Influence of Cereal Varieties and Site Conditions on Heavy Metal Accumulations in Cereal Crops on Polluted Soils of Bangladesh

A. S. Chamon
Department of Soil, Water and Environment, University of Dhaka, Bangladesh

M. H. Gerzabek
Institute of Soil Research, University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria and Austrian Research Centers Seibersdorf, Seibersdorf, Austria

M. N. Mondol
Aftab Biotech, ABFL, Bhagalpur, Bajitpur, Kishoregonj, Bangladesh

S. M. Ullah and M. Rahman
Department of Soil, Water and Environment, University of Dhaka, Bangladesh

W. E. H. Blum
Institute of Soil Research, University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria

Abstract: The present work describes results of pot experiments and field studies including three contaminated sites in Bangladesh. The aim was to investigate possible differences between cereal varieties with regard to heavy metal uptake and accumulation. A total of 10 rice (Oriza sativa L.) and 3 wheat (Triticum aestivum) varieties were studied. Soil samples were digested with HCl:HNO₃ (3:1), and plant
samples were digested with a HNO₃:HClO₄ (5:1) mixture in closed systems. All elements with exception of cadmium (Cd) and mercury (Hg) were measured in the extracts by plasma emission spectroscopy (ICP-AES). Cadmium was measured by atomic absorption spectroscopy (AAS), with a heated graphite-tube system (HGA). Mercury was measured by AAS, using mercury-hydride system (MHS-20). The rice variety BR-14 exhibited the highest yield and in most cases the lowest heavy metal accumulations at harvest. Wheat varieties showed significantly different heavy metal accumulation. It can be concluded that selection of cereal varieties may add to safer crop production on heavy metal contaminated sites. Nevertheless, site specificity of this measure has to be taken into account.

Keywords: Cereal varieties, heavy metals, polluted soils, uptake

INTRODUCTION

Bangladesh has at present about 30,000 large and small industrial units. They are discharging their wastes and effluents into the natural ecosystems in most cases without any treatment, thus causing environmental pollution especially with heavy metals and organic toxics. These hazardous wastes and effluents are generally discharged in low-lying areas, along roadside, or in the vicinity of the industrial installations. In addition, fertilizers and pesticides are being randomly used in agricultural lands by uneducated farmers. Industrial effluents and wastes lead to significant pollution of soils and plants around Dhaka city (Nuruzzaman, Gerzabek, and Ullah 1995). The important heavy metals discharged from industries in Bangladesh are cadmium (Cd), lead (Pb), chromium (Cr), mercury (Hg), zinc (Zn), arsenic (As) and in few cases copper (Cu) and manganese (Mn) (Nuruzzaman, Gerzabek, and Ullah 1995). Heavy metals like As, Cr, Cd, Pb, Hg, Cu, Zn, and nickel (Ni) are toxic for plants and humans. These metals, even in trace amounts, interfere with or inactivate enzymes of living cells (Rahman 1992); therefore, their discharge into the environment must be minimized and carefully controlled.

Metal contamination of agricultural soils by atmospheric deposition or by disposal of sewage sludge constitutes a risk of either leaching of metals into the groundwater or excessive accumulation in the top soil (Adriano 1992; Kabata-Pendias and Pendias 1992). Typical pollution events of heavy metals include Cd, Pb, and Cu pollution in the paddy soils (Lee and Ling 1983; Chen 1988; 1991; Reith 1983). Although some metals are immobile and persistent, other metals are mobile, and, therefore, the potential of transfer either through the soil profile down to the groundwater aquifer or via plant-root uptake (bioavailability) is likely. Cadmium and Pb, which have no known beneficial effects, may become toxic to plants and animals if their concentrations exceed certain values (Adriano 1986; Gough, Shacklette, and Case 1979). Nickel, Cu, and Zn are three micronutrients
essential for plant nutrition. Nickel is an essential component of the enzyme urease, but when Ni concentrations in vegetative tissues of plants exceed 50 mg/kg dry weight (DW), plants may suffer from excess Ni and exhibit toxicity symptoms. Once absorbed, Cu apparently accumulates in roots, even in cases where roots have been damaged by toxicity (Adriano 1986). Zinc phytotoxicity is reported relatively often, especially for acid and heavily sludged soils (Kabata-Pendas and Pendias 1992). The physiology and biochemistry of the toxic effects of Zn in plants are likely to be similar to those reported for other heavy metals; however, Zn is not considered to be highly phytotoxic (Kabata-Pendas and Pendias 1992).

Dicotyledonous crop plants tend to absorb more metals than monocotyledonous crops (Sauerbeck 1982; Kabata-Pendas, Piotrowska, and Dudka 1993). Monocots, which include most of the cereal crops, are known excluders of metal cations (Baker 1991). Metals are known to be poorly transported to grain tissues (Sauerbeck 1982; Kabata-Pendas, Piotrowska, and Dudka 1993; Baker 1991). Thus, cereal crops such as wheat, barley, oat, rye and corn may be considered as excluders (Kabata-Pendas, Piotrowska, and Dudka 1993).

A large number of parameters regulate the chemical fate of specific elements in soils and determine their solubility and availability for plant uptake. The plant uptake of chemical species in soil solution is also dependent on a number of plant factors. These include physical processes, such as root intrusion, water and ion fluxes and their relationship to the kinetics of membrane transport, ion interactions, and metabolic fate of absorbed ions, and the ability of plants to adapt metabolically to changing metal stresses in the environment (Cataldo and Wildung 1978). The characteristics and behavior of an individual plant species or variety are important in determining the amounts of heavy metals that are taken up from soils. There are few reports of differing rates of absorption of Zn$^{2+}$ and Mn$^{2+}$ between species and varieties (Loneragan 1975; Chino, Kawashima, and Takahashi 1997). However, many comparisons have been made between the content of individual heavy metals in the shoot of soil-grown plants. These often show distinct differences between species or varieties (Loneragan 1975; Fleming 1973). Although such differences may reflect differing rates of absorption, they will also depend on the extent of transport from root to shoot. The highest proportions of heavy metals taken up by plants are retained in the root, as for instance, with Pb and Cd in ryegrass (John 1973; Jarvis and Jones 1978) and Mn in some medic and clovers (Loneragan 1975). The proportions retained vary with the metal and plant species (Peterson and Alloway 1979). The differing responses of species and varieties to environmental changes will also contribute to differences in uptake of heavy metals from soils. These effects may be exerted either through the root or shoot or through the whole plant. Generally, the growth rate of different species and varieties is different (Chino, Kawashima, and Takahashi 1997).
Available data on the impact of industrial pollution in Bangladesh especially on soils and crops and the mobility in the human food chain are quite limited. No systematic research work has yet been done on the amelioration of heavy metal uptake into crops from polluted soils. Therefore, the agrobased Bangladesh needs careful investigations.

The main objectives of the present research work were 1) to reduce heavy metal uptake into agricultural crops and thus to minimize metal entry into the food chain; 2) to compare heavy metal accumulation in crops grown in contaminated and uncontaminated soils; 3) to select rice varieties, having low affinity for heavy metals; and 4) to compare heavy metal accumulation of rice with that of wheat.

MATERIALS AND METHODS

Within this research program pot and field experiments were carried out with different varieties of field crops on three different soils collected from Tongi pharmaceutical area (contaminated mainly by phenols of pharmaceutical industry), Tejgaon industrial area (polluted by Zn, Pb, and Cd), and Hazaribagh tannery area (contained elevated concentration of Fe, Cu, Mn, Zn, Cd, Cr, and Pb), all in the vicinity of Dhaka.

Rice pot experiments were (3 plants/pot) varieties: BR-11, BR-30, BR-22, BR-25, BR-28, BR-29, BR-26, BR-16, BR-14, and BR-3; basal dose of fertilizer at low rate: urea (46%N)-0.56 g, triple-superphosphate (TSP) (45% P₂O₅)-0.13 g, and KCl (60% K₂O)-0.27 g per 8 kg soil/pot, 4 replicates in boro season and urea (46%N)-0.39 g, TSP (45% P₂O₅)-0.10 g and KCl (60% K₂O)-0.19 g per 8 kg soil/pot, in aman season (BARC (Bangladesh Agricultural Research Council) 1997) with four replicates. The rice varieties BR-11, BR-30, BR-22, and BR-25 were grown on Tongi soil, and the other six varieties were grown on Tejgaon and Hazaribagh soil.

Pot experiments with wheat were (3 plants/pot) varieties: Kanchan, Agrani, and Akbar; basal dose of fertilizer at low rate: urea (46% N)-0.50 g, TSP (45% P₂O₅)-0.15 g, and KCl (60% K₂O)-0.26 g per 8 kg soil/pot, four replicates (BARC 1997).

Phosphorus, K, Ca, Na, and Mn in the soil was extracted by using calcium-lactate and calcium-acetate (CAL), calcium-lactate (DL), barium chloride with ethanolamine and HCl and barium chloride without ethanolamine and HCl (BT), and EDTA (ethylenediamine-tetra-acetic acid) extractants. Five grams (for BT and CAL), 2 g (for DL), and 10 g (for EDTA) of soil were used for the extraction.

A microplot field experiment with six rice varieties (BR-28, BR-29, BR-26, BR-16, BR-14, and BR-3) was conducted at Tejgaon site with plots size (1 m × 1 m)². The pot experiments were carried out in Dhaka, Bangladesh. The samples (soil and plant) were analyzed at the Austrian Research
Centre, Seibersdorf. The pots were laid out in a completely randomized design with four replications. Soil samples were digested with HCl:HNO₃ (3:1), and plant samples were digested with a HNO₃:HClO₄ (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) (Blum, Spiegel, and Wenzel 1996). Cadmium was measured in the extracts by atomic absorption spectroscopy (AAS), with a heated graphite-tube system (HGA) (Blum, Spiegel, and Wenzel 1996). Mercury (in soil) was measured by AAS, using mercury-hydride system (MHS-20) (Blum, Spiegel, and Wenzel 1996). A gold-platinum net was used in Hg determination. The soil samples collected from Tongi pharmaceutical area belong to the Khilgaon series which comprises seasonally flooded, poorly drained soils. The Khilgaon series, developed on heavy Madhupur clays, occupy mainly deep valleys within the Madhupur tract. The Tejgaon soils including the Khilgaon series are seasonally flooded, with standing water up to 110–120 cm for more than 6 months. The soil series (around Hazaribagh) belong to Khalercher, developed on mainly medium-textured Brahmaputra alluvium in permanently wet channels or depressions, of the old and young Brahmaputra.

The results of the experiment were statistically evaluated by the LSD test (Blum, Spiegel, and Wenzel 1996). The latter was used for testing the significance of differences between mean values. The 0.05 level of probability was chosen for these statistical judgments.

RESULTS

Soils

Some properties of the four experimental soils are shown in Table 1. At the site Tongi, pollutants consist mainly of organic compounds (phenols of pharmaceutical industry). The soil of Tejgaon is acidic (pH 5.7) and contains high amounts of organic matter and elevated concentrations of Zn (685 mg/kg), Pb (136 mg/kg), and Cd (2.6 mg/kg). The Hazaribagh soils are polluted by high amounts of tannery waste water effluents, leading to highly elevated concentration of Fe, Cu, Mn, Zn, Cd, Cr, and Pb in soil profiles. The Bajitpur soil was used as an unpolluted soil.

Pot Experiment with Rice on Tongi Soil

The yield parameters and heavy metal effects determined after harvest of the pot experiment with different rice varieties on the Tongi soil are shown in Table 2.

Grain yields of rice varieties varied significantly with BR-30 and BR-25 being significantly better in grain dry matter (DM) production than BR-11 and...
BR-22. The highest Mn concentration was in BR-30 and the lowest was in BR-25. Copper concentration of BR-30 grains (8 mg/kg) was significantly higher than in all other three varieties (Table 2). The rice varieties differed also with respect to the contents of Ni in grains. BR-11 had the highest concentration followed by BR-22 and the other two varieties BR-30 and BR-22.

Chromium concentration was significantly highest (4.46 mg/kg) and above the toxic limit (Sauerbeck 1982) in BR-11 (Table 2) and lowest in

### Table 1. Physical and chemical properties of the experimental soils

| Properties     | Tongi | Tejgaon | Hazaribagh | Bajitpur |
|----------------|-------|---------|------------|----------|
| % Sand         | 33.1  | 22.5    | 33         | 30.54    |
| % Coarse Silt  | 23.9  | 18.5    | 23.4       | 19.21    |
| % Fine Silt    | 17.3  | 28.6    | 16.9       | 31.2     |
| % Clay         | 25.7  | 30.4    | 25.1       | 19.05    |
| pH (0.01M CaCl₂) | 7.05 | 5.67    | 7.08       | 4.68     |
| % C            | 1.89  | 8.24    | 1.02       | 1.16     |
| % N            | 0.2   | 0.74    | 0.16       | 0.12     |
| mmol IE/kg (BT extract) |       |         |            |          |
| K              | 0.5   |         | 0.46       |          |
| Ca             | 4.5   | 5.6     | 20.6       | 1.1      |
| Mn             | 0.02  | 0.1     | 0.002      | 0.02     |
| Na             | 0.3   | 0.3     | 4.9        | 0.1      |
| Fe             | 0.1   | 0.01    | 0.03       | 0.01     |
| K (Cal extract) | 81   |         | 229        |          |
| K (DL extract) | 50.7 |         | 213        |          |
| Mn (aq.reg.)   | 314   | 300     | 300        | 375      |
| Mn (EDTA)      | 114   | 91      | 123        | 44       |
| Pb             | 25    | 136     | 24.6       | 17       |
| Mg             | 110   | 240     | 70         |          |
| Ca             | 1467  | 2160    | 5120       |          |
| Zn (aqua regia)| 150   | 685     | 133        | 88       |
| Zn (EDTA)      | 52    | 21      | 17         | 5.5      |
| Fe (EDTA)      | 3.72  | 7.12    | 1.71       | 3.01     |
| Cr             |       |         |            | 11000    |
| Cd             | < 0.02| 2.6     | 0.08       | < 0.02   |
| Cu (aqua regia)| 59.7  | 99.7    | 30.6       |          |
| Cu (EDTA)      | 0.05  | 0.05    | 0.07       | 0.01     |
| Ni             | 28.9  | 40.1    | 21         | 36.1     |
| Hg micro-g/kg  | 153   | 581     | 37         | 50       |
Table 2. Biomass yield and heavy metal concentrations in rice and wheat varieties grown on Tongi and Tejgaon soil; yields in g/pot (3 plants/pot)

| Parameter          | BR-11  | BR-30  | BR-22  | BR-25  | BR-11  | BR-30  | BR-22  | BR-25  |
|--------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| DM g/pot (g/pot)   | 102.6 a| 124 b  | 91 a   | 133.8 b| 155.2 a| 192 bc | 209.4 c| 175 ab |
| Length (cm)        | 101 a  | 108 b  | 115 b  | 133 c  |
| 1000 grain wt      | 13.02 a| 17.17 b| 13.88 a| 13.06 a|
| Mn (mg/kg)         | 45 ab  | 58 b   | 52 ab  | 35 a   | 341 ab | 428 b  | 327 ab | 261 a  |
| Cu                 | 6.25 a | 8 b    | 6.01 a | 6.03 a | 9.01 a | 11 b   | 9 ab   | 10 b   |
| Ni                 | 2.46 b | 1.51 a | 2.24 b | 1.5 a  | 0.91 a | 0.49 a | 1.05 a | 0.79 a |
| Pb                 | 0.26 a | 0.2 a  | 0.23 a | 0.06 a | 1.04 b | 0.56 ab| 0.46 a | 0.81 ab|
| Cd                 | 0.05 a | 0.06 a | 0.06 a | 0.06 a | 0.06 a | 0.11 b | 0.04 a | 0.07 a |
| Cr                 | 4.46 b | 1.76 a | 2.41 a | 2.45 a | 1.04 a | 0.76 a | 0.76 a | 0.59 a |

(continued)
| Parameter      | Bajitpur soil (Kanchan) | Kanchan | Agrani | Akbar |
|----------------|-------------------------|---------|--------|-------|
| DM g/pot       | 24 ab                   | 27 b    | 23 ab  | 19 a  |
| Length (cm)    |                         |         |        |       |
| Zn mg/kg       | 45.38 a                 | 422.8 c | 224.5 b| 250.8 b|
| Cu mg/kg       | 3.35 a                  | 5.72 b  | 7.50 c | 6.63 bc|
| Ni mg/kg       | 1.11 a                  | 12.91 c | 10.45 bc| 8.26 b|
| Pb mg/kg       | < 0.02                  | 6.24 b  | 0.57 a | 0.58 a|
| Cd mg/kg       | 0.06 a                  | 0.05 a  | 0.08 ab| 0.11 b|
| Cr mg/kg       | 1.15 a                  | 2.52 a  | 2.67 a | 1.18 a|

Mean values with the same letters are not significantly different ($p \leq 0.05$) by LSD test.

DM, dry matter.
BR-30, BR-22 and BR-25 also accumulated Cr above the toxic limit. Chromium concentration was higher in grains than in shoots of the different varieties. The highest Cu concentration in shoots was observed in BR-30 (11 mg/kg) and BR-22 (9 mg/kg) had the lowest concentration. The highest Pb concentration was obtained in BR-11 (1.04 mg/kg) and the lowest in rice shoots of BR-22 (0.46 mg/kg). There was no significant difference in Pb concentration among the shoots of BR-30, BR-22, and BR-25. Shoots of different rice varieties showed significant differences in their cadmium content. BR-30 exhibited the highest accumulation of Cd compared with the other three varieties, which were not significantly different from each other (Table 2).

**Pot Experiments on Tejgaon Soil**

Table 2 shows the yield parameters and heavy metal effects determined after harvest of the pot experiment with different wheat and rice varieties on the Tejgaon soil.

**Wheat**

The variety Kanchan exhibited the highest grain yield, followed by Akbar, Agrani, and Kanchan grown on Bajitpur soil. Shoot lengths were not significantly different on Tejgaon soil (Table 2). No significant differences of Mn, Cu, Pb, or Cr concentration of shoots among the wheat varieties were obtained. Zinc content was significantly lower in shoots of Kanchan than the other two varieties, which did not differ significantly. All varieties accumulated Zn in concentrations reported to be toxic to plants (Sauerbeck 1982). Nickel accumulation was significantly higher in shoots of Agrani than in Akbar or Kanchan variety. Chromium concentration in shoots was highest in Akbar followed by Agrani and Kanchan. Manganese, Zn, and Pb concentrations in grains were lowest in Agrani and highest in Kanchan variety. Heavy metal concentrations in wheat grains were significantly higher on Tejgaon soil than on Bajitpur soil. Copper concentration was highest in Agrani and lowest in Kanchan, Ni was highest in Kanchan and lowest in Akbar, Cd was highest in Akbar and lowest in Kanchan, and Cr concentrations was highest in Agrani but lowest in the grains of Akbar variety. Chromium concentrations were lower in grains of all varieties compared to shoots.

**Rice**

Rice grain yields (DW) were highest for BR-14 and lowest in BR-3. Rice grown on Tejgaon soil exhibited significantly higher dry matter yield (DM)
compared with rice grown on the unpolluted soil (Table 3). Shoot length of the rice variety BR-29 was significantly higher than the other varieties. Manganese contents in shoots were above the toxic limit for all varieties, and the highest concentration was in BR-29, followed by BR-28, BR-16, BR-14, BR-26, and BR-3 by that order (Table 3). Grains of all varieties accumulated less Mn, with concentrations being below the toxic limit except for BR-28 (126 mg/kg). The lowest Mn concentration in rice grain was in the BR-16 rice variety.

BR-29 and BR-28 contained the least amounts of Cu in shoot or grain, whereas the highest concentration was observed in BR-3 in rice shoots or grain. The grain of BR-29 had the highest and BR-14 had the lowest Zn
accumulation, and the grains of BR-3 contained lowest and BR-28 contained the highest Mn. Nickel concentration was highest in BR-26 (shoots) and BR-29 (grains) and lowest in BR-29 and BR-14 in shoots and grains, respectively. Lead and chromium contents in grains were highest in BR-29 and lowest in BR-14 (Table 3). In case of shoot, Pb and Cr concentration were highest in BR-28 and BR-26 and lowest in BR-26 and BR-16. In rice grain of all varieties, Pb concentrations exceeded limits for human consumption (0.3 mg Pb/kg) (BARC (Bangladesh Agricultural Research Council) 1997).

**Microplot Field Experiment with Rice on Tejgaon Soil**

The small plot experiment on the Tejgaon site was harvested before maturity because of the intensive flood situation in April 1998. Therefore, the results are restricted to biomass yields and phenological data. Significant differences in heavy metal contents in shoots were observed between the six rice varieties. Nickel concentration in shoots of different varieties followed the order of BR-28 > BR-29 > BR-26 > BR-3 = BR-16 = BR-14 (Figure 1). The more interesting observation is that BR-14 accumulated the lowest amounts of most of the heavy metals, especially, Pb, and Cr (Figure 2).

**Pot Experiments with Rice on Hazaribagh Soil**

Rice grain yields were highest for BR-14; the other varieties showed lower yields. Heavy metal concentrations in rice shoots and grains in many cases (Mn, Cr) exceeded limit values reported to be toxic for plant growth (Kabata-Pendias and Pendias 1992) (Table 4). The heavy metal accumulation

![Figure 1. Effect of varieties on Ni concentrations of rice shoots grown on Tejgaon soil (microplot field experiment). Mean values with the same letter (s) are not significantly different ($p \leq 0.05$) by LSD test.](image-url)
in shoots and grains of different rice varieties differed significantly on the Hazaribagh soil. Zinc transport into shoots was highest in BR-26 and BR-3 and lowest in BR-14. Also in grain BR-14 exhibited the lowest Zn concentration. The highest Ni concentration in shoots was in BR-28 and BR-16 followed by BR-3, BR-26, BR-4, and BR-29. Also grains of BR-28, BR-29, and BR-16 exhibited the highest and BR-14 and BR-26 the lowest Ni content. Lead entry into shoots of different varieties followed the order: BR-28 > BR-26 > BR-14 > BR-3 > BR-29 > BR-16. In rice grains Pb concentration followed a similar order, BR-28 > BR-14 = BR-26 > BR-16 > BR-3 = BR-29 (Table 4).

**DISCUSSION**

The pharmaceutical industrial site Tongi was the least contaminated with heavy metals (Nuruzzaman, Gerzabek, and Ullah 1995). In the present pot experiment on Tongi soil, the rice varieties showed differences in their growth and yield production. Due to differing rates of absorption among species and varieties, plants often show wide differences in their growth and yield production (John 1973; Jarvis and Jones 1978). Generally the growth
rates of different species and varieties are different (Chino, Kawashima, and Takahashi 1997). The rice variety influenced the concentrations of Ni in grains. Nickel uptake by plants is normally positively correlated with Ni concentration in the soil solution. Availability of Ni is especially pronounced with added, rather than lithogenic, forms of soil Ni (Kabata-Pendias and Pendias 1992). Adverse effects of organic pollution (especially phenolic compounds) in the Tongi soil was not observed in the pot experiment. This observation may be due to the fact that the phenolic compounds measured previously (Nuruzzaman, Gerzabek, and Ullah 1995) are rapidly decomposed after stop of further release.

Accumulation of metals in plants varied with species, within varieties, and within different parts of a plant, as is reported in literature (Barman, Kisku, and Bhargava 1999). In rice grain of all varieties grown on Tejgaon soil but not on Hazaribagh soil, Pb concentrations exceeded limits for

Table 4. Results of the analysis of rice varieties grown on Hazaribagh soil (pot experiment); yields in g/pot (3 plants/pot)

| Parameter         | Bajitpur soil | Grain |
|-------------------|---------------|-------|
|                   | Control (BR-28) | BR-28 | BR-29 | BR-26 | BR-3 | BR-16 | BR-14 |
| DM 1000 grain wt  | 36 a          | 39 a  | 52 ab | 70 c  | 76 c | 60 bc | 125 d |
|                   | 15.2 abc      | 13.9 ab | 16.0 bc | 17.4 c | 16.4 c | 13.4 a | 20.4 d |
| Mn                | 56 a          | 58 a  | 119 bc | 151 c | 58 a | 218 d | 104 b |
| Cu                | 50 c          | 25 ab | 43 c  | 40 bc | 55 c | 23 a  | 23 a  |
| Ni                | 0.39 a        | 0.9 c  | 1.0 b  | 0.6 ab | 0.8 bc | 1.1 c  | 0.6 ab |
| Pb                | 0.03 a        | 0.3 d  | 0.1 b  | 0.22 cd | 0.1 b | 0.2 c  | 0.22 cd |
| Cr                | 1.45 a        | 6.2 c  | 2.4 a  | 4.7 b  | 2.9 a | 2.9 a  | 2.3 a  |
| DM Shoot         | 34 a          | 47 ab | 98 d  | 61 bc | 63 bc | 71 c  | 99 d  |
| Length (cm)      | 78 b          | 71 a  | 98 de | 86 c  | 97 d  | 78 b  | 101 e |
| Mn                | 138.9 a       | 183.4 ab | 160.0 a | 136.0 a | 180.2 ab | 424.4 c | 242.2 b |
| Cu                | 3.0 a         | 3.0 a  | 8.7d  | 5.6 bc | 6.6 c | 4.6 ab | 3.3 a  |
| Ni                | 0.5 ab        | 0.7 b  | 0.3 a  | 0.4 ab | 0.6 ab | 0.6 b  | 0.4 ab |
| Pb                | 0.6 c         | 0.9 c  | 0.2 a  | 0.4 b  | 0.4 b  | 0.1 a  | 0.4 b  |
| Cr                | 1.88 a        | 17.6 e | 5.2 bc | 7.9 cd | 8.9 d  | 16.4 e | 9.9 d  |

Mean values with the same letters are not significantly different ($p \leq 0.05$) by LSD test.

DM, dry matter.
human consumption (0.3 mg Pb/kg) (Peterson and Alloway 1979). Higher Pb concentrations in rice grain of all varieties might be due to the excess Pb content (above the limit value) of the Tejgaon soil (Kloke 1980). In all pot experiments, BR-14 was the lowest in heavy metal contents. Also in the field experiments BR-14 exhibited the lowest accumulation of most of the metals especially Mn, and Cr by roots.

Wheat varieties except Kanchan (shoot) accumulated Zn above the toxic limit, which might also be due to the excess Zn content of the Tejgaon soil (above the limit value) (Kloke 1980). In grains of the three wheat varieties, Mn, Zn, and Pb concentrations were lowest in Agrani and highest in Kanchan variety. Varieties differed significantly in Pb uptake and translocation (Huang and Cunningham 1996). Nickel and Cr were the lowest in the grains of Akbar variety, and Cd was lowest in Kanchan. Significant differences in Cd species exposed to similar external Cd concentrations may differ in uptake and internal distribution of Cd (Florijn and Van Beusichem 1993). Differential Cd distribution may be the result of differences in the capacity to retain absorbed Cd in the roots or to variations in xylem loading or Cd retranslocation in the phloem. Maize inbred lines exposed to various Cd levels in soil showed differences in the Cd concentrations in shoots (Hinesly et al. 1982). Structural and physiological characteristics of the plants or varieties may lead to the different capabilities to retain Cd inside the roots and in turn to the observed variation in Cd partitioning (Hinesly et al. 1982). In the field experiment with rice, the concentrations of Mn, Cu, and Zn in rice shoots showed variations, ranging from 91 to 160 mg/kg, 24 to 170 mg/kg, and 46 to 91 mg/kg, respectively. The ranges of toxic Mn, Cu, and Zn concentration in leaf tissues are 40–100 mg Mn/kg, 20–100 mg Cu/kg, and 100–400 mg Zn/kg DW (Kabata-Pendias and Pendias 1992). Copper concentrations in rice shoots, resulting from the high Cu concentrations in the Tejgaon soil, reached plant toxic values (BR-3 and BR-28-lime treated plot). Liming increased Cu entry into rice shoots of variety BR-28 considerably.

The significantly low dry matter yield of rice on Bajitpur soil in comparison with the other two soils may be due to the lower OM content of that soil. The length of shoot and root of rice varieties differed significantly on Tejgaon soil. The highest shoot and root length was observed in BR-29 (this trend was also observed in the field experiment), and the highest grain yields (FW) were for the variety BR-14 followed by BR-26 = > BR-29 = > BR-16 = > BR-28 = > BR-3. Suppression in shoot and root length due to heavy metal toxicity was reported previously (Hinesly et al. 1982; Gerzabek and Ullah 1988; Setia, Kaila, and Malik 1988; Rubio et al. 1994; Ullah and Gerzabek 1991). Yield reductions of crops due to the presence of heavy metals were reported also frequently in the literature (Ullah and Gerzabek 1991; Mondol 1995; Faroughi et al. 1975; Collins 1981; Sameni, Olson, and Manning 1987; Juma and Tabatabai 1988; Moser, Tingey, and Rodecap 1986; Hibben, Hgar, and Mazza 1984).
The yield depression on Hazaribagh soil is clearly a result of heavy metal toxicity and heavy metal concentrations in rice shoots and grains. Many cases (e.g., Mn and Cr) exceed limit values reported to be toxic for plant growth (Adamec, Sanka, and Rouchovsanska 1989). The influence of industrial pollution of agricultural land and crops by heavy metals and the subsequent decrease of crop yields were also reported in literature (Adamec, Sanka, and Rouchovsanska 1989; Nemeth and Meszaros 1987; Strand, Zolotareva, and Lisovskij 1990; Sing and Abrol 1985; Wagatsuma, Karashi, and Ishii 1985).

BR-14 exhibited lower accumulation of heavy metals (especially Mn and Cr) on Tejgaon soil although its grain yield production was not significantly higher on that soil. But on Hazaribagh soil, BR-14 yielded the highest grain yield. A significant difference in Cu accumulation occurred among the varieties. The concentration of Cu was lower in shoots than in the grains of rice. In shoots, Cu concentration ranged from 3 to 8.68 mg/kg but in grains from 23 to 55 mg/kg. In shoot or grains, BR-14 exhibited the lowest accumulation of Cu. Copper concentration in the grains being higher than in the shoots was also reported (Lübben and Sauerbeck 1991).

Chromium concentration in shoots and grains were extremely low in comparison to total content on Hazaribagh soil. Tannery waste application increased the total Cr levels of soil but did not result in significantly increased Cr concentration in wheat grain. Similar results were reported (Nuruzzaman, Gerzabek, and Ullah 1995). The general toxic limit for Cr in grain is 1–2 mg/kg (Sauerbeck 1982). The highest Cr concentration was observed in the grains of BR-28 and lowest in BR-14. In shoots of all varieties, Cr concentration exceeded the limit values.

It could be clearly shown that local Bengal varieties of rice and wheat differ significantly with respect to heavy metal tolerance and uptake. These differences seem to be partly site specific. Different combinations of heavy metals in elevated soil concentration result in different responses. Thus, choosing cereal varieties needs site-specific information and recommendations to farmers. Recommendations for sites other than those investigated should be based on experimental results.

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