02	7.19	0.05	0.633	0.466	0.283	0.271	0.54	0.133	0.157	0.081	0.137	0.94	2.831	2.912	1.406	2.217	0.77
	MI		1.393	0.746	1.009			0.150	0.404	0.519			0.575	0.659	1.149			0.089	0.416	0.598			0.736	0.607	0.958			1.186	0.518	1.676			1.029	0.483	1.576	
5	*Brassica oleracea*	0.005	0.007	0.009	0.005	1.41	0.410	0.024	0.014	0.013	0.04	0.985	0.063	0.347	0.137	0.18	556.01	4.90	17.06	7.32	0.02	0.604	0.646	0.264	0.303	0.67	0.087	0.087	0.083	0.057	0.87	1.817	3.792	2.069	1.954	1.43
	MI		1.424	1.264	0.556			0.059	0.576	0.929			0.064	5.517	0.395			0.009	3.481	0.429			1.071	0.409	1.148			1.000	0.954	0.687			2.087	0.546	0.944	
6	*B. oleracea var. botrytis*	0.005	0.009	0.009	0.006	1.70	0.336	0.094	0.019	0.007	0.12	1.588	0.517	0.337	0.275	0.24	303.95	70.33	10.21	12.80	0.10	0.647	0.469	0.339	0.140	0.49	0.113	0.112	0.131	0.121	0.72	3.512	2.595	3.563	1.506	0.73
	MI		2.031	0.920	0.641			0.280	0.198	0.365			0.326	0.651	0.816			0.231	0.145	1.254			0.725	0.722	0.412			0.990	1.176	0.922			0.739	1.373	0.423	
7	*Capsicum annum*	0.009	0.010	0.019	0.014	1.67	0.291	0.236	0.031	0.046	0.36	1.159	1.026	0.447	0.647	0.61	257.38	164.83	10.81	18.63	0.25	0.658	0.631	0.338	0.334	0.66	0.140	0.132	0.101	0.135	0.87	2.867	2.700	2.603	1.694	0.81
	MI		1.182	1.864	0.737			0.809	0.130	1.493			0.885	0.435	1.448			0.640	0.066	1.724			0.959	0.536	0.987			0.943	0.762	1.335			0.942	0.964	0.651	
8	*Coccinia indica*	0.003	0.001	0.002	0.001	0.53	0.308	0.008	0.010	0.013	0.03	1.051	0.094	0.055	0.206	0.11	352.26	28.55	27.77	28.55	0.08	0.446	0.103	0.067	0.139	0.23	0.028	0.096	0.096	0.064	3.08	2.089	4.161	2.168	2.109	1.35
	MI		0.365	2.011	0.672			0.026	1.210	1.342			0.089	0.587	3.749			0.081	0.973	1.028			0.231	0.646	2.082			3.466	1.000	0.667			1.992	0.521	0.973	
9	*Coriandrum sativum*	0.005	0.036	0.040	0.012	5.53	0.318	0.090	0.003	0.011	0.11	1.141	1.019	1.017	0.862	0.85	373.31	33.35	20.43	27.94	0.07	0.750	0.535	0.289	0.331	0.51	0.082	0.174	0.348	0.121	2.60	2.202	31.221	3.964	2.356	5.68
	MI		6.686	1.136	0.304			0.283	0.034	3.522			0.893	0.998	0.847			0.089	0.613	1.367			0.713	0.540	1.145			2.112	1.999	0.347			14.177	0.127	0.594	
10	*Cucumis sativus*	0.005	0.002	0.002	0.003	0.51	0.223	0.018	0.025	0.030	0.11	0.749	0.107	0.027	0.295	0.19	264.54	70.16	37.69	8.90	0.15	0.420	0.311	0.108	0.311	0.58	0.246	0.091	0.082	0.155	0.44	1.904	3.972	2.057	2.200	1.44
	MI		0.400	1.169	1.434			0.081	1.404	1.172			0.143	0.249	11.058			0.265	0.537	0.236			0.740	0.347	2.887			0.370	0.901	1.885			2.086	0.518	1.070	
11	*Cyamopsis soralioides*	0.008	0.017	0.002	0.007	1.13	0.442	0.036	0.015	0.028	0.06	0.938	0.567	0.124	0.596	0.46	267.78	26.62	18.99	10.22	0.07	0.563	0.505	0.256	0.724	0.88	0.213	0.150	0.065	0.164	0.59	3.208	2.334	1.106	4.691	0.84
	MI		2.152	0.144	2.960			0.082	0.414	1.840			0.604	0.219	4.814			0.099	0.713	0.538			0.896	0.507	2.835			0.703	0.437	2.516			0.727	0.474	4.242	
12	*Lagernaria vulgaris*	0.005	0.004	0.008	0.006	1.15	0.233	0.099	0.007	0.035	0.20	0.861	0.630	0.672	0.434	0.67	290.34	73.50	35.66	33.51	0.16	0.483	0.610	0.424	0.610	1.13	0.115	0.110	0.128	0.163	1.16	2.402	1.108	1.644	1.681	0.62
	MI		0.800	1.919	0.728			0.425	0.067	5.282			0.732	1.067	0.646			0.253	0.485	0.940			1.263	0.694	1.440			0.957	1.165	1.271			0.461	1.483	1.022	
13	*Luffa acutangula*	0.007	0.016	0.014	0.004	1.54	0.359	0.054	0.002	0.009	0.06	1.313	0.677	0.536	0.230	0.37	460.38	34.56	33.77	17.33	0.06	0.792	0.279	0.353	0.190	0.35	0.157	0.113	0.148	0.137	0.84	3.480	2.223	2.453	2.079	0.65
	MI		2.150	0.897	0.278			0.151	0.037	4.651			0.516	0.792	0.430			0.075	0.977	0.513			0.353	1.266	0.538			0.718	1.308	0.928			0.639	1.104	0.847	
14	*Lycopersicum esculentum*	0.004	0.006	0.006	0.006	1.42	0.130	0.709	0.019	0.013	1.90	0.183	2.441	0.368	0.549	6.12	127.55	826.09	18.34	11.27	2.24	0.222	1.242	0.188	0.128	2.34	0.110	0.060	0.025	0.014	0.30	3.102	4.567	2.742	3.660	1.18
	MI		1.350	1.105	0.952			5.453	0.027	0.654			13.350	0.151	1.494			6.476	0.022	0.614			5.599	0.152	0.678			0.541	0.420	0.568			1.472	0.600	1.335	

Table 1 continued…

Sr. No.	Name of the Plant (mg L^{-1})	Cd*	Transport of Cd S-R	R-S	S-L	AF	Co*	Transport of Co S-R	R-S	S-L	AF	Cu*	Transport of Cu S-R	R-S	S-L	AF	Fe*	Transport of Fe S-R	R-S	S-L	AF	Ni*	Transport of Ni S-R	R-S	S-L	AF	Pb*	Transport of Pb S-R	R-S	S-L	AF	Zn*	Transport of Zn S-R	R-S	S-L	AF
			L1	L2	L3			L1	L2	L3			L1	L2	L3			L1	L2	L3			L1	L2	L3			L1	L2	L3			L1	L2	L3	
15	*Mentha piperata*	0.009	0.008	0.006	0.005	0.73	0.371	0.073	0.007	0.049	0.12	1.381	0.266	0.240	0.365	0.21	301.63	54.40	29.68	34.65	0.13	0.754	0.295	0.183	0.266	0.33	0.117	0.121	0.062	0.072	0.73	3.417	1.888	1.005	1.975	0.47
	MI		0.880	0.830	0.777			0.197	0.093	7.133			0.192	0.903	1.523			0.180	0.546	1.167			0.392	0.621	1.452			1.033	0.511	1.170			0.553	0.532	1.966	
16	*Momordica charantia*	0.010	0.007	0.005	0.004	0.54	0.045	0.009	0.009	0.005	0.17	0.608	0.321	0.370	0.431	0.62	130.63	11.93	23.42	12.40	0.12	0.370	0.242	0.265	0.455	0.87	0.246	0.300	0.255	0.266	1.11	3.367	3.159	1.621	3.277	0.80
	MI		0.690	0.743	0.804			0.204	1.033	0.493			0.528	1.155	1.164			0.091	1.963	0.529			0.653	1.096	1.719			1.220	0.848	1.044			0.938	0.513	2.021	
17	*Raphanus sativum*	0.002	0.002	0.006	0.015	4.81	0.481	0.095	0.037	0.017	0.10	1.381	0.122	0.153	0.336	0.15	351.66	5.43	6.32	13.52	0.02	0.461	0.143	0.559	0.559	0.91	0.091	0.105	0.101	0.197	1.47	3.091	0.841	1.104	2.470	0.48
	MI		1.427	2.666	2.418			0.198	0.389	0.456			0.088	1.255	2.195			0.015	1.163	2.140			0.309	3.922	1.001			1.153	0.962	1.948			0.272	1.312	2.238	
18	*Solanum melongena*	0.009	0.015	0.005	0.005	0.95	0.312	0.106	0.047	0.035	0.20	0.885	1.119	0.384	0.505	0.76	415.71	36.54	7.53	16.63	0.05	0.688	0.492	0.195	0.609	0.63	0.078	0.164	0.125	0.121	1.74	1.883	2.494	9.803	2.102	2.55
	MI		1.739	0.316	1.008			0.340	0.444	0.741			1.264	0.343	1.317			0.088	0.206	2.209			0.715	0.397	3.117			2.092	0.762	0.969			1.324	3.931	0.214	
19	*Spinacia oleracea*	0.003	0.032	0.020	0.008	5.76	0.284	0.139	0.028	0.026	0.23	0.616	1.309	0.749	0.123	1.18	702.87	70.35	29.00	43.07	0.07	0.511	0.880	0.787	0.331	1.30	0.105	0.100	0.094	0.052	0.78	1.760	3.336	2.572	1.402	1.38
	MI		9.202	0.624	0.407			0.490	0.198	0.932			2.126	0.572	0.165			0.100	0.412	1.485			1.722	0.895	0.420			0.957	0.939	0.547			1.896	0.771	0.545	
20	*Trigonella foenum-graceum*	0.006	0.036	0.009	0.011	3.01	0.244	0.037	0.001	0.002	0.06	0.641	1.050	0.364	0.335	0.91	646.26	24.67	11.19	42.92	0.04	0.531	0.812	0.161	0.262	0.77	0.036	0.090	0.045	0.044	1.65	1.732	6.949	1.956	2.682	2.23
	MI		5.711	0.259	1.239			0.152	0.033	1.537			1.637	0.347	0.921			0.038	0.454	3.835			1.529	0.198	1.622			2.486	0.500	0.983			4.011	0.282	1.371	
	Mean	0.006	0.012	0.010	0.007	1.839	0.274	0.106	0.017	0.022	0.345	0.906	0.667	0.379	0.377	0.810	334.962	80.612	19.931	18.795	0.196	0.527	0.479	0.303	0.331	0.796	0.122	0.121	0.117	0.113	1.217	2.533	4.861	2.525	2.461	1.429
	MI		2.130	1.246	0.953	1.443		0.771	0.371	2.053	1.065		1.329	1.051	1.821	1.400		0.452	1.076	1.123	0.884		1.077	0.968	1.330	1.125		1.220	1.003	1.095	1.106		2.157	0.933	1.297	1.462

* 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 mg L^{-1}.

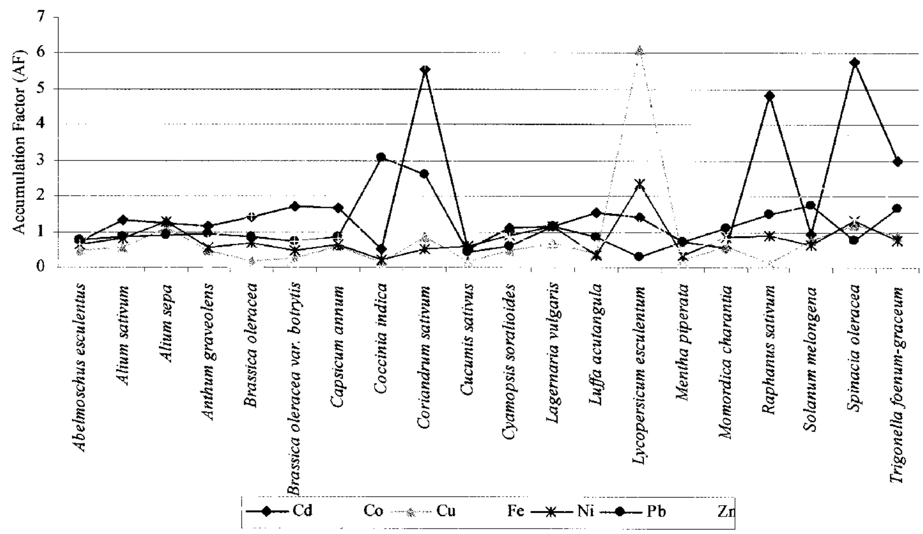

Fig. 1: Accumulation factor (AF) of heavy metals in studied vegetable crop plants.

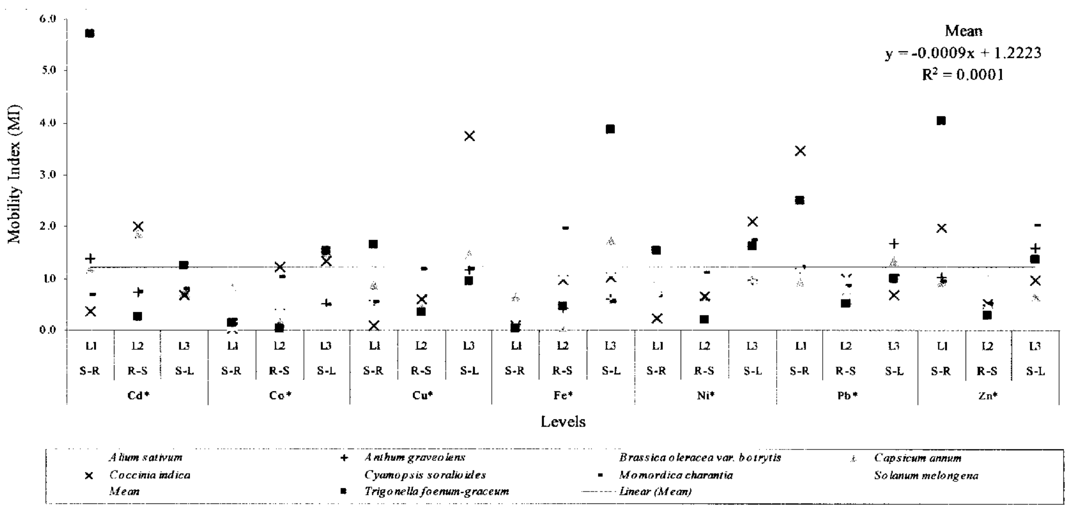

Fig. 2: Mobility index (MI) of heavy metals in different vegetable crop plants (I).

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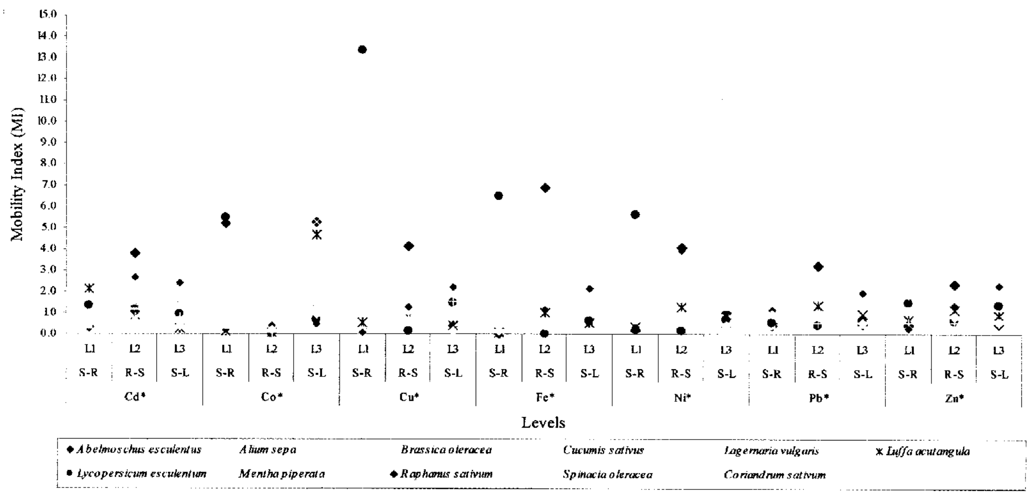

Fig. 3: Mobility index (MI) of heavy metals in different vegetable crop plants (II).

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