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DETERMINATION OF CADMIUM ACCUMULATION POTENTIAL AND TOXICITY THRESHOLD LEVEL FOR RICE IN INCEPTISOL SOIL

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Abstract

Cadmium (Cd) is a potentially toxic element which poses a great concern in the environment, because of its toxicity to animals and humans. Therefore, an experiment was carried out to assess the yield reduction for Cd contamination and the potential transfer and bioaccumulation of Cd in rice as well as the food chain. The trial was conducted in pot with rice (*Oryza sativa* L.) as a test crop using non-calcareous soil (Inceptisol) contaminated with increasing concentrations of Cd (0, 3, 6, 9, 12, 18 and 24 mg/kg soil). Thus, 7 treatments were arranged in CRD with 3 replications. Cadmium found to be phytotoxic for rice. There was a great potential risk of Cd transfer to the human food chain from rice grown in contaminated soil. Moreover, the pre-established maximum acceptable concentration (1 - 20 mg/kg) of Cd in soil of was not safe to prevent Cd contamination in food chain for calcareous soils of Bangladesh.

Introduction

Rice is the staple food of Bangladesh and the world's third largest crop, which has significant role in human nutrition. Cadmium is one of the main pollutants in rice paddy soil near industrial areas and highly toxic to rice growth and development (Chien and Kao 2000). It can be absorbed and transported effectively by rice plants, and thus it could easily enter into the food chain. Among the major staple crops, rice is the particular one with high Cd uptake and accumulation (Chaney *et al.* 2004). People, especially those who take rice as main food for daily energy are exposed to significant amount of heavy metals through rice (Watanabe *et al.* 1996).

The maximum acceptable concentration of Cd among different countries is in the ranges of 1 - 20 mg/kg (Council Directive 86/278/EEC, 1986; McLaughlin *et al.* 2000). A few countries have also established guidelines for allowable concentration of metals in such foods as cereals. According to these guidelines, allowable concentrations of Cd in cereals are 0.4 mg Cd per kg fresh weight (Hamon and McLaughlin 2003). A few countries have also established guidelines for threshold concentrations of Cd to regulate metal levels in soils. Warnings and critical limits are often based on total soil Cd contentration. However, it is widely accepted that the total soil Cd concentrations are poor indicators of their potential effects and their toxicity to terrestrial organisms (Abollino *et al*. 2005, Finžgar *et al.* 2007). As a result, bioavailability and food chain transfer need to be considered to determine the potential of Cd contamination health problems for consumers of crops grown in contaminated soils.

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Metal mobility and bioavailability in soil vary significantly with the soil properties similar total soil metal concentrations. Therefore, the aims of this study were (i) to assess the effect of Cd contaminated soil on the yield reduction of rice, (ii) to determine the bioconcentration of Cd in rice and the risk of food chain contamination, and (iii) to test the suitability of the pre-established soil threshold concentrations of Cd as a substitute for plant metal thresholds to control food chain exposure to Cd.

Materials and Methods

A pot culture experiment was conducted with rice (*Oryza sativa* L.) as a test crop in non-calcareous soil. Soil samples were collected from Bangladesh Agricultural University farm Mymensingh, Bangladesh (24.09^{0}N latitude - 90.26^{0}E longitude). The collected soils were belonged to Sonatola series with inceptisol. The soil samples were air dried and ground to pass through a 2 mm sieve. Soil pH was determined by glass-electrode pH meter maintaining 1: 2.5 soil-water ratio (Page *et al.* 1982). Mechanical analysis of soil was done by hydrometer method (Black 1965) and the textural class was determined by fitting the values for % sand, % silt and % clay to the Marshall's triangular co-ordinate following USDA system. Cation exchange capacity was measured by sodium saturation method (Rhoades 1982). Organic carbon was determined through wet digestion method (Nelson and Sommers 1982). Available Zn was extracted by 0.05M DTPA solution (pH 7.3) maintaining 1 : 2 soil-extractant ratio and directly measured by AAS (Lindsay and Norvell 1978). For total Cd, soil sample was digested with HNO_3-$HClO_4$ (4 : 1) for 1.5 hrs at 190^{0}C (Yoshida *et al.* 1976) and determined by atomic absorption spectrophotometer, Model UNICAM 969, England. Some physico-chemical properties of soils under study are presented in Table 1.

Table 1. Physico-chemical characteristics of the selected soil.

Parameter	Value
Texture	Silt loam
Sand (%)	24.36
Silt (%)	63.30
Clay (%)	12.3
Organic matter (%)	1.33
pH	6.68
Cation exchange capacity ($cmol_+$/kg soil)	11.1
Total N (%)	0.089
Available P (mg/kg)	7.11
Exchangeable K (cmol/kg)	0.10
Available S (mg/kg)	14.46
Available Zn (mg/kg)	1.36
Total Cd (mg/kg)	0.42

Ten kg of soil (dry weight basis) was taken in a series of non-porous and plastic pots. A blanket dose of 115 mg/kg N, 25 mg/kg P, 50 mg/kg K and 10 mg/kg S was applied to each pot (FRG 2012). Full doses of P, K, S and Cd (treatment wise), and 1/3rd dose of N were mixed with soil. The soil was submerged with distilled water for 24 hrs. The remaining N was applied in two equal splits at 20 and 45 days after transplanting. There were 7 treatments consisting different levels of Cd (0, 3, 6, 9, 12, 18 and 24 mg/kg soil) as $Cd(NO_3)_2$ were arranged in CRD with 3 replications. Three rice seedlings (BRRI dhan 31) of 30 days old were transplanted in each pot. The crop was harvested at the maturity. The grain and straw were air-dried and then oven-dried at 70°C. Dried plant tissues and grains were digested with di-acid mixture ($HNO_3 : HClO_4 = 4 : 1$) and analysed for Cd (Yoshida *et al.* 1976) using Atomic Absorbtion Spectrophotometer (UNICAM 969). The total amount of Cd in plants was extracted and analyzed to know the entry of Cd to the food chain. The concentration of Cd in rice at any level of soil contamination was compared with the threshold concentrations of Cd in cereals as established by the Codex Alimentarius Commission (CAC) (Hamon and McLaughlin 2003). From this comparison the maximum allowable concentrations of this metal in soil was defined. The toxic level of Cd was determined by graphical method. Bingham *et al.* (1975) proposed method was employed to calculate the critical toxic concentration of Cd in soil and plants. Per cent relative dry matter yields (Cate and Nelson 1965) were plotted against extractable content of Cd in soil. Critical toxic limits of Cd in soil and plants were determined for 10 per cent reduction in dry matter yield (Lagriffoul *et al.* 1998, Deepali-Joshi *et al.* 2010). Biconcentration factor (BFC) to estimate the potential transfer of Cd to the food chain was calculated.

$$BCF = \frac{\text{Total metal in plant fresh matter (mg/kg)}}{\text{Total metal in soil (mg/kg)}}$$

Results and Discussion

The Cd content in grain and straw of rice was increased gradually up to soil Cd contamination of 24 mg/kg. The maximum accumulation of Cd was 0.97 mg/kg dry rice grain for 24 mg/kg Cd contamination in soil (Fig.1a). On the other hand, maximum accumulation of Cd in rice straw was 20.44 mg/kg for the same level of soil contamination (Fig.1b). It indicates that rice straw accumulate many-olds higher Cd than the rice grain. These results are similar to the findings of Mahler *et al.* (1978).

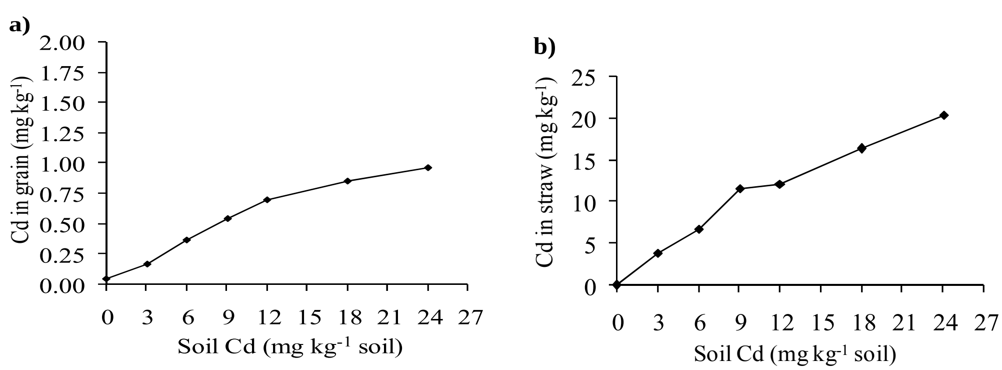

Fig. 1. Concentration of Cd in (a) rice grain and (b) straw for the different levels of Cd contamination in soil.

The biconcentration factor (BCF) ranged from 0.061 (with 6 mg Cd per kg soil) to 0.040 (with 24 mg per Cd kg soil) for grain and from 1.29 (with 3 mg Cd per kg soil) to 0.85 (with 24 mg Cd per kg soil) for straw (Table 2). This result indicates that straw is more risky than grain and thus animal assumed to be more vulnerable by Cd than human.

Relative grain yield was 94.73% at 6 mg/kg soil Cd and 73.25% at 24 mg/kg soil Cd (Fig. 2a,b). On the other hand, straw yield was 95.78% at 6 mg/kg soil Cd and 74.67% at 24 mg/kg soil Cd. The results indicated that the relative yield reduction in rice grain and straw ranged 5.27 -

36.75 and 4.32 - 25.43%, respectively at 6 - 24 mg/kg soil Cd. Adverse effect of Cd on crops were reported by Selvam and Woon Chung (2009). Among the six levels of Cd, per cent yield loss was more in higher level and less in lower level. In higher Cd levels, plants Cd concentrations were more i.e. plants uptake and accumulated more Cd. Therefore, due to toxicity, per cent yield loss was more in higher level and less in lower level of Cd. More yield loss in higher Cd level is in agreement with the findings of Lokhande and Kalkar (1999). Reductions in the dry matter yields of Cd sensitive plants with increasing rates of added Cd were also observed by Gajdos *et al.* (2009).

Table 2. Bioconcentration factor of Cd for rice at different levels of soil Cd contamination.

	Soil total Cd (mg/kg)					
	3	6	9	12	18	24
Grain	0.056	0.061	0.060	0.058	0.047	0.040
Straw	1.290	1.130	1.280	1.010	1.910	0.850

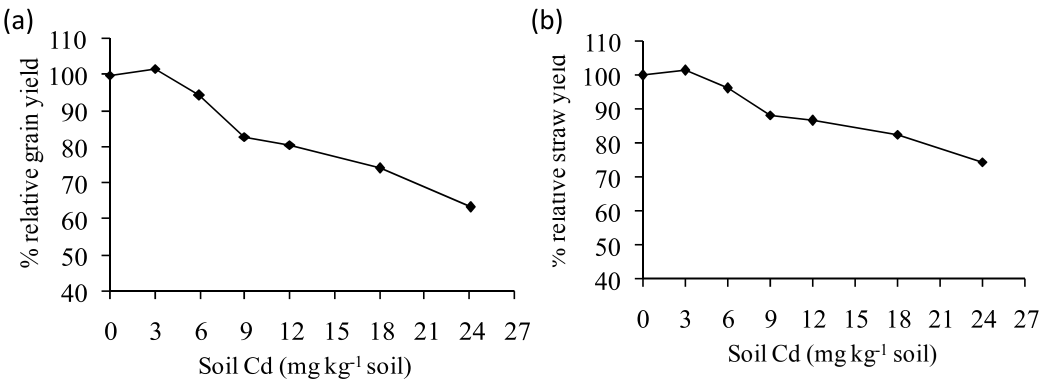

Fig. 2. Relative experimental yield of rice a) grain and b) straw at the different levels of Cd contamination in soil.

At pre-established maximum acceptable concentration of Cd in soil (1 - 20 mg/kg soil) relative yield of rice grain and straw were ≈ 0 to 72.87 and ≈ 0 to 79.60, respectively (Fig. 2a, b). That means the yield reductions, as an indication of metal phytotoxicity, was between ≈ 0 to 27.13% in rice grain and between ≈ 0 and 20.40% in rice straw when soil total Cd was in the range of pre-established maximum acceptable concentration of Cd in soil. In case of rice straw, yield reduction was lower than rice grain i.e. phytotoxicity was higher in rice grain.

The threshold values for Cd phytotoxicity were defined as the concentration in the plant tissue above which growth was reduced or metabolism changed ± 10% (Deepali-Joshi *et al.* 2010). In the graphical method, according to Deepali-Joshi *et al.* (2010), the toxic level of total soil Cd for rice grain was found 7.7 mg/kg but in case of straw, it was 8.0 mg/kg (Fig. 2a, b). Sarkunan *et al.* (1991) also found significant reduction in grain and straw yields of rice at 10 mg Cd per kg soil.

Result show that rice grain concentrations of Cd was fairly greater than the allowable concentration of Cd in cereals of 0.4 mg/kg, when they were grown on a soil with 6.8 mg Cd per kg for non-calcareous soil (Fig. 1a). On the other hand, rice straw Cd concentration was fairly greater than the allowable concentration of Cd in plant tissue (Straw) of 5 mg/kg, when they were grown on a soil with 3 mg Cd per kg (Fig. 1b).These results showed that, for the soil in this study, the pre-established maximum acceptable concentration of Cd in soil of 1 - 20 mg/kg is not safe to prevent the contamination of food chain. Thus, the maximum allowable Cd concentration in rice soil appeared to be 6 mg/kg at best.

Increasing levels of soil Cd significantly reduced the yield of rice as well as increased the Cd concentration in grain and straw. The pre-established maximum acceptable concentration of Cd in soil (1-20 mg/kg) is not safe to prevent the contamination of food chain through rice. The maximum acceptable concentration of Cd for non-calcareous soil found hardly to be 6 mg/kg, but needs further study for conclusive interpretation.

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