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CADMIUM AVAILABILITY AND UPTAKE BY RICE FROM LIME, COW-DUNG AND POULTRY MANURE AMENDED Ca-CONTAMINATED PADDY SOIL

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Abstract

Industrial wastes and effluents are being discharged directly to soils, canals and rivers, which may contain a lot of toxic heavy metals like cadmium (Cd). Thus, the polluted soils need to be amended for crop production. With this idea in mind, pot experiments were conducted at Bangladesh Agricultural University to examine the effect of organic and inorganic amendments on growth, yield and Cd concentrations in rice grown in polluted soils. The addition of cow-dung (CD), poultry manure (PM) and lime significantly increased the grain and straw yields of rice, reduced Cd concentration and uptake of Cd in grain and straw compared with control. However, the addition of PM increased more rice yields, reduced more Cd concentration and uptake and decrease the heavy metal phytoavailability.

Introduction

Cadmium (Cd) has been identified as one of the most common toxic heavy metals for plants and animals. It is also known as one of the major environmental pollutants. This toxic heavy metal if present or accumulated in soils would be taken up by plants and ultimately enters into the food chain (Hong *et al.* 2008, Loganathan *et al.* 2012). Soils in many areas of the world are moderately contaminated with Cd (Kukuchi *et al.* 2007, McGrath *et al.* 2001). This moderate Cd contamination in soils leads to a considerable accumulation of Cd in edible parts of crops (Arao and Ae 2003, Arao *et al.* 2003). Such levels of Cd are not toxic to plants but can contribute to substantial Cd dietary intake by humans (Uraguchi and Fujiwara 2012). High Cd containing rice was the major source of Cd intake for the "Itai-itai disease''patients of Japanese populations (Horiguchi *et al.* 2004, Horiguchi 2012, Ogawa *et al.* 2004). Cadmium exerts its toxic effects mainly on the kidney. It has been reported that The data showed that 17 - 18 million of the adult population suffered from chronic kidney disease (CKD) G1-5; of these, 11 - 12% was CKD G3-G5 (Alam *et al.* 2010, Faroque *et al.* 2010, Hadiuzzaman *et al.* 2010). It is a common belief that higher Cd intake through food chain is one of the major reasons for such a high number of kidney patients.

Bangladeshi people are taking more Cd through contaminated foods including rice (Al-Rmalli *et al.* 2012, Meharg *et al.* 2013, Simmons *et al.* 2008). Although many recent studies have determined Cd in foods especially vegetables (Khan *et al.* 2010, Mor and Ceylan 2008, Naser *et al.* 2009, Zheng *et al.* 2007) and rice (Meharg *et al.* 2013), but the number of studies in Bangladesh is limited.

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Many scientists are currently trying to effectively remediate the soils contaminated with Cd. The immobilization, which transforms Cd into less bioavailable forms were considered as one of the most effective ways to remediate the Cd contaminated soils (Gadepalle *et al.* 2007, Ok *et al.* 2011). Among immobilizing agents, organic amendments have been shown to effectively alleviate Cd toxicity to plants by transforming the metals into less available fractions (Tandy *et al.* 2009, Yassen *et al.* 2007). Metal absorption by plants is pH dependent and liming is a useful way of reducing the toxicity of Cd (Dinesh-Mani *et al.* 2007, Puschenreiter *et al.* 2005).

Poultry industry is a raising industry for protein supply in Bangladesh. It is also important for a huge amount of poultry littre which is also important for OM. On the other hand, CD is the traditional source of OM. The incorporation of organic amendments (PM, CD, etc.) into the heavy metal contaminated soils could maintain soil OM, improve soil physicochemical properties, and increase plant production (Yoon *et al.* 2004, Kim *et al.* 2010). Moreover, many previous studies have demonstrated the benefits of utilizing organic amendments for immobilization of heavy metals in the soils (Bolan *et al.* 2003, Walker *et al.* 2004, Tandy *et al.* 2009). Therefore, the aim of the present study was to assess the effects of organic and inorganic amendments on yield and Cd concentrations in rice, grown in polluted soils.

Materials and Methods

These pot experiments were conducted at Bangladesh Agricultural University (BAU) net-house to examine the effect of organic and inorganic amendments on yield and Cd concentrations in rice in polluted soils during the year of 2011 and 2012. The industrially polluted soil was collected from Tongi, Gazipur, Bangladesh. Top soils (0 - 15 cm) from above mentioned areas were collected, air dried and ground to pass through a 2 mm sieve. Physico-chemical properties of the soils are presented in Table 1. In naturally polluted soils, there were two different organic (CD 80 g/pot and PM 80 g/pot) and one inorganic (lime 10 g/pot) soil amendments. There was a control (no soil amendment) treatment. Hence, the total number of treatment was 4. Ten kilogram of soil (dry weight basis) was taken in a series of non-porous and non-metallic plastic pots. Each pot was 30 cm in diameter and 32 cm in height. 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 container for growing rice. Urea, triple super phosphate, muriate of potash and gypsum were used as sources of N, P, K and S, respectively. Entire amount of P, K, S and $1/3^{rd}$ of N were mixed with soil with a mixer machine. Dolomite, CD and PM were added uniformly into various pots according to the treatments. Remaining 2/3rd N were applied in two equal splits at 20 and 45 days after transplanting.

Results and Discussion

Results of grain and straw yields of rice, grown under different treatments are presented in Table 2. The addition of organic matter (CD and PM) and lime significantly increased the grain and straw yields of rice. The highest grain yield (23.12 g/pot) was obtained in 2012 years when the polluted soils were amended with PM. The yields of rice grain are statistically similar to CD amended soil but higher to other treatments. The straw yields of rice followed the same trend of grain yields obtained from different treatments and soils (Table 2). The results show that the straw yield of crops grown on industrial waste polluted soils had increased with increasing amount of various soil amendments. The lowest yield was obtained from polluted soils with no amendment (control pot).

Addition of organic materials could alleviate the Cd toxicity in plants by redistributing them to less available fractions (Azeez *et al.* 2008). Thus organic matter plays an important role in increasing crop yields through decreasing Cd toxicity. The addition of lime also significantly increased the yields, because liming generally decreased the acidity and increased the Ca^{2+} in soil.

There are reports that the availability of Cd decreases as the soil pH increases. Moreover, the Ca^{2+} added through liming competes with Cd^{2+} for sorption sites, in addition to this Ca^{2+} will also reduce the surface negative charge density of soil colloidal particles, thereby influencing the bioavailability of Cd (Naidu *et al.* 1997). These reasons might be responsible for the obtained increase in yields due to liming. Addition of lime showed significant effect on grain yield of rice and decrease in grain Cd-content by 50 per cent through liming the Cd contaminated soil (Sing and Nayyar 1991).

Table 1. Physical and chemical characteristics of the selected soil.

Characteristics	Amount
Sand (%)	37
Silt (%)	36
Clay (%)	27
Texture	Loam
pH	5.46
OM (%)	1.51
Exchangeable Ca (cmol/kg)	2.26
Exchangeable Mg (cmol/kg)	0.78
Exchangeable K (cmol/kg)	0.11
Total N (%)	0.08
Available P (mg/kg)	5.85
Available S (mg/kg)	15.3
Available Zn (mg/kg)	1.73
Available Mn (mg/kg)	65.0
Available Fe (mg/kg)	109
Available Cu (mg/kg)	3.73
CEC (cmol/kg)	12.5
Total Cd (mg/kg)	0.38

Table 2. Effects of lime, CD and PM as a soil amendment on yield of rice.

Treatment	Grain yield (g/pot)		Straw yield (g/pot)	
	2011	2012	2011	2012
Control	21.10b	21.24b	30.44b	30.51b
$Lime_{15}$	21.55ab	21.69b	30.98ab	31.52ab
CD_{80}	22.03a	22.17ab	31.44a	31.78a
PM_{80}	22.97a	23.12a	31.64a	31.87a
CV (%)	2.98	1.99	2.05	3.32
SE (±)	0.13	0.0.09	0.15	0.20

Values within columns followed by same letters do not differ significantly at 5% level.

The concentration of Cd in rice grain and straw were lower in PM amended soils than in CD and lime treated soils (Table 3). The Cd concentrations of rice grain were found 0.34 µg/g and 0.33 - 0.45 µg/g in 2011 and 2012, respectively. In case of straw, Cd concentrations varied from

5.08 and 5.80 µg/g in different years. Application of OM and lime to the soils reduced Cd concentration in the plant under study as compared with control. The concentration of Cd in plants decreased due to lime, CD and PM application over the control treatments. Soil amendment materials act as an immobilizing agent, therefore amended soil contained lower amount of available Cd. Among immobilizing agents, organic amendments have been shown to effectively alleviate Cd toxicity to plants by transforming the metals into less available fractions (Yassen *et al.* 2007). Several studies have reported that OM may reduce Cd availability and mobility via the redistribution of Cd from the soluble or exchangeable form to fractions associated with OM, carbonates, Fe/Mn oxides or the residual fractions (Walker *et al.* 2004, Han Song *et al.* 2010).

Table 3. Effects of lime, CD and PM as a soil amendment on cadmium content of rice.

Treatment	Grain Cd (µg/g)		Straw Cd (µg/g)	
	2011	2012	2011	2012
Control	0.48a	0.45a	5.85a	5.64a
$Lime_{15}$	0.42b	0.39b	5.52b	5.38b
CD_{80}	0.39c	0.36c	5.36c	5.28c
PM_{80}	0.34d	0.33d	5.25c	5.08d
CV (%)	2.78	1.75	1.63	4.10
SE (±)	0.08	0.14	0.13	0.26

Values within columns followed by same letters do not differ significantly at 5% level by DMRT.

The uptake result of Cd was calculated from the yield and Cd concentration data. The total uptake (grain + straw) are presented in Table 4. The uptake of Cd by rice in Cd polluted soils was lower in OM treated soils than in CD and lime treated soils (Table 4). Such variation indicates a variation of Cd retension capacity of those three materials and also their availability for plant uptake. The grain Cd uptake was found to PM treated soils 7.63 - 7.81 µg/pot in different years, respectively which are lower than other treatments.

Table 4. Effects of Lime, CD and PM as a soil amendment on cadmium uptake by rice.

Treatment	Grain Cd (µg/pot)		Straw Cd (µg/pot)	
	2011	2012	2011	2012
Control	10.13a	9.56a	178.1a	172.1a
$Lime_{15}$	9.05b	8.46b	171.0a	169.6a
CD_{80}	8.59c	7.98c	168.5b	167.8b
PM_{80}	7.81d	7.63d	166.1b	161.9b
CV (%)	3.18	2.26	2.48	2.42
SE (±)	0.19	0.04	0.17	0.14

Values within columns followed by same letters do not differ significantly at 5% level.

In case of straw, Cd uptake was 166.1 - 178.1 and 161.9 - 172.1 µg/pot, respectively in 2011 and 2012. The uptake of Cd was higher in control than inorganic and organic amendments treated soils. Between two manures, the effect of PM was better than CD. It was observed that uptake of Cd was lower in 2012 than 2011. Addition of OM residue favors Cd to react with other solid phase fractions, resulting in Cd immobilization and thus they become less available for plant uptake.

Metal absorption by plants is pH dependent and therefore liming is a useful way of reducing the toxicity of Cd (Puschenreiter *et al.* 2005, Dinesh-Mani *et al.* 2007, Liu *et al.* 2011). The beneficial effect of lime in counteracting the Cd toxicity may be attributed to the decreased solubility and mobility of the Cd in soil. Liming significantly reduced Cd uptake mainly due to immobilization of soil-Cd (Wang Neng *et al.* 2011).

The above findings concluded that the management practices like soil amendments are necessary both in the short and long term to produce heavy metal safe food by maintaining stable and affordable crop production. Therefore, PM can play a vital role to produce Cd-safe rice in contaminated soils.

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