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Distribution of Heavy Metals in Wheat, Mustard, and Weed Grown in Field Irrigated with Industrial Effluents

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In recent years, research has been focused on accumulation of heavy metals in crop plants and naturally growing weeds. As most studies are based on the work done in laboratory conditions, information is scanty on status of heavy metals in soils and standing plants receiving industrial effluents (Beckett and Davis 1977; Jarvis 1978; Miles and Parker 1979; Singh and Mishra 1987; Ray and Barman 1988; Ray *et al.* 1988; Ray and Saha 1988; Ray 1990; Szymczak *et al.* 1993; Barman 1994; Barman and Lal 1994; Sharma and Sharma 1997; Kaer *et al. 1998).*

The process of metal uptake and accumulation by different plants depend on the concentration of available metals in soils, solubility sequences and the plant species growing on these soils (Chaney 1973; Andersson 1977c; Pahlsson 1989; Kufka and Kuras 1997).

Information 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 for selection of suitable plant species that can be used as accumulator plant to minimize the concentration of these metals in the highly polluted soils (Barman and Bhargava 1997; Barman *et al. 1999).*

In the present investigation, an attempt has been made to study the distribution pattern of Fe, Cu, Zn, Ni, Cr, Pb and Cd contents in different parts of IO plant species grown in agricultural fields that are inundated by mixed industrial effluents.

MATERIALS AND METHODS

A large number of tanneries and other industries are located in the adjacent area of Unnao, Uttar Pradesh, India. Most of the industries discharge their treated and untreated waste effluent into a natural drain, which is known as loamy drain. The loamy drain water is being used for irrigation and cultivation of economically important crops and vegetables.

Ten different plant species were collected from these fields. For each species five plants were collected randomly at the maturity stage. The plant samples were thoroughly washed and dried at 70 ° C for 48 hours, ground and mixed for metal analysis. Five composite soil samples were collected with an average depth of 20 cm randomly from the areas on which the test plants were growing. The five soil samples were mixed thoroughly, dried in air and sieved for analysis.

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Both plant and soil samples (1 gm weight equivalent of each) were digested in concentrated nitric acid and perchloric acid (5:1) till a clear solution was obtained (Barman and Lal 1994). The solution was filtered, reconstituted to the desired volume and analysed by Varian Spectr A A-250 Plus. Fe was estimated at $\lambda_{248.3}$, slit 0.2 nm, Optimum working range of detection (OWRD) in μg/ml is 0.06-O. 15; Cu was estimated at $\lambda_{324.7}$ slit 0.5 nm, OWRD is 0.03-10 μg/ml; Zn was estimated at $\lambda_{213.9}$, slit 1 nm, OWRD is 0.1-2.0 μg/ml; Ni was estimated at λ_{232}, slit 0.2 nm, OWRD is 0.1-20 μg/ml; Cr was estimated at $\lambda_{357.9}$, slit 0.2 nm, OWRD is 0.06- 5 μg/ml; Pb was estimated at λ_{217}, slit 1 nm, OWRD is 0.1-30 μg/ml and Cd was estimated at $\lambda_{228.8}$, slit 0.5 nm, OWRD is 0.02-3 μg/ml.

RESULTS AND DISCUSSION

Accumulation of metals in root from soil and subsequent translocation to other parts of plant like stem, leaves and fruits is important for the selection of plant specially crops and vegetables. Plant accumulating least quantity of metals in the edible parts, with the concentration within the permissible limit then the variety or species can be selected for the cultivation on the field having high level of metal contamination (Barman and Bhargava (1997).

In contrast, plants accumulating high concentration of heavy metals from contaminated soil, can be used for detoxification/ phytoremediation of metals from soil or growing medium. Therefore, to identify the hyper accumulator plants we have estimated the concentration of heavy metals in IO different plant species in fields irrigated with mixed industrial effluents. The concentration of heavy metals in the different plant parts is presented in Table 1.

The accumulation of heavy metal from soil to plant parts did not follow any particular pattern and varied with respect to metals, species and plant parts.

The metal content in the cultivated soil irrigated with contaminated water was found to be either below or within the usual typical background values as suggested by Bowen (1966) except for Cd, Pb and Ni [Table 2].

The different heavy metal levels in plant grown on unpolluted soil are Fe = 140, Cu =4-15,Zn=8-100,Ni=1,Cr=0.2-10,Pb=0.1-10,Cd=0.2-0.8 μg/g dry weight as suggested by Allaway (1968). Interestingly the concentrations of heavy metals in almost all the plant species growing on polluted soil are higher than the plants grown on unpolluted soils (Table 2).

The ratio of metals between soil and plant parts is an important criterion for the selection of plant species for phytoremediation of soils contaminated with high level of heavy metals. We observed (Table 3) that out of 32 plant samples analysed, the percentage of sample showing metal accumulation ratio (soil to other parts of plant) $\geq$1 is as follows in descending order :

Fe (84.0%)>Cu (81.3%)>Ni (59.3%)>Cr (46.9%)>Zn (31.3%)>Pb (17.4%)>Cd(9.4%).

Ratio >1, means higher accumulation/concentration in the plant parts than soil. Therefore, plant uptake ratio >1 can be considered as an accumulator plant and can be used for detoxification or phytoremediation of metals from soil or growing medium.

Table 1. Concentration of metals in different parts of plant

PLANTs	Concentration of metals in μg/g d.w.						
	Fe	Cu	Zn	Ni	Cr	Pb	Cd
Dichanthium annulatum	R > S > L (500) (290) (275)	R > S > L (272.5)(92.5)(82.5)	L > S ≃ R (29.1) (25)(24.8)	R > L > S (74.5)(26.3)(15.8)	R > L > S (94) (54) (37.3)	L > R > S (66.3)(62.5)(27.5)	R ≃ S > L 0.75)(0.75) (0.5)
Acacia aburinea	S > R > L (693.8)(656.3)(585)	R > S > L (43.8)(30.5)(21.5)	R ≃ S > L (24.3) (24) (19)	S > R ≃ L (8.8) (7.0)(7.0)	R > S > L (11.5)(9.5)(9.3)	R > L > S (14.5)(13.8)(11.8)	S > R ≃ L (0.75)(0.5)(0.5)
Rumex dentatus	R > S > L (217.5)(187.5)(130)	R > S > L (31)> (28.3) (21.5)	R > S > L (79.3) (76.3) (74.3)	R > L > S (7.8)(6.3)(4.8)	S > L > R (57.0)(53.8)(45.5)	S > L > R (58.0)(26.3)>(22.3)	S > L > R (1.25)(1.0)(0.8)
Alternenthera sessilis	L > S > R (2120.4)(1240)(1031.3)	R ≃ L ≃ S (36.5)(35.5)(35.3)	R ≃ S > L (77.8)(77.5)(22.5)	R > L > S (16) (15.3) (12.5)	R > S > L (749.3)(730.0)(708.3)	R > S > L (20.5)(17.2)>(14.5)	R ≃ S ≃ L (1.3)(1.3)(1.3)
Cynodon dactylon	L > R > S (1150.4)(1109.4)(950.1)	L > R > S (37)(34.5)(27.9)	R > L > S (90) (85) (72.5)	R > S > L (20.8)(19.8)(17.3)	L > S > R (740.0)(725.0)(710.2)	R > L > S (73.3)(52.6)(20.0)	R > S ≃ L (1.5)(1.0)(1.0)
Polygonam lonigerum	R > S > L (572.5)(562.5)(447.5)	R > S > L (38.8)(19.4)(15.8)	S > L > R (40) (35) (30)	R > S > L (6.0)(5.5)(3.3)	R > S > L (56.8)>(38.0)>(28.5)	----	----
Ipomea fistulosa	L > R > S (120.0) (78.0) (65.0)	R > S > L (50.5)(24.3)(22.5)	L > R > S (25)(20.5)(12.5)	S > L > R (4.8) (4.0) (2.0)	L > R > S (16.0)(13.4)(9.0)	----	----
Vallisnaria spiralis	R > S > L (562.5) (400) (230)	S > L > R (16.8) (14.0)(13.0)	R > L > S (20.0)(15.0) (10.0)	R > L ≃ S (6.0)>(5.5)(5.5)	S > R > L (35.0)(33.8)(26.0)	---	-----
Triticum aestivum	R > L > S > G (344.8)(132)(112.2)(93.6)	L > R ≃ G > S (7.0) (5.6) (5.6) (4.0)	G > R > S > L (28)(21.4)(19.4)(18.2)	R > L > S > G (16.8)(5.4)(4.8)(4.2)	R > L > S > G (50.1)(10.7)(10.5)(8.0)	R > L > S > G (17.0)(14.8)(11.6)(9.2)	R ≃ L ≃ G > S (1.0)(1.0)(0.8)(1.0)
Brassica campestrie	L > R > G > S (558)(435.6)(343.8)(236.2)	R > L > G > S (12.4)(7.8)(5.6)(4.6)	R > L > G > S (61.2) (49.4)(28)(26.2)	R > G > L > S (7.8) (4.8) (4.4) (4.0)	L > G > R > S (55.2)(30.3)(20.7)(10.6)	L > S > G > R (21.8)(18.2)(14.6)(14.4)	L > S > G ≃ R (2.0)(1.4)(1.2)(1.2)

R= Root, S= Steam, L=Leaves and G= Gain , Respective values are within ( )

Table 2. Average Concentration of Heavy Metals in the Different Plant Species and Soil.

Name of plant	Average concentration of metals in μg/g dry weight						
	Fe	Cu	Zn	Ni	Cr	Pb	Cd
Dichanthium annulatum	371.70 ± 154.6	149.2 ± 106.9	26.29 ± 2.4	38.83 ± 31.3	61.75 ± 29.2	52.08 ±21.4	0.67 ±0.1
Acacia aburinea	645.00 ± 55.2	31.91 ± 11.2	22.41 ± 2.9	7.58 ± 1.0	10.08 ± 1.23	13.33 ± 1.4	0.58 ± 0.1
Rumex dentatus	178.33 ± 44.5	26.92 ± 4.9	76.54 ± 2.5	6.25 ± 1.5	52.08 ± 5.28	35.5 ± 19.6	1.0 ± 0.25
Alternanthya sessilis	1463.92 ± 578.1	35.75 ± 0.7	59.27 ± 0.7	14.58 ± 1.8	729.17 ± 20.5	17.38 ± 3.0	1.25 ± 0.1
Cyanodon dactylon	1069.94 ± 105.8	33.47 ± 4.9	82.5 ± 9.0	19.25 ± 1.8	725.06 ± 14.9	48.66 ± 26.9	1.16 ± 0.3
Polygonum lonigerum	527.5 ± 69.5	15.75 ± 12.4	35.0 ± 5.0	4.91 ± 1.5	41.08 ± 14.3	-----	1.50 ± 0.3
Ipomea fistulosa	87.66 ± 28.8	32.41 ± 15.7	19.33 ± 6.2	3.58 ± 1.4	12.92 ± 3.57	-----	0.75 ± 0.4
Vallisnaria spiralis	397.50 ± 166.3	14.58 ± 1.9	15.0 ± 5.0	5.66 ± 0.7	31.58 ± 4.88	-----	0.66 ± 0.1
Triticum aestivum	170.65 ± 117.2	5.55 ± 1.2	21.75 ± 4.4	7.8 ± 6.02	19.83 ± 3.4	13.15 ± 3.4	0.95 ± 0.1
Brassica campestries	393.4 ± 136.9	7.60 ± 3.5	41.2 ±16.9	5.25 ± 1.7	29.2 ± 3.50	17.25 ± 3.5	1.45 ± 0.4
Soil	128.0	7.60	64.0	5.80	42.2	36.0	2.4
Background con.(soil)*	38000	20	50	40	100	10	0.06

*Bowen (1966) : Typical background concentration in soil.

Furthermore, establishing the pattern of translocation of metals from root to other parts of a plant species can help in biological monitoring of heavy metal contamination.

The crucial factors in determining the metal distribution in different plant tissues may be in the metal translocation process in plant species (Xiong 1998). A number of mechanisms, including anatomical, biochemical and physiological (Salt *et al.* **1995)** can be involved in heavy metal accumulation and distribution in the above ground parts of plants in the case of soil contamination (Xiong 1998).

On comparing the translocation percentage of the heavy metals from root to other parts of plant (Table 4), it is found that the translocation percentage 100 or more in number of samples is follows in descending order :

Root to stem : Cd (8) > Pb (4) ≃ Cr (4) > Cu (2) ≃ Zn(2) > Fe (1) ≃ Ni (1)
Root to leaves : Cd (7) > Fe (4) > Zn (3) > Cu (2) > Ni (1) ≃ Pb (1)

Table 3. Heavy Metal Ratio between Soil and other Plant Parts

Name of Plant	Plant Parts	Metals						
		Fe	Cu	Zn	Ni	Cr	Pb	Cd
Dichanthium annulatum	Leaves Stem Root	2.15 2.66 4.97	10.85 12.17 35.85	0.45 0.38 0.39	4.53 2.72 12.84	1.28 0.88 2.23	1.84 0.76 1.74	0.21 0.31 0.31
Acacia aburinea	Leaves Stem Root	4.57 5.42 5.13	2.83 4.01 5.76	0.39 0.38 0.37	1.21 1.51 1.21	0.27 0.23 0.22	0.38 0.33 0.40	0.21 0.31 0.21
Rumex dentatus	Leaves Stem Root	1.02 1.46 1.64	2.83 3.72 4.08	1.16 1.19 1.23	1.08 0.82 1.34	1.27 1.35 1.08	0.62 0.73 1.61	0.42 0.52 0.31
Alternanthera sessilis	Leaves Stem Root	16.56 9.69 8.06	4.67 4.64 4.80	0.31 1.22 1.21	2.63 2.15 2.76	17.30 16.78 17.75	0.41 0.48 0.57	1.0 1.0 1.0
Cyanodon dactylon	Leaves Stem Root	8.99 7.42 8.67	3.67 4.37 4.54	1.13 1.11 1.40	2.97 3.41 3.58	17.54 17.18 16.83	1.46 0.55 2.03	0.42 0.42 0.63
Polygonum lonigerum	Leaves Stem Root	4.47 4.39 4.47	5.10 2.53 5.10	1.47 0.63 1.47	1.03 0.95 1.03	1.34 0.90 1.34	----- ----- -----	0.65 0.73 0.63
Ipomea fistulosa	Leaves Stem Root	0.94 0.52 0.31	2.96 3.19 6.64	0.19 0.11 0.31	0.69 0.82 0.34	0.38 0.21 0.33	----- ----- -----	0.42 0.42 0.25
Vallisnaria spiralis	Leaves Stem Root	1.80 3.13 4.39	1.84 2.20 1.71	0.23 0.15 0.31	0.95 0.95 1.03	0.62 0.83 0.80	----- ----- -----	0.75 0.31 0.21
Triticum aestivum	Grain Leaves Stem Root	0.73 1.03 0.88 2.69	0.74 0.92 0.53 0.74	0.44 0.28 0.30 0.13	0.72 0.93 0.83 2.89	0.19 0.25 0.25 1.19	0.25 0.41 0.32 0.47	0.42 0.42 0.33 0.42
Brassica campestries	Mustard Leaves Stem Root	2.68 4.36 1.84 3.40	0.74 1.03 0.61 1.63	0.44 0.77 0.41 0.96	0.83 0.76 0.69 1.34	0.25 1.31 0.49 0.72	0.41 0.40 0.51 0.61	0.50 0.83 0.58 0.50

Although the accumulation of metals was high, the growth of plants was not affected significantly. Comparatively, high accumulation of metals especially Fe and Cr was found in *Alternanthera sessilis* and *Cynodon dactylon* than other species. Both the plant species can be considered as hyper accumulator species (Table 2).

The concentration of metals especially Cd, Pb, Cr and Ni are much higher in wheat and mustard and may exceed the average normal concentration reported by others and are beyond human consumption level. This may create health problems in the long run. The average normal concentration of Cd is 0.05 μg/g (Elinder 1988), Pb is 0.01 to 1.0 μg/g (Warren and Delavault 1962), Cr and Ni are 60 and 250 μg/day respectively (WHO 1994).

Table 4. Percentage of Heavy Metal Translocation from Root to other Plant Parts

Name of plant	Plant Parts	Metals						
		Fe	Cu	Zn	Ni	Cr	Pb	Cd
Dichanthium annulatum	Leaves	52.73	30.28	116.48	35.23	57.44	106.00	66.67
	Stem	50.00	33.94	99.00	21.14	39.63	44.00	100.00
Acacia aburinea	Leaves	89.14	49.14	78.35	100.00	124.32	94.82	100.00
	Stem	97.49	69.71	98.97	125.00	102.70	81.34	150.00
Rumex dentatus	Leaves	59.91	69.35	96.69	80.64	118.13	38.36	133.33
	Stem	86.21	91.13	96.05	61.29	125.27	45.26	106.67
Alternanthya sessilis	Leaves	205.66	97.26	29.03	97.80	97.43	70.73	100.00
	Stem	120.28	96.57	100.39	78.13	94.53	83.66	100.00
Cyanodon dactylon	Leaves	103.70	80.87	94.44	83.13	104.19	72.01	66.67
	Stem	85.67	108.80	80.56	95.18	102.08	27.30	66.67
Polygonum lonigerum	Leaves	78.17	40.64	116.67	54.16	50.22	-------	83.33
	Stem	98.25	49.68	133.33	91.67	66.93	-------	116.67
Ipomea fistulosa	Leaves	153.85	44.55	121.95	200.00	116.36	-------	400.00
	Stem	83.33	48.01	60.98	237.50	65.45	-------	400.00
Vallisnaria spiralis	Leaves	40.89	107.69	75.00	91.67	77.04	-------	150.00
	Stem	71.11	128.85	50.00	91.67	103.70	-------	150.00
Triticum aestivum	Grain	27.15	100.00	130.85	25.00	15.97	54.12	100.00
	Leaves	38.28	125.00	85.05	32.14	21.96	87.06	100.00
	Stem	32.54	71.43	90.65	28.57	20.96	68.23	80.00
Brassica campestries	Grain	78.93	45.16	45.75	61.15	34.98	66.97	100.00
	Leaves	128.10	62.90	80.72	56.41	182.18	66.06	166.67
	Stem	54.22	37.09	42.81	51.28	68.32	83.49	116.67

The pattern of accumulation or uptake of these metals is heterogeneous and as a result might create a big problem for the selection of suitable species/varieties either for cultivation or revegetation. Variable concentration of these metals in the parts of different plant species may be an important criterion for their selection as accumulator plants as they tolerate high concentration of heavy metals.

In the present investigation, we screened 10 different species and found *Alternanthera sessilis* and *Cynodon dactylon* as hyper accumulator of heavy metals from contaminated soil. We therefore suggest the usage of these two plants species for phytoremediation. These plants can be grown on polluted soil and subsequently uprooted/disposed and used as a raw material for commercial extraction of heavy metals. Alternatively these plant species can be used for farmyard manure for use in alkaline soil.

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