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Environmental Contamination and Toxicology

Crop Plants as Biological Tools for Assessing and Monitoring Agricultural Lands Inundated with Sewage and Sludge

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Several workers (Hyde et al. 1979; Adriano 1986) have reported that plants grown on soils amended with municipal sludge accumulate high concentration of heavy metals. The sludge borne potentially toxic elements are reported to enter the food chain through plant uptake (Chaney 1990). The extent of accumulation of an element largely depends on its solubility in the soil solution. The rate of release and the form of the soluble species also influence the rate and extent of accumulation as well as the mobility and toxicity of the heavy metals in the plants and in animals feeding on this (Banin et al. 1981). Sewage, sludge and effluents contain a wide range of plant nutrients and heavy metals and their application is based on the fertilization value (nitrogen and phosphorus) and on the concentration of trace elements present. The heavy metals, when enter the soil in excessive amounts depress the yield of plants and degrade the quality of food and fiber produced. Several workers have listed the concentration of micronutrients present in sludge or effluents (Page 1974) and based on these, application has been formulated (Miller et al. 1979) at many instances. Depending upon the available amount of heavy metals in soil solubility sequences and the plant species growing on these soils, the process of metal uptake and translocation by different plants can be explained (Kufka and Kuras 1997) but the information in this direction is scanty. The literature on the pattern and distribution of heavy metals, their uptake and translocation in plants from the sites of deposition in natural field receiving industrial effluents would be helpful in selecting suitable plant species that can be tried as accumulator plants to minimize the concentration of these metals in the highly polluted soils. At the same time it is also essential to know the status of both trace metals and heavy metals in such soils.

In the present investigation an attempt has been made to study the accumulation of micro and heavy metals, their uptake pattern, translocation in plants from the sites of deposition in the fields receiving industrial effluents and/or sewage sludge.

MATERIALS AND METHODS

Thirty two sites (about half kilometer from site to site) were selected to collect vegetables, cereals and oil crops growing on both sides of Kukrail drain adjacent to Lucknow city. Most of the tanneries discharge their treated and untreated waste

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effluents in this Nallah which is passing through the city. The drain water is also used for irrigation (Table.1) and cultivation of several field crop and vegetables. The effluents of the drain is being used for this purpose for last several years.

Four different plant species – wheat (*Triticum aestivum* L.), mustard (*Brassica campestris* L.), cabbage (*Brassica oleracea* L.), and cauliflower (*Brassica oleracea* L.) were collected from these sites. For each plant species, five plants were collected randomly and in three replicates. Both cauliflower and cabbage were 40 days old whereas wheat and mustard were 95 days old. The plants were collected, sampled, properly washed with 0.01 N HCl and rinsed several times with glass distilled water, separated into roots, stem and leaves and were dried in an oven at 70°C for 48 hours. To make samples homogeneous for chemical analysis were pulverized in blender. After wet digestion with nitric- perchloric acids (10 : 1) (Piper 1942) the concentration of micro and pollutant nutrients were analysed in these samples by Atomic Absorption Spectrophotometer (Thermo Jerrel 121).

Soil (with an average depth of 20 cm randomly) and water samples were also collected from the same site on which the test plants were growing. Soil samples were mixed thoroughly, dried in air and processed for chemical analysis. Soil and water samples were analysed for pH by pH meter, electrical conductivity, by conductivity meter, organic carbon, (Jackson 1979) and calcium carbonate (Piper 1942).

Soil samples were drawn for DTPA extractable, micro and pollutant elements (Lindsay and Norvell 1978) and latter were determined by Atomic Absorption Spectrophotometer.

RESULTS AND DISCUSSION

In sewage effluent irrigated soils, variations ranging from 0.29 to 0.64 dSm^{-1}, 0.68 to 1.50 in $CaCO_3$, 7.1 to 7.5 in pH and 0.92 to 1.92% organic matter content, were recorded respectively (Table 2).

The DTPA extractable Fe, Mn, Cu and Zn varied in soils from different sites and ranged from 46-155, 17.2-31, 3.32-4.87 and 30-55 mg/kg soil respectively (Table 3) whereas that of Ni, Co, Cr and Cd were 1.19-5.21, 9.45-10.59, 0.301-0.385 and 0.042-0.050 mg/kg soil respectively. These results are somewhat similar to those observed by (Adriano 1986).

Out of the four crops tried – wheat, mustard, cabbage and cauliflower the concentration of all essential micronutrients (Fe, Mn, Cu and Zn) as well as heavy metals (Ni, Co, Cr, Cd) varied (Figure 1.) and also the pattern of accumulation of all these metals was different as far as plant parts are concerned. As has been suggested that the ratio between metal concentration in plant parts and soil (Table 3) is an important criterion for selecting plant species for phytoremediation of soils contaminated with high levels of heavy metals. Except Co, ratio of all other

metals (Table 4) are more than 80% in all the four plant species and in descending order are as follows :
Fe (100%) = Mn (100%) = Cu (100%) = Cr (100%) = Cd (100%) > Zn (92%) > Ni (83%) > Co (83%).

The ratio of Co is low (83%) in all four plant species. Almost all plant samples showed a ratio 1 (Ratio 1 means higher concentration in plant parts than soil). Therefore plant uptake ratio of 1 might identify accumulator plant, which can be used for detoxification of phytoremediation of metals from soils. Further biological monitoring of heavy metals, might be helpful for explaining translocation pattern of each metal from roots to other parts of a plant species.

The translocation process in plant species might depend on certain crucial factors responsible for determining the distribution pattern of metals in different plant tissues (Xiong 1998). On comparing the translocation percentage of heavy metals from root to other parts of plant (Table 5), it is found that the translocation percentage 100 or more in various samples is as follows in descending order :

Root to stem : Cu (2) > Fe (1)
Root to leaves : Zn (4) > Cd (3) > Mn (3) > Co (2) > Cr (2) > Cu (1)

The total iron concentration is more than 1000 ppm in cauliflower and hence is in toxic range as 500 or more (ppm) iron has been suggested to be excess (Adriano 1986) which might depend on several factors. The accumulation of iron in cauliflower was much higher than the toxic limits reported earlier (Ottow et al. 1982).

Except cauliflower, the concentration of Mn is high in leaves of rest of the plants and comparatively low in stem suggesting better translocation to the leaves. The total concentration of Mn in wheat was more than 300 ppm whereas in leaves of wheat it was highest among all plant parts and might be in the toxic range (NAS 1973).

The distribution of translocated copper to aerial parts is almost equal in leaves and stem of all plants tried. The total content of Cu in cabbage and cauliflower appears to be near adequate values whereas in wheat and mustard the values are more than 10 ppm, near toxic limits (Gupta 1979). In wheat, the total Cu content was more than 50 ppm and can be suggested as toxic value as has been observed in pea (Adriano 1986). The available soil Cu ranged from 3.32-4.87 mg/kg soil of the fields where these plants were growing and is considered to be more than adequate for normal growth (Adriano 1986) of plants, might be due to soil pH as solubility and availability of Cu to plants is dependent on soil pH.

The total zinc content in all four plants is much higher and almost in toxic range (33 to 105 ppm). The translocation of zinc is more in leaves than in stem of all plants tried. The toxic tissue concentration of zinc in different plant species varies from 50-180-700 ppm and in certain instances it is very high also (Adriano 1986).

The total nickel content in all four plants and that is present in leaves and other parts of the plants are some what below the toxic levels reported for other plant species. The nickel content in roots of all four plants was more than 5 ppm where the accumulation was high and is somewhat similar to that observed by several workers earlier (Adriano 1986; Cottenic et al. 1979). The translocation of nickel is not very rapid as the tops : roots ratio is not very high in any plant species. The available nickel from different fields ranged between 1.19-5.21 mg/kg soil and appears to be towards higher range i.e. more than critical limits of adequacy.

Similar to other heavy metals, the maximum concentration of Co was in roots of all four plants, highest being in mustard and least being in cauliflower. In contrast to the reports of Kafka and Kuras (1997) on cereals and cabbage, in wheat, the accumulation of Co was rather high and in cabbage it was low, in the latter the translocation of Co was low and therefore the top : roots ratio was lowest. More than 20 ppm Co, in tissues has been suggested to be toxic for plants (Adriano 1986; Hunter and Vergnano 1952) as has been observed in the total content of Co in mustard but in leaves of all four plants its content is below toxic levels.

In all plant species the concentration of Cr was highest in roots indicating poor translocation to upper parts (Huffman and Allaway 1973b). The accumulation of Cr content in different parts of plants show higher iron content as has been observed by Adriano1986. In certain parts of four plants, the content of Cr is more than 5 ppm and hence the values may indicate toxic concentration of the metal, although the soil Cr was much below 5 ppm and might not be in the toxic limits.

Out of the plants tried, in wheat the total amount of Cd is less than that reported (Bingham et al. 1975) earlier. Higher accumulation of iron, manganese, zinc and cobalt may show antagonistic relationship between these nutrients and cadmium in all four plants. The pattern of mobility and distribution of Cd in different plant parts also varied in all the four plants tried. In the leaves of cabbage and cauliflower the Cd concentration is less than that reported by Bingham et al. (1975) and Adriano (1986), but is more than that permissible for human consumption.

These observations and data on soil content of heavy metals might suggest that at present the situation is not so alarming at these sites but the accumulation of certain heavy metals in wheat and cauliflower specially could become beyond human consumption level if the discharge of sewage sludge effluent is continued. The average/ normal concentration of Cd is 0.05 μg/g and that of nickel is 250 μg/g dry matter respectively (Adriano 1986).

Wheat out of four plant species can to some extent tolerate the excess limits of heavy metals from contaminated soil and therefore can be treated as an accumulator plant.

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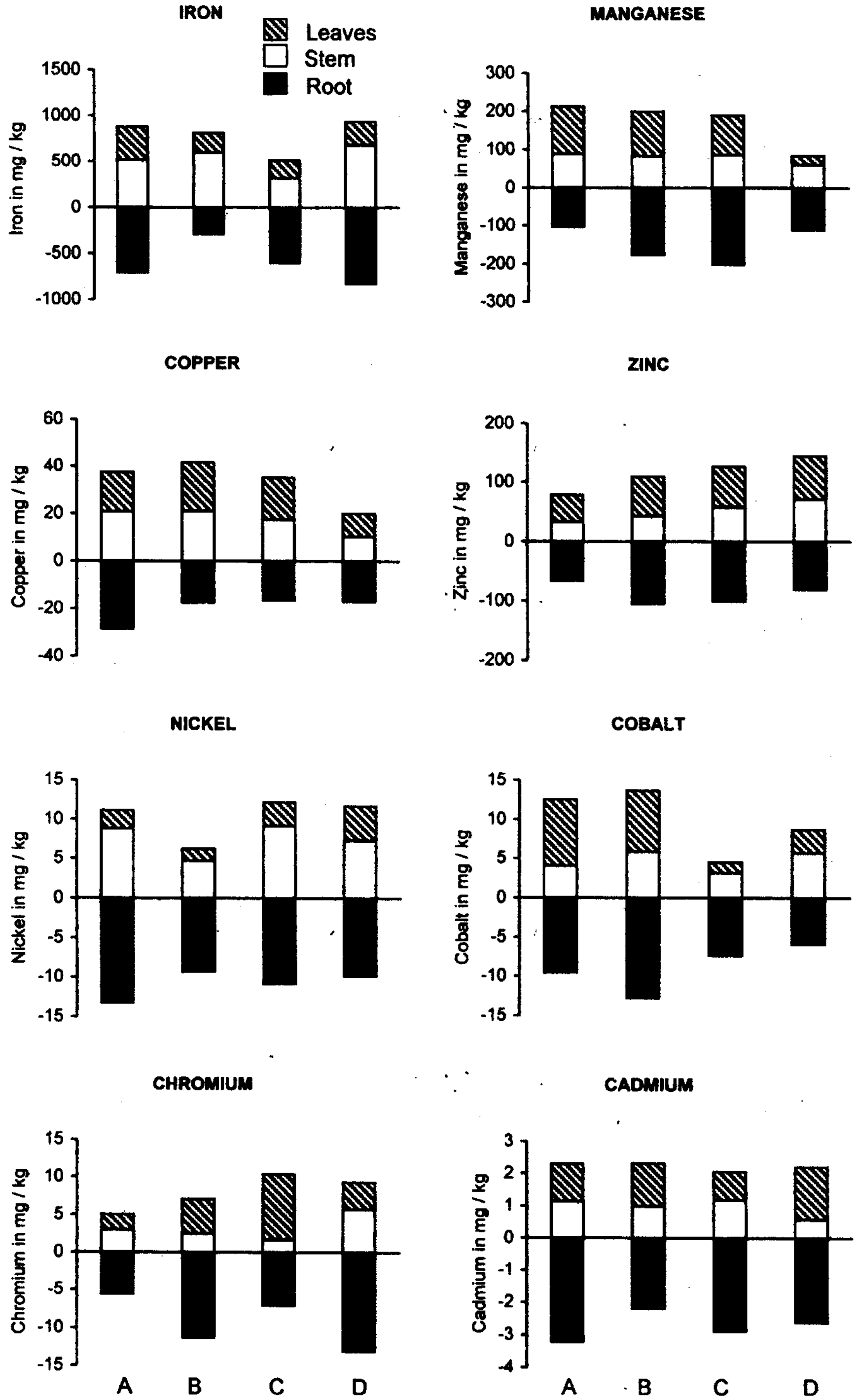

Figure 1. Concentration of micronutrients and pollutant elements in field at Lucknow. A =Wheat; B = Mustard; C = Cabbage; D = Cauliflower.

Table 1. Some of the quality parameters of irrigated water collected from district Lucknow.

Sample	Location	Temp.°C	Colour	pH	EC dSm^{-1}	Total solids (mg/l)	Hard -ness	Acidity (mg/l)
8	Kukrail	30	Blackish	7.6	0.50	591	305	114

Table 2. Some physico-chemical parameters in field near Kukrail Nallah, district Lucknow.

	Locations (mean of 4 locations)			
Parameters	Wheat field	Mustard field	Cabbage field	Cauliflower field
EC_2 (dSm^{-1})	0.64	0.53	0.44	0.29
$CaCo_3$ (%)	1.19	1.50	0.68	0.73
Organic matter (%)	1.92	1.24	1.22	0.92
PH	7.5	7.2	7.1	7.5

Mean of four soil samples

Table 3. Average concentration of heavy metals in different plant species and soil.

Name of plant/ field	Average concentration of metals							
	Fe	Mn	Cu	Zn	Ni	Co	Cr	Cd
	μg/g dry matter							
Wheat	529	105	22.0	48.3	8.12	7.34	3.55	1.83
Mustard	374	125	19.7	71.5	5.17	8.80	6.14	1.50
Cabbage	370	130	17.3	75.9	7.65	3.95	5.81	1.65
Cauliflower	584	65	12.4	75.3	7.18	4.87	7.47	1.61
	mg/kg soil							
Wheat	155	17.2	3.94	35	3.16	10.15	0.323	0.050
Mustard	117	20.2	4.69	30	1.19	10.59	0.301	0.048
Cabbage	67	31.0	3.32	42	1.84	9.80	0.385	0.050
Cauliflower	46	20.5	4.87	55	5.21	9.45	0.353	0.042

Mean of three samples

Table 4. Heavy metal ratio between plant parts and soil.

Plant Part	Fe	Mn	Cu	Zn	Ni	Co	Cr	Cd
				Wheat				
Leaves	2.35	7.30	4.24	1.30	0.74	0.83	6.63	23.0
Stem	3.33	5.06	5.25	0.94	2.78	0.40	9.16	22.8
Root	4.57	6.05	7.23	1.90	4.19	0.94	17.5	64.2
				Mustard				
Leaves	2.06	5.80	4.41	2.22	1.29	0.13	28.8	27.5
Stem	5.09	4.06	4.48	1.43	3.93	0.29	5.61	20.6
Root	2.44	8.71	3.73	3.50	7.82	1.20	23.49	45.8
				Cabbage				
Leaves	2.83	3.35	5.33	1.64	1.63	0.14	22.54	17.4
Stem	4.76	2.74	5.27	1.38	4.97	0.32	4.39	23.6
Root	8.96	6.48	5.0	2.42	5.89	0.75	18.36	57.8
				Cauliflower				
Leaves	5.50	1.22	2.01	1.34	0.84	0.32	10.14	38.57
Stem	14.74	2.88	2.09	1.29	1.39	0.60	16.28	14.05
Root	17.87	5.37	3.51	1.47	1.89	0.63	37.08	62.14

Table 5. Translocation index (%) of metals in stem and leaves from roots of different plant species.

Plant Part	Fe	Mn	Cu	Zn	Ni	Co	Cr	Cd
				Wheat				
Leaves	71	144	81	138	26	211	72	101
Stem	73	84	73	50	87	42	52	36
				Mustard				
Leaves	40	143	99	155	33	1332	190	133
Stem	208	47	120	41	50	46	22	45
				Cabbage				
Leaves	60	122	101	119	33	45	514	30
Stem	51	42	105	57	84	43	24	41
				Cauliflower				
Leaves	37	43	96	104	60	52	62	275
Stem	82	54	60	88	74	96	44	23

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