Soil & Environ. 25(2): 70-77, 2006

Cadmium and lead uptake by rice (*Oryza sativa* L.) grown in three different textured soils

M.G. Kibria[1*], K.T. Osman[1] and M. J. Ahmed[2]
[1]Department of Soil Science, University of Chittagong, Chittagong 4331, Bangladesh.
[2]Department of Chemistry, University of Chittagong, Chittagong-4331, Bangladesh.

Abstract

Rice (Oryza sativa L.) was grown in earthen pots containing soils of three different textures (clay loam, sandy clay loam and sandy loam) and treated separately with different levels of cadmium (0, 1, 3, 5, 7, 9 mgkg^{-1}) and lead (0, 10, 20, 30, 40, 50 mgkg^{-1}). Grain yield, shoot and root dry weights decreased by 18-28, 17-35 and 27-54 %, respectively at the highest Cd treatment and 16-34, 9-24 and 28-43 %, respectively at the highest Pb treatment as compared to the control. The Cd and Pb application affected grain yield significantly except for Pb in sandy clay loam soil. The concentration of Cd in grain significantly increased at 7, 1, 1 mg Cd kg^{-1} soil treatment from the control in clay loam, sandy clay loam and sandy loam soil, respectively. Treatments at 10, 20 and 50 mg Pb kg^{-1}soil caused significantly higher Pb concentration in grain in sandy loam, sandy clay loam and clay loam soil, respectively as compared to the control. In general, Cd and Pb contents in shoot and root increased with increasing Cd and Pb treatments, respectively in all the three soils. Among the soils, accumulation of Cd and Pb in rice followed the order: sandy loam > sandy clay loam > clay loam soil. Cd and Pb concentration in plant parts were highly correlated with Cd and Pb application in soils respectively.

Keywords: Rice, Cadmium (Cd), Lead (Pb), concentration, grain, shoot.

Introduction

In recent years there has been increasing awareness and concern over heavy metal contamination of soils and the effects this may be having on the food chain. The uptake of toxic heavy metals from contaminated soils by food and forage plants comprises a prominent path for such elements to enter the food chain and finally be ingested by humans. Cadmium and lead are ubiquitous and potentially hazardous contaminants in the biosphere (Zaman and Zereen, 1998). Phosphatic fertilizers are widely regarded as being the most ubiquitous source of Cd contamination of agricultural soils (Alloway, 1995). Other sources include farmyard manure, sewage sludges, metal working industries, waste incinerators, urban traffic, atmospheric deposition, cement factories etc (Sanita and Gabbrielli, 1999). Cadimum is readily taken up by plant roots and translocated to above ground tissues (Yang *et al*., 1998), and then poses a potential threat to human health as it enters the food chain (Obata and Umebayashi, 1997). People will suffer from renal tubular disease if they consume rice with relatively high Cd content (Watanabe *et al*., 1998). It appears that the major hazard to man is by ingestion of foodstuffs contaminated by excessive Cd, as in the classic example of "itai-itai" disease in Japan (Yamagata and Shigematsu, 1970). Therefore, addition of toxic heavy metals into soil and transfer of these metals into the food chain have been a matter of concern to people (Grant *et al.*, 1998). Lead (Pb) is a serious cumulative body poison (De. 1996). Acute Pb poisoning in human causes severe damage in the kidneys, liver, brain, reproductive system, and central nervous system and sometimes causes death (Ahmed and Mamun, 2001). The well recognized sources of Pb in soil include vehicle exhausts, mining and smelting activities, sewage sludge and manures in agriculture (Alloway, 1995). Korcak and Fanning (1985) found a positive relationship between the concentration of Pb in the soil and that in the plant.

Some enrichment of Cu, Cd and Pb in soil, river water and vegetables of Bangladesh were observed in a study by Khan (2001). Several industries in Chittagong and other parts of the country produce and dispose a huge amount of wastes and effluents to the environment that may become contaminated with heavy metals. In this background, the present study was conducted to investigate the uptake of Cd and Pb and their effect on growth of rice in soils of Chittagong region, Bangladesh.

* E-mail: kibriactgu@gmail.com

Materials and methods

Pot experiment

Three different textured soils; clay loam, sandy clay loam and sandy loam were collected from (1) agricultural field near new Science Faculty of Chittagong University, (2) agricultural field near Shahid Minar of Chittagong University, and (3) Syed Para at Hathazari Upazilla under Chittagong district from a depth of 0-15 cm, respectively. Soil samples were air dried and ground to pass through a 2 mm sieve to separate dry roots, grasses and other particulate materials. A portion of the soils passed through 2 mm sieve was retained for laboratory analyses. Soil chemical analyses were done by standard methods (Day, 1965; Jackson, 1973). Characteristics of the soils are presented in Table 1.

Table1. Characteristics of the soils used in pot experiment

Properties	Clay Loam Soil	Sandy Clay Loam Soil	Sandy Loam Soil
Sand (%)	30	57	63
Silt (%)	38	22	20
Clay (%)	32	23	17
pH (1:2.5 H_2O)	5.4	5.5	5.1
Organic carbon (%)	0.97	0.83	0.61
CEC (cmolkg^{-1}soil)	7.86	6.93	6.43
Total N (%)	0.15	0.09	0.04
Total P (%)	0.023	0.029	0.020
Total K (%)	0.36	0.24	0.26
Total Cd (µg g^{-1})	0.07	bdl*	bdl*
Total Pb (µg g^{-1})	11.2	7.8	9.6
Total Zn (µg g^{-1})	108.7	58.96	55.02
Total Fe (%)	1.574	0.736	1.472
Total Mn (µg g^{-1})	185.06	190.20	86.90

*bdl = below detection limit

Earthen pots were filled with soil @ 8 kg pot. Different levels of Cd (0, 1, 3, 5, 7 and 9 mg kg^{-1} soil) and Pb (0, 10, 20, 30, 40, and 50 mg kg^{-1} soil) were applied in separate pots in solution form as Cd $(SO_4)_2.8H_2O$ and Pb $(NO_3)_2$, respectively. Each treatment was replicated thrice and the pots were arranged in randomized block design. Nitrogen (in Urea), P (in Triple super phosphate), K (in Murate of potash) and Zn (in Zinc sulfate) were applied equally in the pots (110 N, 25 P, 60 K, 1.5 kg Zn ha^{-1} soil. According to BARC (1997) recommendation, 1/3 N, and whole of P, K, Zn were applied during soil preparation. The second 1/3 N was added at rapid tillering stage and the rest 1/3 N was applied as broadcast at 5-7 days before panicle initiation. Four 30 days old uniform seedlings of a high yielding variety of rice, BR 29, were transplanted in each pot. Water was maintained at the depth of 2.5 ± 0.5 cm above the soil surface. At maturity, rice grains were harvested and shoot and roots were separately collected.

Plant analysis

Oven dried (65^0 C to constant weight) and ground plant samples were digested with tri-acid (HNO_3, H_2SO_4 and $HClO_4$ mixture at ratio of 5:1:2) (Imamul Huq and Alam, 2005). The concentrations of Cd and Pb in the digested solution were measured by atomic absorption spectrophotometer (Varian Spectra AA 220).

Data analysis

The significance of differences between the means of the treatments was evaluated by one way analysis of variance followed by Duncan's Multiple Range Test at the significance level of 5%. Pearson's correlation coefficient was estimated to test the relations between metal concentrations in plant tissues and metal content in soils.

Results and discussion

Growth of rice and cadmium uptake

Biomass production of rice was significantly affected by cadmium treatments (Table 2). Grain yield in sandy clay loam and sandy loam soil, shoot weight in clay loam and sandy loam soil as well as root weight in sandy clay loam soil were significantly decreased at the highest Cd treatment (9 mg kg^{-1} soil). Grain, shoot and root weight of rice were reduced by 18-28, 17-35 and 27-54 %, respectively at the highest Cd treatment compared to the control. Muramoto *et al*. (1990) also reported that root and shoot weights of rice were reduced by 32 and 21% by 100 mg kg^{-1} Cd. In another study, however, Cd did not affect the growth of Chinese cabbage, winter greens and celery at the level upto 2.30 mg kg^{-1} soil extractable Cd in pot experiment and 0.5 mg L^{-1} in nutrient solution under sand culture experiment (Wu *et al*., 2002). Bingham (1979) observed that the most sensitive soil grown plants tested in his study (spinach and soybean) required 4 to 5 mg kg^{-1} soil to produce a 25% yield decrease. John *et al*. (1972) reported effect of Cd on radish growth with 30 different surface soils. Root weight and shoot weight were reduced by an average of 67 and 47% by addition of 100 mg kg^{-1} Cd, respectively. Sadana and Singh (1987) investigated the effects of Cd added to a loamy sand soil on lettuce. Lettuce growth was reduced by 23% by the addition of 4 mg Cd kg^{-1} soil. It was concluded that radish was more resistant to Cd than lettuce. Cadmium accumulated in plants can interfere with several physiological processes resulting in low productivity (Obata and Umebayashi, 1997) .The excess amount of Cd in soil causes disturbances in mineral nutrition and carbohydrate metabolism (Moya *et al*., 1993).The reduction of biomass by Cd toxicity could be the direct consequence of the inhibition of chlorophyll synthesis and photosynthesis (Padmaja *et al.*, 1990).

Table 3 shows the concentration and total accumulation of Cd in grain, shoot and root of rice grown in Cd treated soils. The concentration and total accumulation of Cd in grain, shoot and root were significantly affected by Cd treatments in all three soils. The concentration of Cd in grain significantly increased at the 7, 1, 1 mg Cd kg^{-1} soil treatment in clay loam, sandy clay loam and sandy loam soil, respectively. It could be observed that Cd concentration in shoot and root increased with increasing Cd treatments in all the three soils. Total accumulation of cadmium in grain, shoot and root also increased with increasing Cd application in clay loam and sandy clay loam soil. In sandy loam soil, accumulation of Cd in root was reduced above the 5 mg kg^{-1} soil treatment and the values obtained at 3-9 mg kg^{-1} soil treatments were statistically similar. The results of the present investigation are in agreement with Wu *et al*. (2002). Jiang *et a*l. (2004) also reported that Cd accumulation in both shoots and roots of Indian mustard increased with increasing soil Cd treatments. In the present study, Cd concentration in grain, shoot and root increased about 4-6, 2-5 and 4-9 fold, respectively at 9 mg kg^{-1} soil treatment over that in 1 mg kg^{-1} soil treatment except in grain in clay loam soil. Kim and Kim (1980) reported that Cd content in brown rice was 0.35 mg kg^{-1} fresh weight at 5 mg kg^{-1} Cd treated soil. In the present study, concentration of Cd in rice grain were 0.12, 6.41 and 5.48 mg kg^{-1} dry weight at the 5 mg Cd kg^{-1} soil treatment in clay loam, sandy clay loam and sandy loam soil, respectively. Total Cd content in soils and Cd concentrations in grain, shoot and root were highly correlated in all three soils (Table-6). Lund *et al.* (1981) also found significant correlations between Cd in the soil and Cd concentrations in the leaves of several crop species. At all levels of Cd application, Cd levels in different plant parts followed the order grain<shoot<root in all three soils. The highest concentration of Cd was upto12.10, 54.42 and 367.19 mg kg^{-1} dry weight of grain, shoot and root, respectively. Jiang *et al.* (2004) reported the highest concentration of Cd up to 160 mg kg^{-1} dry weight in the shoots and 300 mg kg^{-1} dry weight in the roots of Indian mustard with 10-190 mg Cd kg^{-1} soil treatment. John (1973) found that the leaf cadmium level (207.5 mg kg^{-1}) was nearly equal to that in the roots (213.9 mg kg-^{1}) in spinach grown on soil treated with 40 mg Cd kg^{-1} soil. In soybean plants, 2% of the accumulated Cd occurred in the leaves and 8% in the seeds (Cataldo *et al*., 1981).

Among the soils, Cd uptake was more pronounced in sandy loam soil than that in clay loam and sandy clay loam soil. These findings are in accordance with those of Eriksson (1989) who found that for soils of the same total Cd content, Cd was more soluble and more plant available in sandy soil than clay soil. However, in the present study, Cd content in rice grain was higher in sandy clay loam than that in clay loam and sandy clay loam soil. It may be due to soil pH. Bingham *et al*. (1980) stated that Cd content of rice grain is highly dependent upon the soil pH and is highest at pH 5.5.

Growth of rice and lead uptake

Lead treatments significantly affected the grain yield and root weight of rice except grain yield in sandy clay loam soil (Table 4). Shoot weight was also significantly affected by Pb treatments in sandy loam soil. The lowest dry weight of grain, shoot and root were found at the highest Pb treatment (50 mg Pb kg^{-1} soil) except

Table 2. Effects of cadmium on grain, shoot and root yield of rice (g pot^{-1})

Treatment (mg Cd kg^{-1} soil)	Clay Loam Soil			Sandy Clay Loam Soil			Sandy loam Soil		
	Grain	Shoot	Root	Grain	Shoot	Root	Grain	Shoot	Root
0	58.58 a	70.67 a	4.07 a	39.23 a	55.33 a	4.01 a	28.09 a	40.67 a	2.66 a
1	52.44 ab	67.00 ab	3.75 ab	38.21a	47.33 ab	3.91 a	28.45 a	33.67 ab	2.37 ab
3	50.01 ab	69.67 ab	3.21bc	35.71 ab	46.00 b	3.35 ab	27.17 a	36.33 ab	2.51 ab
5	50.90 ab	65.33 ab	3.33 bc	34.93 ab	43.33 b	3.07 ab	26.18 ab	29.67 ab	2.08 ab
7	46.86 b	63.33 ab	2.96 c	33.30 ab	43.66 b	3.09 ab	26.91ab	31.33 ab	1.83 bc
9	44.29 b	59.00 b	2.99 c	28.23 b	42.00 b	2.73 b	22.94 b	26.33 b	1.22 c
Significance of F Value (P)	0.05	0.05	0.01	0.05	0.05	0.05	0.05	0.05	0.01

Mean values in the column followed by the same letter(s) are not significantly different according to DMRT (P? 0.05).

Table 3. Concentration and total accumulation of cadmium (Cd) in rice plant (expressed in dry weight basis)

Cd concentration in rice (µg g^{-1})

Treatment (mg Cd kg^{-1} soil)	Clay Loam Soil			Sandy Clay Loam Soil			Sandy loam Soil		
	Grain	Shoot	Root	Grain	Shoot	Root	Grain	Shoot	Root
0	bdl c	0.53 f	0.68 e	bdl e	bdl d	bdl f	bdl f	bdl f	bdl e
1	bdl c	9.79 e	38.63 d	3.44 d	14.04 c	38.52 e	1.37 e	11.49 e	42.60 d
3	bdl c	13.60 d	65.98 c	4.73 d	20.08 b	62.57 d	4.38 d	23.30 d	233.24 c
5	0.12 c	17.91 c	94.14 b	6.41 c	23.00 b	101.85 c	5.48 c	38.32 c	308.14 b
7	3.02 b	33.06 b	106.07 b	8.57 b	30.83 a	132.35 b	6.73 b	46.13 b	331.07 b
9	5.07 a	42.51 a	160.66 a	12.10 a	33.87 a	205.52 a	7.50a	54.42 a	367.19 a
Significance of F Value (P)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Total accumulation of Cd in rice (mg pot^{-1})

Treatment (mg Cd kg^{-1} soil)	Clay Loam Soil			Sandy Clay Loam Soil			Sandy loam Soil		
	Grain	Shoot	Root	Grain	Shoot	Root	Grain	Shoot	Root
0	bdl c	0.461 e	0.024 e	bdl e	bdl d	bdl e	bdl e	bdl e	bdl b
1	bdl c	0.655 e	0.144 d	0.132 d	0.669 c	0.152 d	0.038 d	0.389 d	0.101 b
3	bdl c	0.951 cd	0.212 c	0.167 d	0.924 b	0.209 cd	0.119 c	0.845 c	0.588 a
5	0.006 c	1.159 c	0.313 b	0.222 c	0.998 b	0.312 bc	0.143 b	1.140 b	0. 641 a
7	0.141 b	2.102 b	0.314 b	0.285 b	1.344 a	0.413 b	0.180 a	1.446 a	0.605 a
9	0.224 a	2.507 a	0.479 a	0.342 a	1.429 a	0.559 a	0.172 a	1.433 a	0.446 a
Significance of F Value (P)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	.001	0.001

Bdl = below detection limit; Mean values in the column followed by the same letter(s) are not significantly different according to DMRT (P? 0.05).

Table 4. Effects of lead on grain, shoot and root yield of rice (g pot^{-1})

Treatment	Clay Loam Soil			Sandy Clay Loam Soil			Sandy loam Soil		
(mg Pb kg^{-1} soil)	Grain	Shoot	Root	Grain	Shoot	Root	Grain	Shoot	Root
0	50.12 a	70.67 a	4.09 a	39.56a	48.00 a	4.10 a	34.79 a	43.67 a	2.61 a
10	47.30 a	68.67 a	3.76 a	37.99 a	43.00 a	3.36 ab	30.48 b	42.33 a	2.52 a
20	47.51 a	68.67 a	3.71 ab	37.63 a	40.33 a	3.22 ab	29.74 b	40.67 ab	2.34 a
30	44.76 a	67.33 a	3.42 ab	34.77 a	40.00 a	3.29 ab	28.91 b	37.00 ab	2.35 a
40	42.01 ab	67.66 a	3.37 ab	33.04 a	38.67 a	3.09 b	27.66 b	37.00 ab	2.12 a
50	35.59 b	64.00 a	2.94 b	33.24 a	37.33 a	2.64 b	23.08 c	33.33 b	1.49 b
Significance of F Value (P)	0.05	NS	0.05	NS	NS	0.05	0.01	0.05	0.01

NS= Not Significant; Mean values in the column followed by the same letter (s) are not significantly different according to DMRT (P? 0.05).

Table 5. Concentration and total accumulation of lead (Pb) in rice plant (expressed in dry weight basis).

Pb concentration in rice (µg g^{-1}).

Treatment	Clay Loam Soil			Sandy Clay Loam Soil			Sandy loam Soil		
(mg Pb kg^{-1} soil)	Grain	Shoot	Root	Grain	Shoot	Root	Grain	Shoot	Root
0	bdl b	3.19 e	22.23 f	bdl e	1.77 d	28.42 e	1.57 e	3.92 e	13.79 e
10	bdl b	4.08 d	29.03 e	bdl e	2.39 c	32.66 e	2.47 d	4.25 e	66.42 d
20	bdl b	4.97 c	54.17 d	1.65 d	3.32 b	58.33 d	2.53 d	5.92 d	71.85 d
30	bdl b	7.88 b	79.58 c	2.54 c	3.33b	84.28 c	3.09 c	6.48 c	134.49 c
40	bdl b	10.68 a	95.14 b	3.26 b	4.69 a	100.04 b	3.24 b	7.40 b	193.30 b
50	1.72 a	10.48 a	103.02 a	3.99 a	4.63 a	128.12 a	4.14 a	8.55 a	227.19 a
Significance of F Value (P)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Total accumulation of Pb in rice (mg pot^{-1}).

Treatment	Clay Loam Soil			Sandy Clay Loam Soil			Sandy loam Soil		
(mg Pb kg^{-1} soil)	Grain	Shoot	Root	Grain	Shoot	Root	Grain	Shoot	Root
0	bdl b	0.226 d	0.091 d	bdl d	0.086 c	0.117 c	0.055 a	0.171 c	0.036 d
10	bdl b	0.280 d	0.110 b	bdl d	0.103 bc	0.110 c	0.076 b	0.179 c	0.168 c
20	bdl b	0.242 c	0.201 c	0.062 c	0.134 b	0.187 bc	0.076 b	0.240 b	0.169 c
30	bdl b	0.530 b	0.267 b	0.088 b	0.134 b	0.278 ab	0.089 ab	0.239 b	0.316 b
40	bdl b	0.721 a	0.326 a	0.109 ab	0.181 a	0.310 a	0.089 ab	0.273 ab	0.409 a
50	0.061 a	0.671 a	0.303 ab	0.133 a	0.172 a	0.341 a	0.096 a	0.285 a	0.337 b
Significance of F Value (P)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

bdl= below detection limit ; Mean values in the column followed by the same letter (s) are not significantly different according to DMRT (P? 0.05).

grain in sandy clay loam soil. Grain yield declined by 16-34 %, shoot weight by 9-24 % and root weight by 28-43 % at the highest Pb treatment as compared to control. Sharma and Dubey (2005) reported that when rice (*Oryza sativa* L.) seedlings were raised in sand culture for 10 and 20 days in nutrient medium containing 500 µM and 1000 µM $Pb(NO_3)_2$, root growth was reduced by 22 to 42 % and shoot growth by 25 %, whereas localization of absorbed Pb was 1.7 to 3.3 times higher in roots compared to shoots. A considerable decrease in dry weights of plant parts under Pb treatment was observed also by Kosobrukhov *et al*. (2004).

The concentration and total accumulation of Pb in rice were significantly affected by Pb treatments (Table 5). The concentration and total accumulation of Pb in grain significantly increased at 10, 20 and 50 mg kg^{-1} soil treatment in sandy loam, sandy clay loam and clay loam soil, respectively. In general, the Pb concentration in shoot and root increased significantly with increasing Pb concentration in all the three soils. Rolfe (1973) showed that Pb uptake by eight tree species, grown on soil treated with five soil Pb levels (0 to 600 $\mu g g^{-1}$),was significantly affected by soil Pb concentration with higher uptakes associated with higher soil Pb levels. In the present study, Pb application in soils and Pb concentration in grain, shoot and root were highly correlated in all three soils (Table-6). Korcak and Fanning (1985) also found positive relationship between the concentration of Pb in the soil and that in the plant.

elements such as Mn under reducing soil conditions, as compared to oxidized conditions, may result in the formation of Pb complexes with these elements in/on roots, retarding Pb translocation and resulting in more Pb accumulation in roots. Lead uptake studies in plants have demonstrated that roots have an ability to take up significant quantities of Pb whilst simultaneously greatly restricting its translocation to have above ground parts (Lane and Martin, 1977). The limited transport of Pb from roots to other organs is due to the barrier of the root endodermis (Sharma and Dubey, 2005).

Among the soils, Pb uptake of rice was more pronounced in sandy loam soil than that in clay loam and sandy clay loam soil. Davies (1995) showed that soil particle size and cation exchange capacity affected the availability and uptake of Pb. Riffaldi *et al*. (1976) also have reported the dominant roles of clay and organic matter contents in soil sorption of Pb. In rice, Reddy and Patrick (1977) found that Pb uptake, including root uptake, decreased with an increase in pH and suspension redox potential which is in agreement with the present study.

Conclusions

The concentration of Cd and Pb in rice grain significantly increased with increasing their application in soils except in clay loam soil. In general, Cd and Pb contents in shoot and root

Table 6. Correlation between Cd concentration in soil and plant parts; and between Pb concentration in soil and plant parts.

Element	Soil	Grain	Straw	Root
Cadmium	Clay Loam	0.866**	0.964**	0.976**
	Sandy Clay Loam	0.973**	0.938**	0.980**
	Sandy Loam	0.965**	0.986**	0.941**
Lead	Clay Loam	0.677**	0.969**	0.985**
	Sandy Clay Loam	0.985**	0.953**	0.992**
	Sandy Loam	0.955**	0.986**	0.977**

**represents that the correlative relationship is significant at the level of 1%.

Lead levels in different plant parts of rice followed the order: root > shoot >grain. It was agreed that the bulk of the Pb taken up by the plants remains in the roots (Kumar *et al*., 1995). Reddy and Patrick (1977) reported that increased uptake by the rice plants of P and Fe, and other trace

increased with increasing Cd and Pb treatments, respectively in all the three soils. Among the soils, accumulation of Cd and Pb in rice followed the order: sandy loam > sandy clay loam > clay loam soil. Cd and Pb concentration in plant parts were highly correlated with Cd and Pb application in soils respectively.

Acknowledgments

This paper is a part of Ph. D thesis of the first author. The authors are grateful to Dr. S. M. Imamul Huq, Director, Bangladesh –Australia Centre for Environmental Research, University of Dhaka, for the assistance to analyze the Cd and Pb contents of soil and plant samples in the Centre.

References

Ahmed, M.J. and M.A. Mamun. 2001. Spectrophotometric determination of lead in industrial, biological and soil samples using 2,5 dimercapto-1, 3,4-thiadiazole.*Talanta* 55: 43-54.

Alloway, B.J. 1995. Heavy Metals in Soils. 2nd Ed. Blackie Academic & Professional, An imprint of Chapman & Hall, U K.

BARC (Bangladesh Agricultural Research Council). 1997. Fertilizer Recommendation Guide. BARC Soils Publication No. 41.

Bingham, F.T. 1979. Bioavailability of cadmium to food crops in relation to heavy metal content of sludge amended soil. *Journal of Environmental Health Perspective* 28: 39-43.

Bingham, F.T., A.L. Page and J.E. Strong. 1980. Yield and cadmium content of rice grain in relation to addition rates of cadmium, copper, nickel, and zinc with sewage sludge and liming. *Soil Science* 130: 32-38.

Cataldo, D.A., T.R. Garland and R.E. Wildung. 1981. Cadmium distribution and chemical fate in soybean plants. *Plant Physiology* 68: 835-839.

Davies, B.E. 1995. Lead and other heavy metals in urban areas and consequences for the health of their inhabitants. p.287-307. In: Environmental Contaminants, Ecosystems and Human Health. S.K. Majumdar, E.W. Miller and F.J. Brenner (eds). The Pennsylvania Academy of Science, Easton PA, USA.

Day, P.R. 1965. Particle fractionation and particle size analysis. p. 545-567. In: Methods of Soil Analysis C.A. Black (ed.). Part I. Agronomy Monograph, Academic Press, New York.

De, A.K. 1996. Environmental Chemistry. 1st Ed. New Age International (P) Limited, New Delhi.

Eriksson, J. E. 1989. The influence of pH, soil type and time on adsorption and uptake by plants of Cd added to the soil. *Water, Air, and Soil Pollution* 48:317-335.

Grant, C.A., W.T. Buckley, L.D. Bailey and F. Selles. 1998. Cadmium accumulation in crops. *Canadian Journal of Plant Sciences* 78:1-17.

Imamul Huq, S.M. and M.D. Alam (eds). 2005. A handbook on Analyses of Soil, Plant and Water. BACER-DU, University of Dhaka, Bangladesh.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Private Limited, New Delhi, India.

Jiang, X.J., Y.M. Luo, Q. Liu, S.L. Liu and Q.G. Zhao. 2004. Effects of cadmium on nutrient uptake and translocation by Indian mustard. *Environmental and Geochemical Health* 26(2-3): 319-324.

John, M.K. 973. Cadmium uptake by eight food crops as influenced by various soil levels of cadmium. *Environmental Pollution* 4:7-15.

John, M.K., C. Van Laerhoven and H.H. Chuah. 1972. Factors affecting plant uptake and phytotoxicity of cadmium added to soils. *Environmental Science and Technology* 6(12): 1005-1009.

Khan, A.H. 2001. Heavy metals profile in Bangladesh Environment: Soil and Irrigation Water Components. Final Completion Report. Bangladesh Agricultural Research Council, Dhaka.

Kim, K.S. and B.J. Kim. 1980. Establishment of crop phytotoxicity benchmark by pollutant. Annual Report of Agricultural Science Institute, Korea.

Korcak, R.F. and D.S. Fanning. 1985. Availability of applied metals as a function of type of soil material and metal source. *Soil Science* 140:23-34.

Kosobrukhov, A., I. Knyazeva and V. Mudrik. 2004. Plantago major plants responses to increase content of lead in soil: growth and photosynthesis. *Plant Growth Regulation* 42: 145-151.

Kumar, N.P.B.A., V. Dushenkov, H. Motto and I. Raskin. 1995. Phytoextraction: the use of plants to remove heavy metals from soils. *Environmental Science and Technology* 29:1232-1238.

Lane, S.D. and E.S. Martin. 1977. A histochemical investigation of lead uptake in *Raphanus sativus*. *New Phytology* 79: 281-286.

Lund, L.J., E.E. Betty, A.L. Page and R.T. Elliot. 1981. Occurrence of naturally high cadmium levels in soils and its accumulation by vegetation. *Journal of Environmental Quality* 10:551-556.

Moya, J.L., R. Ros and I. Picazo. 1993. Influence of cadmium and nickel on growth, net photosynthesis and carbohydrate distribution in rice plants. *Photosynthesis Research* 36: 75-80.

Muramoto, S., H. Nishizaki and I. Aoyama. 1990. The critical levels and the maximum metal uptake for wheat and rice plants when applying metal oxides to soil. *Journal of Environmental Science and Health* 25(2): 273-280.

Obata, H. and M. Omebayashi. 1997. Effects of cadmium on mineral nutrient concentrations in plants differing in tolerance for cadmium. *Journal of Plant Nutrition* 20: 97-105.

Padmaja, K., D.D.K. Prasad and A.R.K. Prasad. 1990. Inhibition of chlorophyll synthesis in *Phaseolus vulgaris* seedlings by cadmium acetate. *Photosynthetica* 24: 399-405.

Reddy, C.N. and W.H. Patrick. 1977. Effect of redox potential and pH on the uptake of cadmium and lead by rice plants. *Journal of Environmental Quality* 6: 259-262.

Riffaldi, R., R. Levi Minzi and G.F. Soldatini. 1976. Pb adsorption by soils II. Specific adsorption. *Water, Air, and Soil Pollution* 6: 119-128.

Rolfe, G.L. 1973. Lead uptake by selected tree seedlings. *Journal of Environmental Quality* 2: 153-157.

Sadana, U.S. and B. Singh. 1987. Yield and uptake of cadmium, lead and zinc by wheat grown in soil polluted with heavy metals. *Journal of Plant Sciences Research* 3:11-17.

Sanitá, L.T. and R. Gabbrielli. 1999. Response to cadmium in higher plants. *Environmental and Experimental Botany* 41: 105-130.

Sharma, P. and R.S. Dubey. 2005. Lead toxicity in plants. *Brazilian Journal of Plant Physiology* 17:35-52.

Watanabe, Y., Z.W. Zhang, J.B. Qu, G.F. Xu, L.H. Song, J.J. Wang, S. Shimbo, H. Nakatsuka, K. Higashikawa and M. Ikeda. 1998. Urban-rural comparison on cadmium exposure among general populations in Shandong Province, China. *Science of the Total Environment* 217: 1-8.

Wu, Z.N.I., Y. Xio-e and L. Xin-xian. 2002. Differences of cadmium absorption and accumulation in selected vegetable crops. *Journal of Environmental Science* 14: 399-405.

Yamagata, N. and I. Shigematsu. 1970. Cadmium pollution in perspective. *Bulletin Institute of Public Health* 19: 1-27.

Yang, M.G., X.Y. Lin and X.E. Yang. 1998. Impact of Cd on growth and nutrient accumulation of different plant species. *Chinese Journal of Applied Ecology* 19: 89-94.

Zaman, M.S. and F. Zereen. 1998. Growth responses to radish plants to soil cadmium and lead contamination. *Bulletin of Environmental Contamination and Toxicology* 61: 44-50.