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Influence of Soil Amendments on Heavy Metal Accumulation in Crops on Polluted Soils of Bangladesh

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Abstract: Pot experiments with soils from three contaminated sites and an additional field experiment were conducted. The aim of the experiments was to test different organic and inorganic soil amendments to heavy metal uptake and to alleviate toxicity in different agricultural crops. Elements in the extracts were measured by

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plasma emission spectroscopy (ICP-AES). Cadmium in the extracts was measured by atomic absorption spectroscopy (AAS), with a heated graphite-tube system (HGA). The results of the experiment were statistically evaluated by the LSD test. Almost all treatments had positive effects on crop productivity or reduced heavy metal uptake. Organic manures especially reduced manganese (Mn), chromium (Cr), and nickel (Ni) uptake. Iron (Fe) oxides contained in red mud, a by-product of the aluminum industry, reduced soil to plant transfer of zinc (Zn), Ni, cadmium (Cd), and Cr. The results from these experiments show that it is necessary to select and combine amendments taking into account both site and crop characteristics.

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INTRODUCTION

Bangladesh possesses many industrial sites, whereby waste water and solid wastes are directly discharged into the environment without any treatment or cleaning processes. Agricultural areas are contaminated thereby, and food quality is impaired.

Treatment of soils contaminated by trace metals is classically based on the application of lime and phosphates and the addition of organic matter (1). The addition of lime, however, does not always deliver the aimed effects on the solubility of trace metals (2). Heavy metals in soils are either retained by the solid phase or exist as ions in the soil solution, adsorbed on the soil colloids or as soluble organo-metallic complexes (3). The environmental effects and transport of heavy metals in a soil as well as their uptake by plants are governed by metal mobility (3). The adsorption and coprecipitation of toxic metals with colloidic hydrous oxides are important processes in decreasing metal availability (4). Lime, different types of organic matter, and iron oxides seem to be suitable soil amendments to stabilize soils polluted with heavy metals (5).

Because soil pH is a major factor governing micronutrient availability in soils, lime application might be expected to bring about changes in the levels of some extractable micronutrients. Available Zn, Mn, and Fe tend to be lower in soils with high pH values, whereas Cu is scarcely affected by soil pH (6–8). The pH of soil fundamentally modulates the behavior and availability of heavy metals in soil for plants, through adsorption or precipitation of metals, and formation of insoluble hydroxides, carbonates, and organic complexes (9–18). Adsorption of heavy metals onto clay minerals and organic matter is also increased with increasing soil pH conditions (9). The availability of trace elements to plants is generally larger at low pH than at high pH, and the effect of an increase in soil pH value, by liming of soil, for example, is a reduction in metal absorption by plants (10).

The main objectives of the present research work were 1) to heavy metal uptake into crops through soil amendments with cow dung, city waste compost, water hyacinth, oil cake, and poultry litter and 2) to reduce heavy metal uptake into crops by applying lime and iron oxides.

MATERIALS AND METHODS

Pot experiments were conducted with contaminated soils from Tongi pharmaceutical, Tejgaon industrial, and Hazaribagh tannery areas, and also a field experiment was conducted at the Tejgaon industrial area. Soil samples were collected from the top layer (0–15 cm) for pot experiments. Different types of organic matter, lime, and iron oxides were added as remedial measures. The experiments were as follows.

Experiment 1

Organic manures applied on Tongi soil (pot exp.); rice variety, BR-11. Basal dose of fertilizer; urea (46%N)-0.39 g, triple-superphosphate (TSP) (45% P_2O_5)-0.10 g, and KCl (60% K_2O)-0.19 g per 8 kg soil/pot (BARC, 1997), with four replicates. Treatments: control, cow dung (73 g/8 kg soil), city waste compost (73 g/8 kg soil), oil cake (mustard, 73 g/8 kg soil), water hycinth compost (73 g/8 kg soil), poultry litter (73 g/8 kg soil).

Experiment 2

Lime applied on Tejgaon soil and Hazaribagh soil (pot exp.); test crops: rice, variety BR-28 (3 plants/pot), wheat, variety Kanchan (3 plants/pot) and tomato, variety Ratan (1 plant/pot). Basal dose of fertilizer at low rate for rice (11); urea (46% N)-0.56 g, TSP (45% P_2O_5)-0.13 g, and KCl (60% K_2O)-0.27 g per 8 kg soil/pot, four replicates. Basal dose of fertilizer at low rate for wheat (11); urea (46% N)-0.50 g, TSP (45% P_2O_5)-0.15 g, and KCl (60% K_2O)-0.26 g per 8 kg soil/pot, four replicates. Basal dose of fertilizer at low rate for tomato (11); urea (46% N)-0.70 g, TSP (45% P_2O_5)-0.22 g, and KCl (60% K_2O)-0.51 g per 8 kg soil/pot, four replicates. Treatment: 36 g/8 kg soil limestone (calcitic) (powder form).

Experiment 3

A microplot field experiment, size of plots; $(1\ m \times 1\ m)^2$, with rice, variety BR-28 was conducted on Tejgaon industrial area. Lime (calcitic) (powder form) (10 t/ha) was applied as a treatment. Rice was harvested at flowering stage with four replicates.

Experiment 4

Pot experiment with red mud application. Soils: Hazaribagh tannery soil, Tejgaon soil, 8 kg/pot, crop: rice, variety BR-28, 3 plants/pot, four replicates. Treatment: 80 mg red mud/pot.

Soil samples were digested with HCl:HNO_3 (3:1), and plant samples were digested with a HNO_3:$HClO_4$ (5:1) mixture in closed systems. All elements with exception of Cd and Hg were measured in the extracts by plasma emission spectroscopy (ICP-AES) (12). Cadmium was measured in the extracts by atomic absorption spectroscopy (AAS), with a heated graphite-tube system (HGA) (12). Mercury (in soil) was measured by AAS and mercury-hydride system (MHS-20) (12). A gold-platinum net was used in Hg determination.

The results of the experiment were statistically evaluated by the LSD test (12). The latter was used for testing the significance of differences between mean values. The 0.05 level of probability was chosen for the statistical judgment.

RESULTS

Organic Manures

Carbon and nitrogen (N) contents of the five applied organic materials varied considerably. The highest nitrogen content was in oil cake (5.24%), followed by cow dung (1.99%), poultry litter (1.44%), water hyacinth (0.49%), and city waste (0.47%). The pH values of all organic materials were between 6.34 and 7, neutral or slightly acid. Excluding the city waste compost, which exhibits allevated levels of Zn (508 mg/kg), lead (Pb) (173 mg/kg), Cd (2.8 mg/kg), copper (Cu) (297 mg/kg), and mercury (Hg) (514 mg/1000 kg), all organic materials can be classified as less contaminated and suitable for agricultural use according to their heavy metal concentrations. Manganese contents were higher in cow dung, water hyacinth, and poultry litter. C:N ratios of the organic material ranged from 7.2 (oil cake) to 15.8 (poultry litter). Oil cake had an extremely low value.

Tongi Soils

The amendment of organic residues did not significantly alter rice grain yields (Table 1). Oil cake showed a negative influence on plant growth and city waste compost seemed to improve yields followed by poultry litter and water hyacinth compost (Table 1). Accumulation of manganese (Mn), chromium

Table 1. Impact of organic manures on heavy metal concentration, rice variety BR-11

	Rice grain					
Parameter	Control (no amendment)	Cow dung	City waste	Oil cake	Water hyacinth	Poultry litter
			Rice grain (mb/kg)			
DM	92.5B	105B	106.3B	57.7A	96.3B	96.8B
Mn	52A	44A	55A	48A	36A	41A
Zn	20.3A	26AB	25AB	31B	24AB	21A
Cu	6.3A	6.3A	6.3A	6.8A	6.5A	6.8A
Ni	2.46B	2.27B	1.53A	1.37A	1.56A	1.19A
Cd	0.05A	0.04A	0.02A	0.03A	0.05A	0.04A
Cr	4.06 C	3.63 C	2.61B	1.86AB	2.29AB	1.42A
			Rice shoot (mg/kg)			
DM	156.3A	155A	172.5A	137.5A	168.8A	131.3A
Mn	362A	356A	365A	318A	159B	129B
Zn	76A	134B	96A	96A	106AB	104A
Cu	8.7AB	8.9AB	9.8ABC	10.9 C	7.9A	10.5BC
Ni	0.91B	0.61A	0.91B	0.62AB	0.67AB	0.51A
Cd	0.06AB	0.07AB	0.07AB	0.05A	0.1B	0.07AB
Cr	0.99AB	0.72AB	0.91AB	0.74AB	1.33B	0.57A

Mean values with the same letters in rows are not significantly different ($p \leq 0.05$) by LSD test. DM, dry matter.

(Cr), and nickel (Ni) in rice straw and grains were suppressed by organic residue applications (Table 1).

Pot Experiments on Tejgaon Soil

Rice

Dry weights (DW) of grain, shoot, and root were significantly lower in the unpolluted soil from Bajitpur than on the Tejgaon soil. Higher soil fertility of the Tejgaon soil, compared with the Bajitpur soil (probably due to a more favorable pH and a considerably higher N_t), produced high yields (Table 2).

Liming of the Tejgaon soil did not result in significant changes in yield parameters of variety BR-28, which implies that soil fertility was not improved by liming or heavy metals at levels present seem not to have a negative influence on rice productivity on this soil. Moreover, there was a tendency for improved root growth in the lime treated pots (14). Root fresh

Table 2. Result of chemical analysis of tomato and rice samples grown on Bajitpur (unpolluted soil), Tejgaon and Hazaribagh soil, DW in g/pot (tomato, 1 plant/pot and rice 3 plant/pot), test of lime treatment

	Tomato fruit			Tomato shoot		
	Bajitpur soil	Lime + Tejgaon soil	Tejgaon soil	Bajitpur soil	Lime + Tejgaon soil	Tejgaon soil
DW	40A	62B	42A	15A	34B	32B
Mn (mg/kg)	44.6AB	37.7A	59.33B	1364A	1114A	1355A
Zn (mg/kg)	11.3A	13.9B	12.6AB	24.8A	36.2B	32.0AB
Cu (mg/kg)	60.8A	170B	194C	782A	3745B	5743C
Ni (mg/kg)	4.8A	14.4B	21.11C	24.89A	46.57A	86.9B
Pb (mg/kg)	0.69A	0.64A	0.96A	6.08A	7.82A	35.7B
Cd (mg/kg)	0.39A	0.18B	0.31A	3.58B	2.76A	3.21AB
Cr (mg/kg)	1.42A	3.7AB	7.66B	26.73B	3.71A	6.18A
	Rice grain			Rice shoot		
	Bajitpur soil	Lime + Tejgaon soil	Tejgaon soil	Bajitpur soil	Lime + Tejgaon soil	Tejgaon soil
DW	49A	160B	158B	49A	106B	104B
Mn (mg/kg)	90AB	96.8B	125.9C	443A	392A	866CD
Zn (mg/kg)	3.7B	6:00AM	4.2B	3.06D	7.67E	5ABC
Cu (mg/kg)	34CD	46AB	48.0AB	62.9A	87.9AB	146E

Ni (mg/kg)	0.32A	0.33A	1.03B	0.65A	0.58A	0.55A
Pb (mg/kg)	<0.02	0.66AB	4.55C	1.28BC	0.73C	1.60A
Cd (mg/kg)	<0.02	<0.02	<0.02	<0.02	0.06A	0.32B
Cr (mg/kg)	0.95A	1.2AB	1.4AB	0.47A	1.2AB	1.6BC

	Rice grain			Rice shoot		
	Bajitpur soil	Lime + Hazaribagh soil	Hazaribagh soil	Bajitpur soil	Lime + Hazaribagh soil	Hazaribagh soil
DW	36A	46A	39A	34A	58B	47AB
	mg/kg					
Mn (mg/kg)	56B	22A	58B	138.9A	148.1A	183AB
Zn (mg/kg)	50C	44C	25AB	3.06A	5.5BC	3.00A
Cu (mg/kg)	23C	26.7C	30.1AD	35.8BC	28.6B	41.3CD
Ni (mg/kg)	0.39A	0.52A	0.94B	0.48AB	0.27A	0.66B
Pb (mg/kg)	0.03D	0.12A	0.27C	0.58C	0.57C	0.85D
Cd (mg/kg)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cr (mg/kg)	1.45A	2.44A	6.24C	1.88B	3.6BC	17.6E

Mean values with the same letters in rows are not significantly different($P \leq 0.05$) by LSD test. DM, dry matter.

and dry weight and root length seemed to be positively influenced by the lime treatment (Table 3).

Micronutrient concentrations, especially manganese (Mn), copper (Cu), zinc (Zn), and chromium (Cr) were 2.0, 1.68, 2.32, and 3.49 times higher in shoots of BR-28 on Tejgaon soil compared with the shoots of BR-28 on Bajitpur soil (Table 2). Also in grains a similar trend was observed. Manganese, Cu, Ni, and Cr accumulation in grains of BR-28 were 1.39, 1.13, 3.22, and 1.46 times higher, respectively, on Tejgaon soil than on Bajitpur soil (Table 2). The grains of BR-28 on Tejgaon soil accumulated significantly higher amounts of Pb compared to the Bajitpur soil.

The ameliorative effect of lime was clearly observed for the Tejgaon soil. Manganese, zinc (Zn), lead (Pb), and Cr concentrations were 54%, 40%, 54%, and 55% lower in shoots of BR-28, and Mn, Zn, nickel (Ni), Pb, and Cr concentrations were 23%, 3.8%, 68%, 85.9%, and 14% lower in grains of BR-28 in limed pots compared to the unlimed pots (Table 2).

Wheat

The variety Kanchan exhibited the highest grain yield, followed by Akbar and Agrani. Kanchan did not show significantly different grain yields and shoot length on Tejgaon and Bajitpur soil. However, straw biomass and the number of tillers were significantly lower on Bajitpur soil, which reflects once again the poor nitrogen status of this soil. The lower number of tillers was compensated by a significantly higher 1000-grain weight on the Bajitpur soil. No significant difference in 1000-grain weight occurred among the varieties.

As observed for rice, lime treatments had no significant influence on wheat yield parameters. Nitrogen, sulfur (S), magnesium (Mg), calcium (Ca), copper (Cu), zinc (Zn), nickel (Ni), and chromium (Cr) concentration in grains were 32%, 11.6%, 29.1%, 356%, 71%, 832%, 11.6%, and 119% higher on Tejgaon soil than on the Bajitpur soil, which was considered as unpolluted agricultural soil. Lead concentration in wheat grain (variety-Kanchan) were also significantly higher on Tejgaon soil (6.24 mg/kg) than on the unpolluted Bajitpur soil (Figure 1).

Tomato

The response of tomato was clearly different from the two cereal species described above (Table 2). Most of the yield parameters were lowest for the Bajitpur soil; especially tomato fruit fresh matter and shoot dry matter production on Bajitpur soil were significantly lower than on the Tejgaon soil. Bajitpur soil exhibited 53% lower shoot DW than the Tejgaon soil, which reflects once again the poor nitrogen status of the Bajitpur soil. Also DW of tomato fruit production was significantly higher by 48% in limed pots

Table 3. Result of the chemical analysis of rice grain and shoot samples; (pot experiment with rice and red mud application on Tejgaon and Hazaribagh soil)

	Rice grain		Rice shoot		Rice grain		Rice shoot	
	Hazaribagh soil	Hazaribagh soil + iron oxide	Hazaribagh soil	Hazaribagh soil + iron oxide	Tejgaon soil	Tejgaon soil + iron oxide	Tejgaon soil	Tejgaon soil + iron oxide
DW	39A	90B	47A	63A	158D	126C	104B	95B
%N	1.98 B	1.59A	1.96B	1.18A	1.61A	1.46A	0.98A	1.09A
%P	0.16A	0.16A	0.19A	0.20A	0.41B	0.19A	0.25B	0.25B
%S	0.6A	0.22B	0.37A	0.28A	0.52D	0.40C	0.69B	0.39A
%K	0.36AB	0.41B	0.81A	1.93B	0.32A	0.40B	1.23A	2.15B
%Mg	0.58A	0.49A	1.09C	0.72B	0.69A	0.45A	0.82B	0.48A
Ca (mg/kg)	621A	500B	4506A	5183AB	623A	576AB	5512B	4698AB
Fe (mg/kg)	178A	278A	1.2A	93B	195A	219A	1.0A	113B
Mn (mg/kg)	20A	13A	164B	170B	88B	22A	164B	95A
Cu (mg/kg)	24AB	28AB	13A	33B	11A	38B	18A	21A
Zn (mg/kg)	29.5B	22.4A	40.8A	28.6A	48.0D	42.3C	205C	104B
Ni (mg/kg)	0.94B	0.76AB	0.66A	0.09B	1.52C	0.39A	0.88A	0.55A
Pb (mg/kg)	0.26A	0.02A	0.85B	0.52A	4.55B	0.33A	1.20C	0.44A
Cd (mg/kg)	0.04B	0.01A	0.03A	0.001A	0.10D	0.06C	0.25B	0.04A
Cr (mg/kg)	6.24C	1.93AB	26.7C	17.6B	2.65B	1.39A	5.54A	1.10A

Mean values with the same letters in rows are not significantly different ($p \leq 0.05$) by LSD test. DM, dry matter.

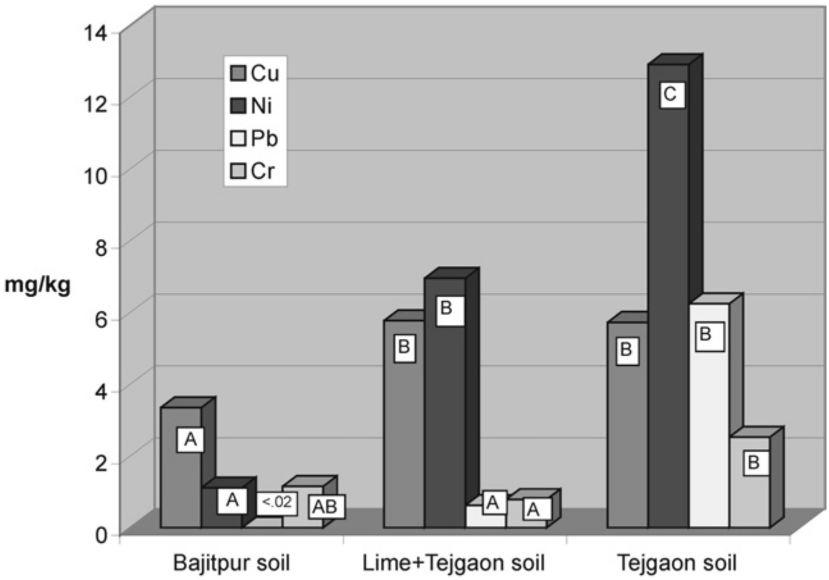

Figure 1. Effect of liming on Cu, Ni, Pb, and Cr concentrations of wheat grains on Tejgaon soil. Histograms with same letters are not significantly different ($p \leq 0.05$) by LSD test.

compared to the unlimed pots with Tejgaon soil. This effect of liming could be due to heavy metal toxicity in the Tejgaon soil, which was alleviated by the lime treatment and this is supported by the results of the heavy metal analyses (Table 2). Considering the limit values for heavy metals in plants, tomato shoots on Tejgaon soil concentrated more manganese (Mn), copper (Cu), zinc (Zn), nickel (Ni), lead (Pb), and chromium (Cr) than the permissible value (19). The tomato fruits on Tejgaon soil accumulated 4 times more Cr than the limit value. Due to lime application in Tejgaon soil, a tendency of increasing Cu concentration was observed for both shoots and fruits (Table 2).

Microplot Field Experiment with Rice on Tejgaon Soils

Liming did not significantly affect yield parameters but significantly ameliorated heavy metal concentration in rice (BR-28) shoots and roots. Manganese, Zn, Ni, Pb, Cd, and Cr concentrations were less in shoots on limed plots than on unlimed plots (Table 4). Liming increased Cu accumulation into rice shoots of variety BR-28 considerably (Figure 2). Copper concentration was also

Table 4. Results of chemical analysis of rice samples (variety, BR-28); microplot field experiment on Tejgaon soil, test of lime treatment (25 seedlings/plot)

	Shoot		Root	
Parameter	Lime + Tejgaon soil	Tejgaon soil	Lime + Tejgaon soil	Tejgaon soil
DW, kg/plot	2.92A	3.22A	0.39A	0.54A
Length, cm	83B	86B	52A	49A
Mn (mg/kg)	91A	157B	42A	55A
Cu (mg/kg)	161B	24A	44A	36A
Zn (mg/kg)	46A	91B	174A	197A
Ni (mg/kg)	2.3A	4.0B	12A	19B
Pb (mg/kg)	2.3A	9.7B	16A	36B
Cd (mg/kg)	0.02A	0.05B	0.10A	0.05A
Cr (mg/kg)	2.2A	4.9B	20A	37B

increased by 22% in rice roots due to liming. A similar effect of lime was observed in the pot experiments with wheat and tomato plants.

Pot Experiment with Rice on Hazaribagh Soil

Biomass production by BR-28 on Hazaribagh soil was significantly different from that on Bajitpur soil. BR-28 produced significantly higher shoot length on Bajitpur soil than on Hazaribagh soil. Liming increased grain yields (DW) by 15% on Hazaribagh soil compared with the unlimed pots

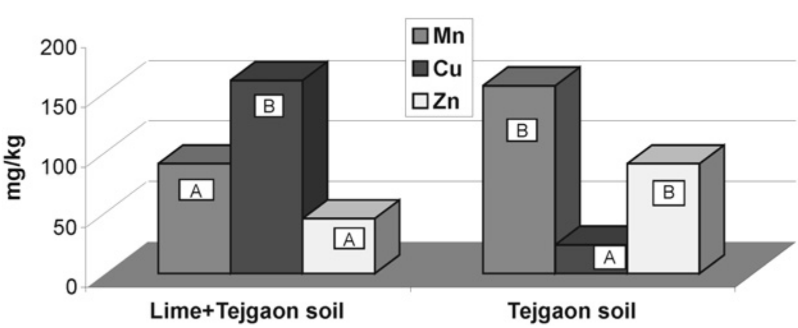

Figure 2. Effect of liming on Mn, Cu, and Zn concentrations of rice shoots on Tejgaon soil (micro-plot field experiment). Histograms with same letters are not significantly different ($P \leq 0.05$) by LSD test.

(Table 2). Because of the ameliorative effect of lime, Zn, Ni, Pb, and Cr, concentrations of shoots and grains of BR-28 were reduced significantly as compared to the unlimed pots.

Pot Experiments on Hazaribagh and Tejgaon Soil with Rice and Red Mud Application

Another pot experiment with the Hazaribagh soil and the Tejgaon soil and rice focused on the effect of red mud application on heavy metal toxicity and accumulation.

In the Hazaribagh soil, red mud ameliorated plant growth and yield parameters significantly (Table 3). Grain yield increased by more than a factor of 2. The 1000-grain weight, shoot length, and biomass production were positively influenced as well. On Tejgaon soil, the effect of red mud on grain yield production was less clear. Grain yields decreased significantly with red mud application, but 1000-grain weight and shoot length increased by 8% and 6%, respectively. The suppression of grain yield might be due to a lower availability of macronutrients in red mud treated pots (Table 3).

The chemical analysis of rice shoot and grain samples clearly reflected the heavy metal toxicity symptoms of the rice plants (Table 3) (e.g., heavy metal chlorosis was clearly demonstrated by the low Fe contents in rice shoots on not-amended soils). On Hazaribagh soil, plants in red mud-treated pots exhibited significantly lower N, Mg, and slightly lower S accumulation in shoots, and in grains significantly lower N, S, and Ca accumulation than in the pots without red mud. On the other hand, potassium (K) and Ca concentrations increased in shoots and also K in grains. On Tejgaon soil, N and K accumulation in shoots and K in grains of BR-28 increased on red mud-treated pots, but accumulation of other macro-nutrients decreased in shoots and grains.

Heavy metal accumulation by BR-28 was significantly ameliorated in both soils. Manganese accumulation by rice shoots on Hazaribagh soil was not significantly different although its concentration was above the toxic limit (40–100 mg Mn/kg). On Tejgaon soil, red mud diminished Mn concentration into rice shoots by 42%. On Hazaribagh and Tejgaon soil, 35% and 75% less Mn was concentrated in the grains of BR-28, respectively, following red mud application. Red mud application suppressed Cu, Zn, Ni, Pb, Cd, and Cr concentration in shoots of BR-28 by 61%, 30%, 86%, 39%, 97% and 34%, respectively, compared to the untreated pots with Hazaribagh soil (Table 3). On Tejgaon soil, Cu, Ni, and Cr accumulations by shoots were not significantly different among treatments, but 49%, 63%, and 84% less Zn, Pb and Cd concentrations were observed, respectively, due to red mud application. The ameliorative effect of red mud application was also clearly observed in the grain samples for both soils. Zinc, Ni, Pb, Cd, and Cr concentration into rice grains diminished by 24%, 19%, 92%, 75%, and 69%, respectively, due to red mud application on Hazaribagh soil (Table 3). On Tejgaon soil, the grains of BR-28 exhibited 71%, 12%, 74%, 93%, 40%, and 48% lower Cu, Zn, Ni, Pb, Cd, and Cr accumulation on red mud-treated pots compared with the untreated pots (Table 3).

DISCUSSION

The dry matter yield of rice grain was increased 27% by the application of cowdung, which was also reported before (19). The short root lengths in the city waste-treated pots probably exerted toxicity due to heavy metals contained in it. Reduction in shoot and root length was due to heavy metal toxicity (Ullah and Gerzabek, 1990) (17, 20–22). The positive influence of organic substances on plant growth is a well-known phenomenon, which is due to indirect effects of humic substances acting as suppliers and regulators of plant nutrients and due to direct effects of humic substances (e.g., as respiratory catalysts) (23, 24). On the other hand, oil cake exerted some toxic effect on physiological functions, especially in the process of grain production. This may be in connection with the unfavorable C:N ratio of the oil cake of approximately 7, which resulted in the highest nitrogen concentration in biomass in this treatment. The uncontrolled use of organic materials may give rise to problems due to their high salinity or high heavy metal contents (25). They can block the present nitrogen by inducing a competition between microorganisms and plants, diminishing the oxygen at the root level or raising the temperature in such a way so that levels are reached plant are incompatible with normal plant development. They can also cause Q3 an accumulation of phytotoxic substances such as organic acids of low molecular weight and different pathogenic organisms (26, 27). The adsorption of metal could be ascribed more to the type than to the amount of organic matter (28–31). The complexation of heavy metals with organic matter affects the distribution of metal ions between the adsorbed and soluble phases of the soil (32), and the positive effect of organic compost on adsorption and retention of Zn and Cd in soil is well known (33, 34). Grains and roots of rice (BR-11) had the highest concentration of Zn in oil cake amendments (31 mg/kg). The significantly larger increase in Zn content due to oil cake addition can be explained by possible changes in metal complexation that took place during composting which may have increased the availability of Zn for rice (35). Muck and manure were the two best soil amendments, which showed a 73% and 63% reduction of Pb uptake, respectively, in soils with a 25% (by volume) addition of organic matter (16). The importance of increased cation exchange capacity and organic matter in reducing Pb uptake was already emphasized (28, 36–38).

Fresh weight of tomato shoot and dry weight of tomato fruits were significantly enhanced in limed pots compared with the unlimed pots with Tejgaon soil. The positive effect of liming on tomato yields was also reported especially for acid soils (39).

The ameliorative effect of lime was clearly observed in Tejgaon and Hazaribagh soil for the three crops and for both pot and field experiments. When soil pH increased, root absorption of most heavy metal cations decreases. Available Zn and Mn tend to be lower in soils with higher pH values, reported by many workers (8, 40). The Cr concentration in shoots and grains were extremely low in comparison with total concentration on Hazaribagh soil. Tannery waste application increased total Cr levels of soil but did not result in significantly increased Cr concentration in wheat grain (40). The general toxicity limit for Cr is 1–2 ppm (41). It is most interesting that liming increased Cu uptake into rice shoots of variety BR-28 considerably. At the first glance, this result seems to be an artefact. One would expect a decrease in Cu uptake by liming an acid soil like the Tejgaon soil. However, there is sufficient evidence in the literature (42, 43) that liming increase Cu availability to plants by enhancing mineralization of soil organic matter and at the same time inducing a higher portion of copper being present in soil solution in the form of organic chelates. In our case, Cu concentrations in rice shoot tissues even reached values suggested to be toxic according to the literature, after liming, although yield parameters did not show toxicity clearly. It is also interesting that liming diminished both Mn and Zn concentrations by a factor of 2 in BR-28.

Iron and Mn oxides are known to absorb or complex metallic ions. Several studies have been undertaken to determine the influence of these oxides on the extractable concentrations of metals in soils (44). Reduced conditions can be achieved by adding ferrous iron. For example, under reduced conditions mobile Cr (VI) will be converted to Cr (III), which precipitates readily in normal soil pH ranges (45). The addition of ferrous sulfate to soils contaminated with chromate washing residue in Japan was successful in reducing soluble hexavalent Cr to insoluble trivalent chromium (46). Hydrous oxides of Fe are well known to enhance metal immobilization in soils (47, 48). Thirty-five to 50% decrease in Ni uptake by the shoot of ryegrass in hydrous iron oxide treated pots compared with the untreated pots was reported by many authors (47–49), which supports our findings.

CONCLUSION

The amendment by organic residues significantly improved soil fertility indicated by an increase of harvested rice. Cow dung was shown to be most effective, followed by city waste compost, poultry litter, and water hyacinth compost. Oil cake showed a negative influence on plant growth. Contents of

Mn, Cr, and Ni in rice straw and in rice grains were reduced by organic residue applications. The tested cereal crops after lime application on Tejgaon soil did not show a significant effect in harvested yield. For tomato plants, however, after liming the biomass yield was nearly doubled. Also at the Hazaribagh site, the positive effect of liming was proven. In all experiments, liming led to a significant suppression of heavy metal transfer into above ground biomass and into harvested products. Only Cu showed an aberrant behavior: for this element no reduction was observed. Applied in small amounts, the ferric oxides led to an increase in biomass production and improved yield for rice plants and caused significant reductions of soil to plant transfer of Zn, Ni, Cd, and Cr. In summary, it may be stated that all investigated methods (selection of suitable plant varieties as described in part 1 of the publication, lime application, soil amendments with organic residues and red mud) caused partly significant reductions of heavy metal accumulation from contaminated soils. Nevertheless, for the optimization of the reduction effects, it is necessary to select and combine the different methods according to site specific and variety specific characteristics.

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