Uptake of Cadmium and Lead by Rice Grown in Four Contaminated Soils of Chittagong, Bangladesh

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Rice was grown on soils collected from four different contaminated areas of Chittagong including city sewage, tannery, fertilizer factory and cement factory. Cadmium concentrations in grain of rice were 0.98, 0.10, 0.22 and 0.36 mg/kg^{-1} dry weight for city sewage, tannery, and fertilizer factory and cement factory soil, respectively. Cadmium concentration ranged from 2.73 to 6.91 mg/kg^{-1} in straw and 3.50 to 27.91 mg kg^{-1} in root. Lead concentration in grain, straw and root was significantly differed among the soils with the highest values (0.75, 4.13 and 39.37 mg kg^{-1}, respectively) in city sewage soil and the lowest values (0.34, 2.16 and 29.53 mg kg^{-1}, respectively) in tannery soil. Among different plant parts (root, straw and grain), the lowest values of Cd and Pb were observed in the grains. Almost all of the Cd and Pb absorbed by rice grain were likely to accumulate in the edible parts and Cd and Pb have not been detected in the grain chaffs. These results have implied that higher concentrations of Cd and Pb exceeding the maximum safe-intake levels (0.1 mg kg^{-1}) in grains proposed by the FAO/WHO could result in human health problem.

Keywords: Cadmium, Lead, Rice, Grain, Food safety, Food chain.

Introduction

Food safety and human health issues have led to an increased attention to contamination of soil and plants with heavy metals all over the world. Urbanization and industrialization are the two major causes for the increasing contamination of heavy metals in soil. When heavy metal contaminated soils are used for food crops production then metal pollutants can easily enter the food chain. Higher accumulation of heavy metals in rice grown in agricultural soils may lead to health disorder. Among the heavy metals, cadmium and lead are the metals of greatest concern because they may cause serious problems through food chain (Jackson and Alloway, 1992). The entry of Cd into the food chain can cause chronic health problems in humans such as bone disease, lung oedema, renal dysfunction, liver damage, anaemia and hypertension (Jackson and Alloway, 1992; Wagner, 1993; Staessen *et al.,* 1999). The disease known as *itai itai* was caused by the production of paddy rice on soil contaminated with Cd in Japan. The United States Environmental Protection Agency (USEPA) considers Pb as the second most important hazardous substance (Chen *et al.,* 2003). Lead poisoning in humans causes severe damage in the kidneys, liver, brain, reproductive system and central nervous system and sometimes causes death (Traina and Laperche, 1999). The potential public health risk associated with dietary intake of heavy metals like Cd and Pb has become of increasing concern.

Studies on the contamination of Cd and Pb in soils and plants have so far been restricted to highly industrialized temperate regions and limited data on the fate of these pollutants in soils of tropical regions are available. The accelerated growth of various industries in Chittagong city of Bangladesh and potential uses of city waste water for irrigation in the adjoining agricultural land bring into focus the question that the agricultural soils of Chittagong city and soil-crop system could be subjected to contamination with Cd and Pb. Kibria (2008) reported that discharge of city sewage and tannery effluents and atmospheric deposition of dust particles from fertilizer and cement factory significantly contributed to the accumulation of Cd and Pb in agricultural soils of Chittagong Municipal area, Bangladesh. The objectives of the present study were to investigate the uptake of Cd and Pb by rice grown in four soils contaminated with city sewage, tannery, fertilizer factory and cement factory effluents and atmospheric deposition of dust particles.

Materials And Methods

Collection of Soil

Surface soils (0-15 cm) were collected from the vicinity of the source point of four contaminated sites namely (i) city sewage (ii) tannery (iii) fertilizer factory (iv) cement factory. Soil samples were air dried and larger and massive aggregates were broken down by gentle crushing with wooden plank. Dry roots, grasses and other particulate materials were separated from the soils by passing through 2 mm sieve and processed for pot experiment. A portion of the soils passed through 2 mm sieve was retained for laboratory analyses. The properties of four contaminated soils are presented in Table 1.

TABLE 1

Properties of Contaminated Soils Used in Pot Experiment of Rice

Soil	Texture	pH	Organic matter (%)	CEC (cmol kg^{-1})	Total N (%)	Cd (mg kg^{-1})	Pb (mg kg^{-1})
City sewage	Sandy Clay loam	5.4	3.51	13.35	0.22	2.48	54.31
Tannery	Clay Loam	8.5	1.95	9.31	0.13	0.24	23.84
Fertilizer Factory	Silty Clay	5.4	2.61	12.51	0.17	0.27	40.29
Cement Factory	Clay	6.3	1.93	11.97	0.16	1.03	33.16

Pot Experiment

Three earthen pots (10 kg capacity) were taken for experiment with soils of each site. Eight kilogram air dry soil was filled in each pot. Nitrogen, phosphorus, potassium and sulfur were added at the rate of 110, 25, 60 and 15 kg/ha^{-1} respectively from the corresponding fertilizers urea, TSP, MP and Zinc Sulfate. According to Bangladesh Agricultural Research Council (1997) recommendation, 1/3 N, and whole of P, K, S were applied during soil preparation. The second 1/3 N was added at rapid tillering stage and the rest 1/3 N was applied at 5-7 days before panicle initiation. Four uniform 30 days old seedlings of a high yielding rice variety, BR 29, were transplanted in each pot. The pots were arranged in randomized block design. Water at a height of 2.5±0.5 cm above the soil surface was maintained by periodic addition of tap water. At maturity, rice plants were harvested just above the soil surface and separated into straw and rice grain. Roots were collected carefully and washed thoroughly with tap water first to remove adhering soil particles and then with distilled water. The straws were also washed to remove dust particles. Root, straw and grains were oven dried at 65°C for 72 hours and weights were recorded.

Soil and Plant Analysis

Physico-chemical properties of soils were determined by standard methods (Day, 1965; Jackson, 1973). Soil samples were digested with aqua regia (Jackson, 1973) on a sand bath for the determination of total Cd and Pb. Oven dried (65°C to constant weight) and ground plant samples were digested with ternary acid mix (HNO_3, H_2SO_4

and $HClO_4$ mixture at the ratio of 5:1:2) for the determination of Cd and Pb in the plant tissues (Huq and Alam, 2005). The concentrations of Cd and Pb in the digests 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 (ANOVA) followed by Duncan's Multiple Range Test at the significance level of 5%. The statistical software Excel (Excel Inc. 2003) and SPSS version 12 (SPSS Inc. 2003) were used in the analysis.

Results And Discussion

Yield of Rice

Dry weight of grain, straw and roots of rice grown in contaminated soils varied from 34.75 to 42.74, 42.95 to 57.85 and 3.49 to 3.81 g pot^{-1} (Table 2). All of grain, straw and root weights were the highest in city sewage soil and the lowest in tannery soil. The city sewage soil contained higher organic matter, total N and CEC; probably growth and yield of rice was therefore higher in this soil.

TABLE 2

Grain, Straw and Root Weight of Rice (g pot^{-1}) Grown on Contaminated Soils

Soil	Grain	Straw	Root	Grain : Root	Straw : Root
City sewage	42.74 a	57.85 a	3.81 a	11.26 a	15.24 a
Tannery	34.75 a	42.95 b	3.49 a	9.95 a	12.30 b
Fertilizer factory	37.19 a	46.23 b	3.68 a	10.10 a	12.56 b
Cement factory	38.14 a	48.18 b	3.72 a	10.23 a	12.93 b
Significance of F value (P)	NS	0.01	NS	NS	0.01

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

Concentrations of Cd and Pb in Rice

Cadmium concentration of rice grain showed significant difference among various contaminated soils. The mean Cd values in rice grains were 0.98, 0.10, 0.22 and 0.36 mg kg^{-1} dry weight for city sewage; tannery, fertilizer factory and cement factory soil, respectively (Table 3). The Cd concentration in straw and root also varied significantly among the soils. Cadmium concentration ranged from 2.73 to 6.91 mg kg^{-1} in straw and 3.50 to 27.91 mg kg^{-1} in root. Lead concentrations in grain, straw and root significantly differed among the soils with the highest values (0.75, 4.13 and 39.37 mg kg^{-1}, respectively) in city sewage soil and the lowest values (0.34, 2.16 and 29.53 mg kg^{-1}, respectively) in tannery soil (Table 4). Among different plant parts (root, straw and grain), the lowest values of Cd and Pb were observed in the grains. Arao and Ae (2003) observed 0.30 mg kg^{-1} Cd concentration in grain of Nippon bare rice grown on contaminated soil containing 0.8 mg kg^{-1} total Cd. The mean total concentrations of Cd in brown rice in two contaminated sites of Taiwan were 1.5 and 3 mg kg^{-1}; the corresponding totals Cd in soils were 4.7 and 378 mg kg^{-1}. The mean total concentrations of Pb in brown rice were 1.1 and 8.4 mg kg^{-1} with respective concentrations in soils 25.8 and 3140 mg kg^{-1} (Chen, 1991; Chen *et al.*, 1996).

TABLE 3

Concentration and Bioaccumulation Coefficient of Cd in Rice Grown on Contaminated Soils

Soil	Cd concentration (mg kg^{-1})			Bioaccumulation coefficient		
	Grain	Straw	Root	Grain	Straw	Root
City sewage	0.98 a	6.91 a	27.91 a	0.40 b	2.79 b	11.23 c
Tannery	0.10 c	2.73 c	3.50 c	0.42 b	11.39 a	14.60 b
Fertilizer factory	0.16 c	3.38 bc	4.92 c	0.59 a	12.51 a	18.21 a
Cement factory	0.36 b	4.08 b	9.59 b	0.35 b	3.97 b	9.31 c
Significance of F value (P)	0.001	0.001	0.001	0.05	0.001	0.001

Mean values in the column followed by the same letter (s) are not significantly different according to DMRT ($P \leq 0.05$). Bioaccumulation coefficient of Cd is the ratio between Cd concentrations in plant parts (mg kg^{-1} DW) and Cd concentration in soil (mg kg^{-1}).

TABLE 4

Concentration and Bioaccumulation Coefficient of Pb in Rice Grown on Contaminated Soils

Soil	Pb concentration (mg kg^{-1})			Bioaccumulation coefficient		
	Grain	Straw	Root	Grain	Straw	Root
City sewage	0.75 a	4.13 a	39.37 a	0.014 a	0.08 c	0.73 d
Tannery	0.34 d	2.16 b	29.53 d	0.014 a	0.09 b	1.24 a
Fertilizer factory	0.69 b	3.99 a	36.30 b	0.017 a	0.10 b	0.90 c
Cement factory	0.53 c	4.08 a	32.41 c	0.016 a	0.12 a	0.98 b
Significance of F value (P)	0.001	0.001	0.001	NS	0.001	0.001

Mean values in the column followed by the same letter (s) are not significantly different according to DMRT ($P \leq 0.05$). Bioaccumulation coefficient of Pb is the ratio between Pb concentrations in plant parts (mg kg^{-1} DW) and Pb concentration in soil (mg kg^{-1}).

Although the concentration of Cd in the rice grain was low relative to the other parts of the plants, it is a potential cause for concern. The Codex Alimentarius Commission, an international foods standards organization, has set a limit of 0.2 mg Cd kg^{-1} in cereals and legumes for human consumption (Codex Alimentarius Commission, 2001). According to a retrospective study on the relationship between renal dysfunction and Cd concentration in rice in Jinzu River, Japan (Osawa *et al.*, 2001), the allowable range of Cd concentrations in rice is estimated at 0.05-0.20 mg kg^{-1}. In the present study, cadmium concentrations in rice grains were found to be above these critical levels except in tannery soil.

The present experiment showed that Cd concentrations in rice grain grown in city sewage, fertilizer and cement factory soils were 9.8, 2 and 3.6 times higher respectively than the maximum safe-intake levels (0.1 mg kg^{-1}) in grains proposed by the FAO/WHO (1995), while the grain Cd concentration of rice in tannery soil was equal to the level. The values of Cd concentrations for city sewage and cement factory soil exceeded by 4.9 and 1.8 times respectively the tolerance limit of Cd concentration (0.2 mg kg^{-1}) to human health in rice permitted by the Chinese Standard (He *at el.*, 2006). However, The Codex Alimentarius Commission (2005) is considering a new international standard for Cd concentration in staple crops, which would allow less than 0.4 mg Cd kg^{-1} in brown rice. The Pb concentration in the grain of rice in the four studied soils were all below the safety level of 10 mg kg^{-1} reported by Lin *et al.* (1993) but were all beyond the maximum level (0.2 mg kg^{-1}) of Joint FAO/WHO Food Standards Programme (2002).

The variation of Cd and Pb uptake depend on the physical and chemical nature of the soil and absorption capacity of heavy metals by the plant (Bahemuka and Mubofu, 1999; Liu *et al.*, 2003, 2005). The uptake of metals is frequently related to their concentrations in soil. This is especially true for elements that are mobile (Bañuelos and Ajwa, 1999). In general, increases in Cd and Pb content in soil resulted in increases in the uptake of Cd and Pb by plants. For instance, Liu *et al.* (2005) observed the Cd concentrations in brown rice range from 0.22 to 2.86 mg kg^{-1} when grown in highly Cd contaminated soil (100 mg kg^{-1}). Concentrations of Cd and Pb in rice were found to be higher in the city sewage soil than in other soils in the present study. This is possibly because soils in this site contained high Cd and low pH values which can effectively increase metal bioavailability for plants. The bioavailability of Cd in soil is highly dependent on soil pH, organic matter and total Cd concentration (Janssen *et al.,* 1997; Sauve *et al.,* 2000). However, many factors and variables may have an effect on the absorption and storage of cadmium and lead in the grains of rice. Soil pH is an important factor that affects the concentration of the Cd and Pb of the soil solution because an increase of pH causes a decrease in the solubility of the lead and cadmium compounds. It is possible that the organic contaminant in city sewage enhanced Cd uptake.

The bioaccumulation coefficient (BC) was calculated as the ratio of content of heavy metal in the plant part to that in the soil. Bioaccumulation coefficient range of Cd in rice grain was 0.35-0.59, that in straw was 2.79-12.51 and in root was 9.31-18.21 (Table 3). Cadmium was more easily taken up and accumulated than Pb by rice plants through the root systems from soil. BC range of Pb was 0.014-0.017 for grain, 0.08-0.12 for straw and 0.73-1.24 for root (Table 4). The results indicated that Pb bioavailability was low.

Distribution of Cd and Pb in Rice

Cadmium uptake by rice grain, straw and root were significantly different among the contaminated soils. The Cd uptake by rice grain, straw and root among the soils varied: fertilizer factory > city sewage > cement factory > tannery, fertilizer factory > tannery > cement factory > city sewage and fertilizer factory > tannery > city sewage > cement factory, respectively.

The distribution of heavy metals in various parts of rice grains in the present study has demonstrated that almost all the Cd and Pb absorbed by rice grain were likely to accumulate in the edible parts and Cd and Pb have not been detected in the grain chaffs. These results have implied that higher concentrations of Cd and Pb exceeding the maximum safe-intake levels (0.1 mg kg^{-1}) in grains proposed by the FAO/WHO (1995) could result in human health problem.

The percentage of total Cd and Pb uptake in the roots was lower than that in the straw but higher than that in the grains (Fig. 1) in spite of the highest concentrations in the roots. This may be due to the higher biomass of straw than that of grains and roots. Another explanation of such a high Cd content in straws could be the presence of Cd binding peptides in them (Wójcik and Tukendorf, 1999). Cadmium and Pb retention in the roots is an important mechanism in regulating or mobilizing their translocation to the straw and particularly to the grains. The mobility of Cd and Pb in roots may depend on adsorption to the cell wall (Nishizono *et al.*, 1989) and/or chelation to organic compounds (Wagner, 1993). Retention of the highest amount of the metal taken up by roots, being characteristic for numerous plant species (Meuwly and Rauser, 1992) is considered as one of the detoxification mechanisms particularly in monocotyedones (Baker and Walker, 1990). Cadmium concentration in roots can reach upto 80% of the total pool of the metal taken up (Baszynski and Krupa, 1992) but in the present study it was only 9 to 20%.

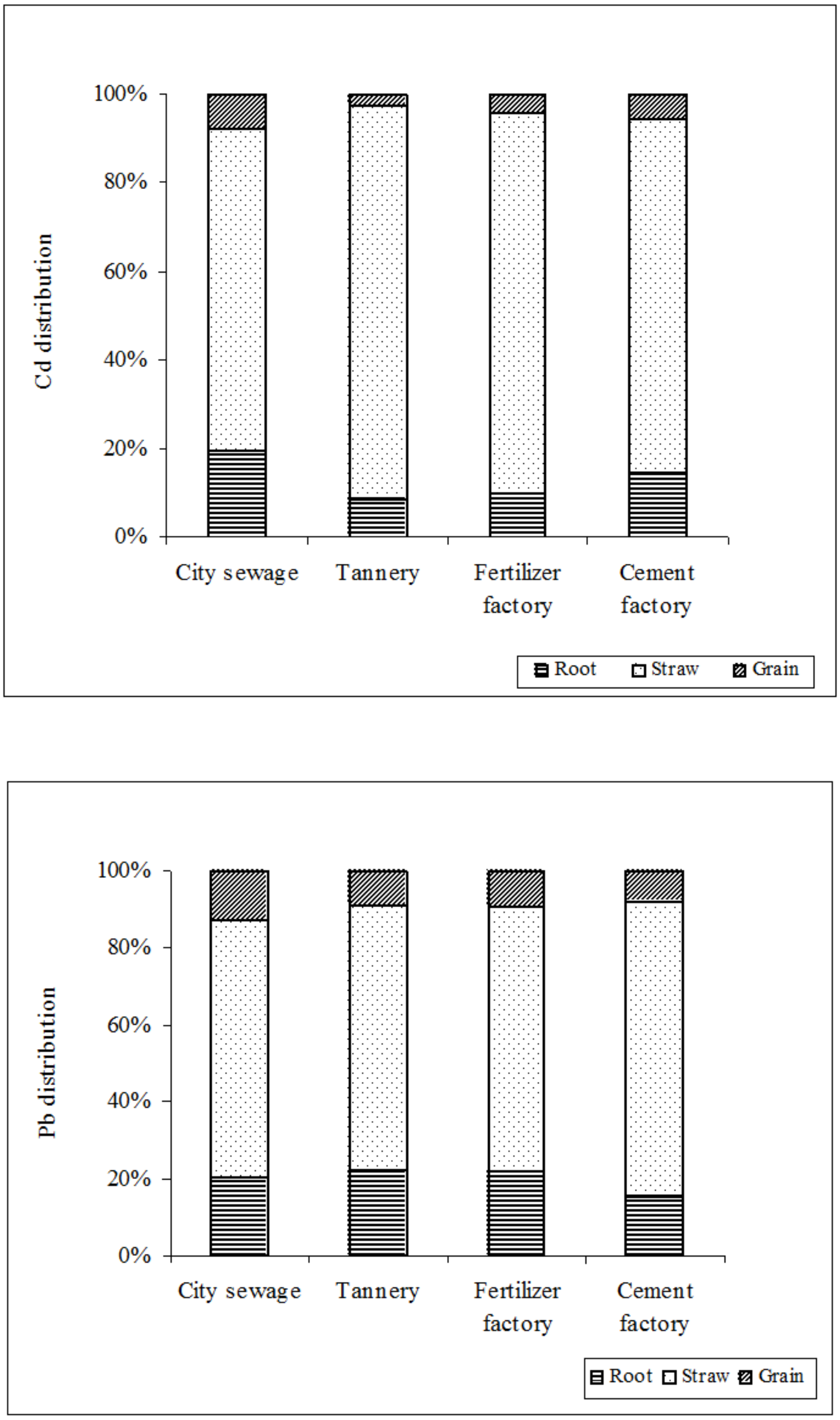

Fig. 1
Distribution of Cd and Pb in rice grown in soils contaminated by city sewage, tannery, fertilizer factory and cement factory

Conclusion

Potential transfer of metals from soil to plants may be an especially important issue in areas where agricultural production has been pushed onto marginal lands. The distribution of heavy metals in various parts of crops implies that it would be a high risk to human health if paddy rice were grown in soils heavily polluted with Cd since a large proportion of this metal accumulated in the edible parts. However, growing paddy rice in soil contaminated with Pb would be less risky because this metal is accumulated mostly in the roots with only a very little translocation to the grain. Less contaminated soils can be utilized for production of crops, provided that they accumulate only small amounts of toxic metals in edible parts. Accumulation of heavy metals in edible parts of plants such as grain of rice may also depend on genotypes. Therefore, further works may be conducted with different rice varieties and with widely different types of contaminated soils.

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