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Uptake of cadmium by rice crop in sewage irrigated soil

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ABSTRACT

The results of green house experiment indicated that the yield of root, shoot and total dry matter of rice increased from 0.18 to 0.23 g pot^{-1}, from 1.49 to 1.87 g pot^{-1} and from 1.67 to 2.09 g pot^{-1}, respectively with increasing levels of Cd-FA (fulvic acid). The dry matter yields, concentrations and uptake of Cd by rice were significantly and positively correlated with organic carbon and DTPA-extractable Cd in soil. Root density and root length of rice exhibited positive and significant correlation with organic carbon, CEC, EC and negative correlation with clay content of the soil. On the other hand, root radius and half distance between roots showed significant and negative correlation with these parameters. DTPA-extractable Cd increased with increasing levels of Cd-FA application in soils. A regression model developed was found to predict the uptake of Cd on the basis of root parameters (root radius, root length, root density, half distance between roots) and diffusion coefficient of Cd in soils with almost 95 % level of confidence.

Key words: *Sewage water, regression model, cadmium, root parameters*

INTRODUCTION

The implications associated with heavy metal contamination are of great significance, particularly in agricultural production system. Rapid increase in human population and expanding industry and urbanization has not only used a large area of world productive lands, but is also generating a large volume of sewage water every day. In India, estimate revealed that 73,000 hectares were irrigated with sewage water during early nineties and presently the area under sewage water irrigation is on the rise (Strauss and Blumenthal, 1990). Many small to medium scale industries operating in peri-urban residential areas of Patna, Bihar are disposing their contaminated effluents directly in sewage system. Nutrients and water being the most critical input in agriculture, harvesting the nutrients and irrigation potential of sewage water are of prime importance for maximizing the food, fodder and fuel production. Even, the conservative estimates on the basis of 70 % of the sewage available from large cities, shows that these effluents have the potential for irrigating (7.5 cm) about 21 thousand hectares of land on daily basis or alternately about 7.8 million ha on annual basis (Minhas and Samra, 2004).

Land application of sewage sludge is one of methods for disposal of wastes while recycling of nutrients contained in sewage sludge. However, one constraint with this approach is possible contamination of the human and animal food chain with toxic substances such as heavy metals when food crops are grown on sewage water irrigated soils. Use of sewage sludge as a source of nutrients and irrigation water increased load of heavy metal, on soils and may pose phytotoxicity and human hazards. Regulation of safe agricultural use of sewage sludge and effluents aims at development of some predictive models on the basis of soil and crop properties that can be used for prediction of transfer of sewage sludge borne Cd into food and feed chain. This can be achieved by estimating their eventual effects on plant growth and uptake of metal cations by crops grown on such soils.

MATERIALS AND METHODS

Ten bulk surface soil samples (0-15 cm) of old alluvium soil of Patna (Vertisols) which has been receiving sewage effluents for more than hundred years were collected for this study (Table 1). Physico-chemical properties of these soils are given in Table 2. A modified procedure of Kononova (1966) was followed for fractionation of fulvic acid from sewage sludge. Stock solutions of Cd-fulvate were prepared by mixing 2 x 10^{-2} M cadmium sulphate with 2 x 10^{-2} M fulvic acid. Now stock solution of Cd-fulvate becomes 1 x 10^{-2} M strength due to double dilution.

A pot experiment was conducted in plastic pots in green house. Four kg of ten processed soils were filled in each pot in three replications. To each pot, 60 mg N/ kg soil, 40 mg/ P_2O_5 kg and 40 mg/ K_2O kg soil in the form of urea, KH_2PO_4 and KCl solutions, respectively were added. Fertilizers in solution form were thoroughly mixed with soil. The treatments include Cd-fulvate @ 0, 5 and 10 mg Cd kg^{-1} soil. The pre-sowing irrigation was also given. The treatments were replicated thrice. Three healthy seeds of rice were sown in each pot at proper moisture condition. After establishment of seedlings plants were thinned to one per pot. For irrigation in pots, deionised water was used as and when required. The plants with roots intact as far as possible were removed from pots after span of 55 days growth of crop. Crop was separated from soil by tap water. The soil was diluted and plant was separated out from soil. Root and shoot portions were separated and washed thoroughly in acidified water and then in distilled water. Then the washed samples were first dried in air then in oven at 65^0C. The air dried root and shoot samples of plant were weighed and ground in stainless steel grinder. The whole root and shoot portions and root samples were taken separately and were digested with 10 ml tri-acid mixture of HNO_3: $HClO_4$ H_2SO_4 in 10 : 3 : 1 (Jackson, 1973). The acid was dissolved in double distilled water and after filtration (Whatman filter paper No. 42) final volume made to 50 ml and total Cd in root and shoots were determined from these digests of root and shoot with atomic absorption spectrophotometer (Perkin Elmer A Analyst 200). The uptake of Cd by rice was computed from weight of root and shoot and concentration of Cd in plant.

The root density (Lv) is equal to the length per unit volume of soil. The value of Lv is readily determined for roots without root hairs or mycorrigae, but their presence of the geometry of nutrients absorbing system were more difficult to describe quantitively. Lv = root length (cm)/volume of the soil (cm^3). The root length was computed by the equation $I = V/r^2$ where V = volume of root and r = radius of roots. The half distance between the root (rh) was determined by Taylor and

Table 1. Location of soil samples used.

Sl. No.	Site No.	Locations of Sites	Details of soil samples sites
1.	S_1	Near to discharge point, south of Patna bye-pass, north of the Nala.	Lands are plain and vegetable crops (lady finger, cauliflower, potatoes, onion, cabbage, toria, maize, rice) are grown in area of soil sampling. In rainy season, soils are submerged and vegetable crops are generally grown in rabi season when soils are not submerged. Small industry units and domestic effluents both from Patna town and Patna city are producing sewage sludge and sewage water which are disposed/used on agricultural land for irrigation and organic manure.
2.	S_2	East of first Advertisement Board, south of Patna bye-pass, south of the Nala.	
3.	S_3	Half km, west of Ranipur-Pajwa towards west south of Nala.	
4.	S_4	Besides the village Ranipur-Pajwa towards west, south of the Nala.	
5.	S_5	Half km east of village, south of the Nala.	
6.	S_6	Nearer to the village Begampur-Sati Chaura, west of tube well, south of the Nala.	
7.	S_7	WEST of Footpath bridge, north of the Nala.	
8.	S_8	Beneath the Advertisement Board south of the Nala.	
9.	S_9	Half km South from Karmalichak village, west of the Nala.	
10.	S_{10}	A.R.I., Patna farm (ground water irrigated soil).	

Note : S_1 to S_9 sewage water irrigated soils.

Table 2. Physical and chemical properties of soils used for various studies.

Soils	pH	Ec (dS/m)	Organic carbon (%)	C.E.C [cm (P+) kg^{-1}]	DTPA extractable Cd (mg kg^{-1})	Sand (%)	Silt (%)	Clay (%)	Textural class
S_1	7.74	1.85	3.02	24.36	0.298	54.98	33.45	10.96	Silty loam
S_2	7.86	1.80	2.33	21.53	0.254	56.02	34.20	9.15	Silty loam
S_3	7.58	1.67	1.14	20.67	0.098	53.48	29.75	16.04	Silty clay loam
S_4	7.76	1.72	1.28	20.84	0.128	45.30	39.25	14.86	Silty clay loam
S_5	7.35	1.75	0.92	18.15	0.046	36.52	50.05	12.10	Silty clay loam
S_6	7.28	1.70	0.86	17.32	0.040	34.78	44.50	19.25	Silty loam
S_7	7.66	1.75	1.16	18.35	0.065	52.01	32.40	14.58	Silty clay loam
S_8	7.24	1.65	0.98	15.08	0.038	39.18	39.25	20.00	Silty loam
S_9	6.92	1.58	0.84	12.73	0.028	25.75	50.50	23.84	Silty loam
S_{10}	6.85	1.45	0.58	8.75	0.026	22.55	52.20	24.30	Silty clay loam

Klepper (1978) using by the equation $r_h = (4LV)^{-1/2}$. The values of root radius was computed considering primary, secondary and tertiary roots by simple microscope and finally the average values of radius was taken as root radius. Statistical analysis was done according to methods outlined by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Dry matter yield

The dry matter yield of rice crop grown in pots with ten soils having received sewage sludge effluents over a period of more than 100 years with or without treatments of Cd-fulvate are presented in Table 3. The root, shoot and total dry matter yield harvested in pots with ten different soils varied from 0.12 to 0.27 g, 0.75 to 2.44 g and 0.92 to 2.69 g pot^{-1}, respectively. The dry matter production significantly differed in different soils. This may be attributed to variation in soil properties like organic carbon content, clay content and nutrients status. The root, shoot and total dry mater yield increased significantly from 0.18 to 0.23, from 1.49 to 1.87 and 1.67 to 2.09 g pot^{-1}, respectively with increasing levels of Cd-FA application from 0 to 10 mg kg^{-1}. This indicated that the level of applied Cd is in a safe range where Cd toxicity is not observed. The increase in dry matter production due to application of Cd-FA may be due to fulvic acid as Cd being non-essential to plants may not influence the crop growth. It may also be inferred that continued application of sewage sludge

Table 3. Dry matter of rice (g pot^{-1}) grown on sludge treated soil with and without application of Cd-FA complex.

Levels	Root weight				Shoot weight				Total dry matter			
soils	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean
S_1	0.21	0.24	0.25	0.23	2.05	2.32	2.44	2.27	2.26	2.54	2.69	2.50
S_2	0.19	0.21	0.22	0.21	1.75	1.88	2.12	1.92	1.94	2.09	2.34	2.12
S_3	0.20	0.23	0.22	0.22	1.93	1.99	2.12	2.01	2.13	2.22	2.34	2.23
S_4	0.20	0.25	0.23	0.23	1.46	1.65	1.94	1.68	1.66	1.90	2.17	1.91
S_5	0.17	0.19	0.23	0.20	1.27	1.52	1.77	1.52	1.44	1.71	2.00	1.72
S_6	0.15	0.18	0.20	0.18	1.06	1.35	1.47	1.29	1.21	1.53	1.67	1.47
S_7	0.17	0.20	0.23	0.20	1.38	1.50	1.77	1.55	1.57	1.70	2.00	1.76
S_8	0.21	0.22	0.27	0.23	1.60	1.68	1.92	1.73	1.81	1.90	2.19	1.96
S_9	0.19	0.20	0.22	0.20	1.62	1.63	1.95	1.73	1.81	1.83	2.17	1.93
S_{10}	0.12	0.17	0.20	0.16	0.75	0.96	1.20	0.97	0.92	1.13	1.40	0.86
Mean	0.18	0.21	0.23		1.49	1.65	1.87		1.67	1.85	2.09	
		SEm ±	CD (0.05)			SEm ±	CD (0.05)			SEm ±	CD (0.05)	
Soil		0.006	0.018			0.025	0.071			0.025	0.072	
Level		0.010	0.035			0.013	0.039			0.014	0.042	
Soil x level		0.011	0.031			0.044	0.124			0.040	0.121	

Table 4. Concentration of cadmium (mg kg^{-1}) in plant parts grown on sewage sludge treated soil with and without application of Cd-FA complex.

Levels soils	Root				Shoot				Whole plant			
	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean
S_1	18.53	21.08	24.71	21.44	0.66	0.73	0.77	0.72	2.29	2.67	2.94	2.63
S_2	16.44	20.27	22.44	19.72	0.58	0.64	0.65	0.62	2.14	2.60	2.65	2.46
S_3	13.37	16.46	19.36	16.40	0.52	0.56	0.60	0.56	1.70	2.20	2.49	2.13
S_4	15.02	17.77	19.87	17.55	0.56	0.61	0.63	0.60	2.34	3.04	2.57	2.65
S_5	12.35	15.42	16.47	14.75	0.48	0.54	0.57	0.53	1.85	2.20	2.23	2.09
S_6	9.94	13.22	13.64	12.27	0.44	0.49	0.53	0.49	1.62	1.98	2.11	1.90
S_7	14.43	16.51	18.93	16.62	0.47	0.49	0.52	0.49	2.33	2.38	2.63	2.45
S_8	12.40	12.68	16.72	13.92	0.42	0.46	0.49	0.46	1.65	1.89	2.37	1.97
S_9	10.64	12.41	15.51	12.85	0.39	0.42	0.43	0.40	1.51	1.72	1.96	1.73
S_{10}	8.50	10.01	13.01	10.51	0.47	0.49	0.49	0.48	1.49	1.89	2.25	1.88
Mean	13.16	15.58	18.07		0.50	0.54	0.57		2.36	2.26	2.42	
		SEm ±	CD (0.05)		SEm ±		CD (0.05)			SEm ±	CD (0.05)	
Soil		0.593	1.665		0.015		0.042			0.296	0.832	
Level		0.325	0.912		0.008		0.023			0.162	0.456	
Soil x Level		1.027	2.884		0.026		0.073			0.513	1.440	

having less than 0.1 mg kg^{-1} Cd over a period of more than 100 years may not significantly reduce the yields of crop. The organically complexed Cd was applied to soils to simulate a condition of sewage sludge application over a period of years. The effect of soils, levels of Cd and their interaction were statistically significant on dry matter yields.

Concentration

The contents of Cd in roots, shoot and whole plant as influenced by the nature of soils and application of Cd-FA are presented in Table 4. The Cd concentration varied from 8.50 to 24.71 mg kg^{-1} (av. 15.6 mg/ kg), 0.39 to 0.77 mg kg^{-1} (av. 0.48 mg/ kg) and 1.49 to 3.04 mg kg^{-1} (av. 2.18 mg kg^{-1}) in root, shoot and whole plant, respectively. The application of Cd-FA in soils resulted in significant increase in Cd concentration in plants but increase was more pronounced in the roots than in shoots. Such increase may be due to its low translocation inside the plant from root to shoot (Chatterjee and Dube, 2005; Patra and Das, 2006; Rattan et al.,2005). The observed concentration of Cd in plants was found to be well within the range reported in literature for normal crops (Sommers, 1985). The concentration of Cd in rice exhibited positive and highly significant correlation with organic carbon (r = 0.730*), CEC (r = 0.735*), pH (r = 0.907**) and EC (r = 0.746*) and negative and significantly correlation with clay (r = -0.83**). This indicated that soil properties and available Cd influenced Cd content in plant.

Uptake

The mean Cd uptake increased from 2.43 to 4.08 µg pot^{-1} by root, 0.75 to 1.08 µg pot^{1} by shoot and 3.22 to 5.11 µg pot^{1} by whole plant with increasing level of Cd (Table 5). The uptake of Cd by rice ranged from 1.74 to 4.96 µg pot^{1} in root, from 0.47 to 1.63 µg pot^{1} in shoot and from 2.21 to 6.64 µg pot^{1} in whole plant, in different soils. The utilization of sewage-sludge increased the yield and uptake of Cd by crops as reported by Ramulu, 1994; Behbahaninia and Mirbagheri, 2008; Yadav et al., 2013; Mehmandoost et al., 2015; Balkhair and Ashraf, 2016; Rahimi et al., 2017;). The effect of soils, levels of Cd and their interaction on uptake of Cd by crop were statistically significant. The uptake of Cd by crop was significantly correlated with pH (r = 0.848**), EC (r = 0.802**), organic carbon (r = 0.892**), CEC (r = 0.892**), DTPA-Cd (r = 0.884**), clay (r = 0.777**) and concentration, (r = 0.978**).

Root parameters of rice

The data on root radius, root density and half distance between roots of rice grown on sludge treated soils are presented in Table 6. The mean root radius varied from 0.022 cm to 0.024 cm due to increase in levels of Cd from 0 to 10 mg kg^{-1}. Different soils influenced root radius significantly and ranged from 0.018 to 0.027 cm

Table 5. Uptake of cadmium by rice (µg pot-1) grown on sewage sludge treated soil with and without application of Cd-FA complex.

Levels soils	Root				Shoot				Total dry matter			
	0 mg kg-1	5 mg kg-1	10 mg kg-1	Mean	0 mg kg-1	5 mg kg-1	10 mg kg-1	Mean	0 mg kg-1	5 mg kg-1	10 mg kg-1	Mean
S_1	3.83	5.09	5.97	4.96	1.35	1.69	1.87	1.63	5.18	3.79	7.96	6.64
S_2	3.15	4.24	4.83	4.07	1.01	1.20	1.38	1.20	4.16	5.44	6.21	5.27
S_3	2.67	3.79	4.21	3.56	0.99	1.10	1.27	1.12	3.63	4.89	5.53	4.68
S_4	3.07	4.47	4.53	4.02	0.82	1.01	1.21	1.01	3.89	5.77	5.57	5.08
S_5	2.09	2.94	3.70	2.91	0.60	0.82	1.00	0.81	2.67	3.76	4.46	3.63
S_6	1.49	2.37	2.73	2.20	0.47	0.65	0.78	0.63	1.97	3.03	3.52	2.84
S_7	2.44	3.30	4.33	3.36	0.64	0.73	0.98	0.78	3.66	4.04	5.26	4.32
S_8	2.56	2.82	4.51	3.30	0.66	0.78	0.94	0.79	2.98	3.59	5.20	3.92
S_9	2.10	2.42	3.43	2.65	0.63	0.69	0.83	0.71	2.73	3.12	4.25	3.69
S_{10}	0.94	1.69	2.58	1.74	0.35	0.47	0.58	0.47	1.37	2.13	3.15	2.21
Mean	2.43	3.31	4.08		0.75	0.91	1.08		3.22	4.26	5.11	
		SEm ±	CD (0.05)			SEm ±	CD (0.05)			SEm ±	CD (0.05)	
Soil		0.170	0.478			0.032	0.089			0.161	0.453	
Level		0.093	0.262			0.017	0.049			0.088	0.248	
Soil x Level		0.295	0.828			0.055	0.156			0.279	0.785	

in different soils. Mean root density varied from 2.361 to 2.479 cm m^{-3} soil with increasing levels of Cd applied to soils whereas, among soils, the mean root density ranged from 1.086 to 4.407 cm m^{-3} soil. The effects of levels of Cd and soils and their interaction on root radius, root density and distance between roots were statistically significant (Bahmanyar, 2008; Salakinkop and Hunshal, 2014).

The root density exhibited a positive and significant correlation with organic carbon (r = 0.900**), CEC (r = 0.917**), pH (r = 0.859**), EC (r = 0.859**), Cd uptake (r = 0.883**) and dry matter yield (r = 0.734*) and negative and significant correlation with clay (r = -0.917**). Root length also showed positive and significant correlation with pH (r = 0.907**), EC (r = 0.791**), organic carbon (r = 0.831**), CEC (r = 0.867**), Cd uptake (r = 0.954**) and dry matter yield (r = 0.819**) and negative and significant correlation with clay (r = 0.845**). The root radius and half distance between roots were negatively and highly significantly correlated with pH (r = -0.865**, -0.527**), EC (r = -0.874**, -0.947**), organic carbon (r = -0.704**, -0.949**), CEC (r = 0.906**, -0.986**), Cd uptake (r = -0.769**, -0.756*) and dry matter yield (r = -0.685*, -0.921**) and positively and significantly correlated with clay (r = 0.781*, 0.844**), respectively (Table 7). These results are in line with finding of Singh and Pandeya (1998) and Mullins et al. (1986). These results suggested that soil properties also affected root length, root radius, root density and half distance between roots and similarly these plant parameters influenced crop yield and Cd uptake by rice significantly. The dry matter yield of rice was positively and significantly correlated with root length (r = 0.819**) and root density (r = 0.734*) whereas root radius and half distance between roots influenced dry matter yield adversely. The dry matter yield of crop was found to have significant and positive correlation with organic carbon content (r = 0.845**), DTPA extractable Cd (r = 0.820**) and clay (r = 0.895**). Significant and positive correlation between dry matter yields and organic carbon content indicated that humic substances in soils helped in producing higher dry matter yield probably by providing complexation of insoluble nutrients in soils and making them in readily available form and balanced nutrients. The contribution of organic matter in influencing crop yield by providing all essential nutrients in balanced and suitable forms to plant was well documented (Prasad 1989). The positive and highly significant correlation of organic carbon (r = 0.845**), clay (r = 0.895**) and DTPA-extractable Cd (r = 0.820**) with dry matter yield emphasised that organic carbon and DTPA-Cd play important role in predicting dry matter yield of rice.

DTPA extractable cadmium

The data on DTPA extractable Cd in sewage sludge

Table 6. Determination of different root parameters in soils with and without application of Cd-FA complex.

Levels soils	Root radius (cm) (ro)				Half distance between roots (cm) (rh)				Root density (cm/cm^3 soil) (LV)			
	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean
S_1	0.016	0.019	0.020	0.018	0.229	0.237	0.249	0.238	4.754	4.434	4.034	4.407
S_2	0.018	0.021	0.022	0.020	0.286	0.276	0.286	0.282	3.054	3.287	3.061	3.134
S_3	0.018	0.020	0.022	0.020	0.303	0.315	0.295	0.304	2.773	2.520	2.871	3.040
S_4	0.020	0.022	0.024	0.022	0.307	0.299	0.302	0.302	2.648	2.795	2.751	2.731
S_5	0.022	0.023	0.025	0.023	0.335	0.287	0.289	0.303	2.225	3.032	2.987	2.748
S_6	0.019	0.021	0.022	0.021	0.354	0.378	0.327	0.353	1.992	1.755	2.332	2.026
S_7	0.017	0.019	0.020	0.019	0.326	0.346	0.319	0.330	2.353	2.098	2.461	2.304
S_8	0.022	0.024	0.025	0.024	0.396	0.395	0.389	0.393	1.596	1.610	1.654	1.620
S_9	0.024	0.025	0.027	0.025	0.448	0.421	0.416	0.428	1.248	1.406	1.443	1.365
S_{10}	0.025	0.026	0.029	0.027	0.510	0.480	0.456	0.482	0.968	1.088	1.203	1.086
Mean	0.020	0.022	0.024		0.325	0.326	0.318		2.361	2.402	2.479	
		SEm ±	CD (0.05)			SEm ±	CD (0.05)			SEm ±	CD (0.05)	
Soil		0.001	0.003			0.007	0.021			0.060	0.170	
Level		0.001	0.003			0.004	0.011			0.033	0.093	
Soil x level		0.002	0.004			0.012	0.035			0.105	0.296	

treated soils after the harvest of rice are presented in Table 8. The DTPA extractable Cd increased from 0.069 to 0.109 mg kg^{-1} with increasing level of Cd-FA from 0 to 10 mg kg^{-1} soil. DTPA-extractable Cd varied from 0.012 to 0.308 mg kg^{-1} in different treatments. Similarly average DTPA extractable Cd ranged form 0.021 to 0.259 mg kg^{-1} in different soils. Available Cd extracted by DTPA decreased from the initial DTPA extractable Cd indicating depletion of Cd after the harvest of rice. Rice acted as good sink for depletion of DTPA extractable Cd. The effects of levels of Cd and soils and their interaction on DTPA-extractable Cd were statistically significant(Behbahaninia and Mirbagheri, 2008; He et al., 2017; Chaoua et al., 2018).

Table 7. Correlation coefficients of root parameters with soil properties in Cd-FA complex treated soils.

Soil and plant parameters	Root length (cm)	Root radius (cm)	Root density (cm/cm^3 soil) (Lv)	Half distance between roots (cm) (rh)
pH	0.907**	-0.865**	0.859**	-0.527*
EC	-0.971**	-0.874**	0.859**	-0.947**
Organic carbon	0.831**	-0.704*	0.900**	-0.949**
CEC	0.867**	-0.906**	0.917**	-0.968**
Clay	-0.845**	0.781**	-0.917**	0.844**
Uptake	0.954**	-0.769**	0.883**	-0.756**
Yield	0.819**	-0.685*	0.734*	-0.921**

Regression model to predict Cd uptake

The multiple regression equation to predict the uptake of Cd by crop as dependent variables (Y) as a function of independent variables like root radius (X_1), root density (X_2), half distance between roots (X_3), root length (X_4) and diffusion coefficient (X_5) was developed for rice as given below :

$$Y = 0.759 - 416.617X_1 (-0.917) + 0.650X_2 (0.556) + 12.114X_3 (1.439) + 0.421X_4 (1.066) + 1215.681X_5 (0.018)$$

$$(R^2 = 0.949^{**}, \text{Adj}, R^2 = 0.885)$$

The values in parentheses indicated standard regression coefficients.

This prediction model indicated the relative contribution of different root parameters and diffusion coefficient on uptake of Cd by plant. It was further observed from the regression model that the combined contribution of root radius, root density, half distance between roots, root length and diffusion coefficient is 95% to Cd uptake by rice. The standard regression coefficients values suggested that half distance between roots, root length, root density and porous self-diffusion-coefficient played dominant role in predicting Cd uptake by rice with highest contribution of half distance between roots. These results are in line with the finding of Singh and Pandeya (1998) and Tudoreanu and Phillips (2004). The root parameters and diffusion coefficient of Cd-fulvate in soil were able to predict

Table 8. DTPA extractable Cadmium (mg kg^{-1}) in post harvest soil of rice in sludge treated soil with and without application of cadmium complex.

Levels Soils	0 mg kg^{-1}	5 mg kg^{-1}	10 mg kg^{-1}	Mean
S_1	0.202	0.267	0.308	0.259
S_2	0.163	0.219	0.261	0.214
S_3	0.076	0.084	0.106	0.088
S_4	0.085	0.102	0.135	0.107
S_5	0.037	0.039	0.052	0.042
S_6	0.028	0.030	0.048	0.035
S_7	0.041	0.049	0.072	0.054
S_8	0.027	0.032	0.043	0.034
S_9	0.017	0.022	0.033	0.024
S_{10}	0.012	0.020	0.031	0.021
Mean	0.069	0.086	0.109	
	SEm ±	CD (0.05)		
Soil	0.002	0.005		
Level	0.001	0.003		
Soil x level	0.003	0.009		

rate of Cd uptake by crop with high levels of confidence (Singh and Pandeya 1998).

CONCLUSION

The dry matter production due to application of Cd-FA may be due to fulvic acid as Cd being non essential to plant and not influence crop growth. Soil properties also affected root length, root density and half distance between root and similarly these plant parameters influenced crop yield and Cd uptake by rice significantly. The prediction model indicated that combined contribution of root radius, root density, half distance between roots, root length and diffusion coefficient is 95% to the Cd uptake by rice.

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