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Effects of mercury on some growth parameters of rice (*Oryza sativa* L.)

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Abstract

Rice (Oryza sativa L.) was grown in earthen pots containing soils of three different textures (clay loam, sandy clay loam and sandy loam) and treated with different levels of mercury (0.00, 0.25, 0.50, 1.00, 1.50 and 2.00 mg Hg kg^{-1} soil). The effects of mercury (Hg) on agronomic parameters of rice plant were recorded. Crop performance as observed from plant height, number of tiller, number of panicle pot^{-1} and yield among the three soils was better in the clay loam soil and poorer in the sandy loam soil. The application of Hg resulted significant variation in plant height in clay loam and sandy clay loam soil. In general, there was a decrease in plant height with increasing application of Hg in soil. Significantly lower tiller formation from the control treatment in clay loam and sandy clay loam soil started at 1.50 and 1.00 mg Hg kg^{-1} soil treatment, respectively. The number of panicles was reduced by 8, 20, 18% with the highest Hg treatment from the control in clay loam and sandy clay loam and sandy loam soil, respectively. The number of unifilled grains panicle^{-1} showed the opposite trend of change to that of grains panicle^{-1}, the highest being observed with the highest rate of Hg application. Grain yield gradually decreased from control to the highest rate of Hg application indicating unfavourable effects of Hg on grain filling process.

Keywords: Mercury, rice, tiller, panicle, grain, straw

Introduction

The sources of contamination of soil with mercury (Hg) are related mainly to base metal processing industries and some chemical works (chloralkali, in particular), as well as due to use of fungicides containing Hg (Kabata-Pendias, 2001). Extremely high concentrations of Hg were found in soils at a former battery recycling facility (Henry *et al.*, 1999). Plants seem to take up Hg from soil and there are much evidence that increasing soil Hg generally causes an increase the Hg content of plants. Hogg *et al*. (1978) showed that Hg is easily absorbed by the root system and is also translocated within the plants. Soil Hg is not only directly absorbed by plants but also indirectly absorbed from Hg vapour gradually released in soils (Kabata-Pendias, 2001). Mercury is an extremely toxic metal (Fergusson, 1990) and symptoms of mercury (methyl mercuiy) poisoning include instantaneous neurological damages (Fergusson, 1990) particularly irritability, paralysis, insanity, blindness, chromosome damage and birth defects (Venugopal and Lucky, 1978). One example of acute mercury poisoning is the " Minemata disease" which causes mental disturbance, loss of balance, speech, sight and hearing difficulty in swallowing and degeneration of brain (Venugopal and Lucky, 1978).

In Bangladesh, industrial wastes and effluents are commonly discharged onto agricultural land, into canals and rivers, along road sides or in the vicinity of industrial operation without any primary or secondary treatment (Kashem and Singh, 1999). As a result, they are major pollutants of productive soils, natural water systems and ground water in this country. The normal range and toxic level of Hg in soil is 0.005-0.17 mg kg^{-1} and 1.00–3.00 mg kg^{-1} in soils, respectively (Aswathanarayana, 1999). Nuruzzaman (1995) reported a Hg concentration of 4.90 mg kg^{-1} in agricultural soil of the battery industrial site at Tongi in Bangladesh. The distribution of Hg in different plant parts of rice grown in that area was 2.50, 1.55 and 0.01 mg kg^{-1} Hg for root, shoot and grain, respectively. The most significant problem of Hg pollution of agricultural soils still seems to be that of organic mercurials added in the form of seed dressing and of foliar sprays against plant diseases. Since mercury compounds are used in agriculture and other industry for the control of plant diseases (e.g. the use of mercuric oxide, mercuric chloride, or mercurous chloride for the control of common scabe of potatoes, club rot in species in the family *Brassica,* white rot of onion, brown patch, dollar spot and snow mold in tirf and others), there is concern not only about the transfer of Hg to the food chain but also about the direct effect of Hg on plant growth. As rice is the stapple food of Bangladesh, the present study was undertaken to investigate the effects of mercury on growth and yield of rice.

Materials and Methods

A pot experiment was conducted to investigate the effects of Hg on some growth parameters of rice plant. Rice was grown on three different textured soils; clay loam, sandy clay loam and sandy loam. Soils used in the experiment were collected from (i) agricultural field near

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new Science Faculty of Chittagong University (Clay loam soil), (ii) agricultural field near Shahid Minar of Chittagong University (Sandy clay loam soil) and (iii) Syedpara at Hathazari Upazilla under Chittagong district (Sandy loam soil) from a depth of 0-15 cm. Soil samples were air dried and passed through a 2.00 mm sieve to separate dry roots, grasses and other particulate materials. A portion of the soils passed through 2.00 mm sieve was used for laboratory analyses.

The properties of three different textured soils are presented in Table 1. Particle size distribution was determined by hydrometer method of Day (1965) and organic carbon (wet–oxidation method) and cation exchange capacity of the soils by the method of Jackson (1973). Soil pH was measured by glass electrode pH meter using soil: water ratio of 1:2.5. Total nitrogen was determined by Kjeldahl method as described by Jackson (1973). Soil samples were digested with a mixture of HNO_3 and HCl at the ratio of 1:3 (Jackson, 1973) for determination of total P, K, Fe, Mn, Zn, Cd and Pb. Phosphorus was determined by vanadomolybdophosphoric yellow color method in nitric acid system according to Jackson (1973). Potassium was determined by flame photometer and Fe, Mn, Zn, Cd and Pb were determined by atomic absorption spectrophotometer (Varian spectra AA-220).

Earthen pots were filled with soil @ 8 kg pot^{-1}. Different levels of mercury (0. 00, 0.25, 0.50, 1.00, 1.50 and 2.00 mg Hg kg^{-1} soil) were applied in soil in solution form as $HgCl_2$. Each treatment was replicated thrice and the pots were arranged in randomized block design. The doses of nitrogen (as Urea), P (as Triple super phosphate), K (as Muriate of potash) and S (as Zinc sulfate) were applied in the pot experiment (110 kg N, 25 kg P, 60 kg K and 15 kg S ha^{-1} soil). 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 applied at rapid tillering stage and the rest 1/3 N was applied as broadcast before 5-7 days of panicle initiation. Four seedlings of 30 days, old and of uniform size of a high yielding rice variety, BR 29, were transplanted in each pot. The level of standing water at a height of 2.5 ± 0.5 cm above the soil surface was maintained by periodic addition of tap water. Growth parameters such as plant height, tiller number were recorded at 70 days after transplantation (DAT) and panicle number, dry weight (straw and root) and grain yield at maturity. At maturity, rice plants were harvested just above the soil surface level 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 ^{0}C for 72 hours and weights were recorded.

The experimental data were statistically analyzed. The significance of differences between the means of the treatments was evaluated by one way analysis of variance followed by Duncan's Multiple Range Test at the significance level of 5%. The statistical software SPSS Version 12.0 was used in the analysis (SPSS Inc., 2003).

Results and Discussion

Growth parameters of rice (plant height, tiller number, panicle number and grain yield) are presented in Table 2. Overall, crop performance as observed from plant height, number of tiller, number of panicle pot $^{-1}$ and yield differed appreciably among the three soils. Generally growth and yield was better in the clay loam soil and poorer in the sandy loam soil. The heights of rice plants were recorded at 70 DAT. The application of mercury resulted significant variation in plant height in clay loam ($p\leq 0.01$) and sandy clay loam soil ($p\leq 0.01$). In general, there was a decrease in plant height with increasing application of Hg in soil. Except in sandy loam soil, the highest plant height was found with control treatment and the lowest with 2.00 mg Hg kg^{-1} soil treatment. In sandy loam soil, the highest value was obtained with 0.25 mg Hg kg^{-1} soil treatment and then a gradual decrease was found with the increase of mercury application in soil and the lowest value was obtained with 2.00 mg Hg kg^{-1} soil treatment. The reduction in plant height at the highest Hg treatment (2.00 mg Hg kg^{-1} soil) from the control was about 13, 13 and 10% in clay loam, sandy clay loam and sandy loam soil, respectively.

The number of tillers were significantly affected by Hg treatments in clay loam and sandy clay loam soils. In both the soils, the lowest number of tillers was observed with 2.00 mg Hg kg^{-1} soil treatment and the highest number of tillers with 0.25 mg Hg kg^{-1} soil. The data indicated that significantly lower tiller formation from the control treatment in clay loam and sandy clay loam soil started at 1.50 and 1.00 mg Hg kg^{-1} soil treatment, respectively. There was no definite trend of variation in tiller formation with the rates of Hg application in sandy loam soil. However, the highest rate of Hg application reduced the number of tillers by 12, 16 and 8% in clay loam, sandy clay loam and sandy loam soil, respectively as compared to the control treatment.

The number of panicles varied significantly among the treatments in sandy loam and sandy clay loam soil. It could be observed that number of panicles produced in sandy clay loam soil with Hg application from 0.25 to 2.00 mg kg^{-1} soil was statistically similar with each other but was significantly lower from that with the control treatment. On the other hand, mercury application in sandy loam soil at only 2.00 mg kg^{-1} soil significantly decreased the number of panicles from that with the control treatment. However, the number of panicles was reduced by 8, 20, 18% with the highest Hg treatment from the control in clay loam, sandy clay loam and sandy loam soil, respectively.

The application of Hg significantly affected the average number of grains $panicle^{-1}$ in clay loam and sandy loam soil. Although the average number of grains $panicle^{-1}$ was not significantly different among the treatments in sandy clay loam soil, the value decreased gradually with the increasing Hg application. The decrease of grains $panicle^{-1}$ with 2.00 mg kg^{-1} soil treatment in clay loam, sandy clay loam and sandy loam soil was 17, 16 and 35%, respectively from the control treatment. Mercury application at 1.00 and 1.50 mg kg^{-1} started to decrease the average number of grains $panicle^{-1}$ significantly in clay loam and sandy loam soil, respectively. The average number of unfilled grains $panicle^{-1}$ showed the opposite trend of change to that of grains $panicle^{-1}$, the highest being observed with the highest rate of Hg application which indicated depressive effect of Hg on grain formation in all the three soils. The significant increase in unfilled grains $panicle^{-1}$ was observed from 1.50 mg kg^{-1} soil of Hg apllication in all the three soils as compared to the control treatment. The percent unfilled grains gradually incresed with increasing rate of Hg application like the number of unfilled grains $panicle^{-1}$. Significantly higher percent unfilled grains was observed from 1.00 mg Hg kg^{-1} soil treatment in clay loam and sandy clay loam soil as well as from 1.50 mg Hg kg^{-1} soil treatment in sandy loam soil. Mercury application in increasing rate gradually decreased the weight of 1000 grains in all the three soils. The weight of 1000 grains significantly decreased from that of the control with Hg apllication above 0.50 mg kg^{-1} in clay loam and sandy clay loam soil as well as 1.00 mg kg^{-1} in sandy loam soil.

Grain yield pot^{-1} was significantly different among the treatments. Grain yield gradually decreased from control to the highest rate of Hg application indicating unfavourable effects of Hg on grain filling process (Figure 1). Significantly decreased grain yield in clay loam and sandy clay loam soil started at 1.50 mg Hg kg^{-1} soil treatment while in sandy loam soil at 0.50 mg Hg kg^{-1} soil as compared to the control treatment. Grain yield reduction at the highest Hg treatment from the control was 27, 22 and 27% in clay loam, sandy clay loam and sandy loam soil, respectively. Mercury application significantly decreased the straw weight in sandy clay loam and sandy loam soil as well as root weight in all the three soils. The highest straw and root yield productions were obtained with control treatment and then a gradual decrease, in general, was observed with the increase in Hg application (Figures 2 and 3).

The decrease in grain yield, straw and root weight and other growth parameters of rice might be the results of physiological disorders by accumulated Hg in plants such as reduction of chlorophyll, decrease of photosynthesis and related enzyme activities and disturbances in mineral nutrition finally leading to lower growth and yield (De La Cruz, 2002; Kabata-Pendias, 2001; Patra and Sharma, 2000). The bioaccumulation of Hg in roots and shoots of rice plants was reported by several investigators (Du *et al*., 2005; Liu *et al*., 2007; Vizarova *et al*., 1995). Rice plant was reported to be Hg accumulator as shown by the extent of its Hg uptake with increasing concentrations in the nutrient medium (De La Cruz, 2000). The reduction in chlorophyll content and concomitant changes in chloroplast ultrastructure were observed in rice plants grown on Hg contaminated soil (De La Cruz, 2002). Mercury affects both light ad dark reaction of photosynthesis (Patra and Sharma, 2000). Mercury accumulated in the root tissues inhibits K^+ uptake by plants (Kabata-Pendias, 2001). The interactions between Hg and other nutrients may lead to changes in the nutrient content and physiological disorders as well as reduction of growth and yield. In agreement with the present study, Du *et al.* (2005) reported that increasing Hg^{2+} concentrations in the nutrient solution decreased both root and shoot biomass of rice. The growth and development of oats grown on Hg contaminated soil was also strongly inhibited (Wyszkowski and Wyszkowska, 2004).

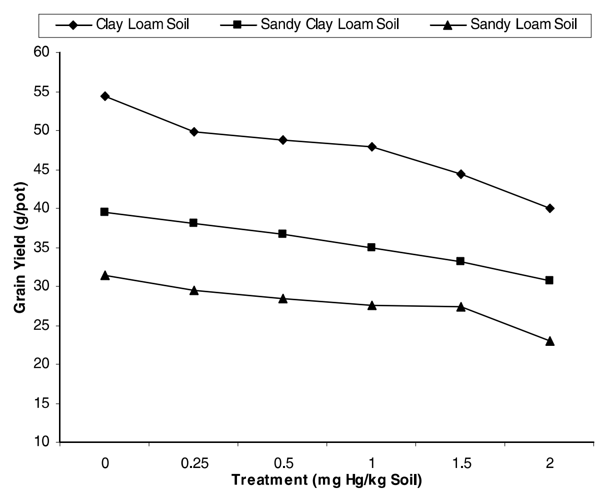

Figure 1. Effects of mercury on grain yield of rice

In the present study, however, a significant reduction in straw weight as compared to the control in sandy clay

Table 1. Physical and chemical properties of the soils used in pot experiment

Properties	Clay Loam Soil	Sandy Clay Loam Soil	Sandy Loam Soil
Sand (%)	30	57	63
Silt (%)	38	22	20
Clay (%)	32	23	17
pH (1:2.5 H_2O)	5.4	5.5	5.1
Organic carbon (%)	0.97	0.83	0.61
CEC (cmolkg^{-1}soil)	7.86	6.93	6.43
Total N (%)	0.15	0.09	0.04
Total P (%)	0.023	0.029	0.020
Total K (%)	0.36	0.24	0.26
Total Cd (μg g^{-1})	0.07	bdl*	bdl*
Total Pb (μg g^{-1})	11.2	7.8	9.6
Total Zn (μg g^{-1})	108.7	58.96	55.02
Total (Fe%)	1.574	0.736	1.472
Total Mn (μg g^{-1})	185.06	190.20	86.90

*bdl = below detection limit

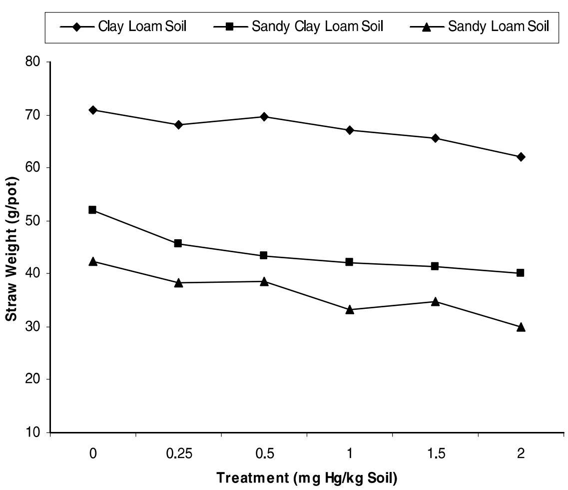

Figure 2. Effects of mercury on straw weight of rice

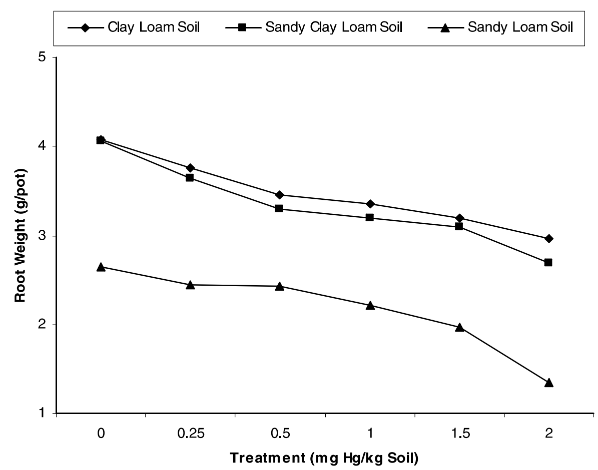

Figure 3. Effects of mercury on root weight of rice

loam and sandy loam soil was started at 0.25 and 1.00 mg Hg kg^{-1} soil treatment, respectively. It was found that Hg application at 0.50 mg kg^{-1} in clay loam and sandy clay loam soil as well as at 1.50 mg kg^{-1} in sandy loam soil started to decrease the root weight significantly from that with the control. Kloke *et al*. (1984) reported the retardation of growth of sensitive plant species at Hg content ranging from 0.5 to 1 ppm (DW). Toxic effects in young barley were obseved at an Hg level of 3 ppm (DW), and at a concentration of 0.01 ppm (AW) was reported to be severely toxic (Davis *et al.*, 1978). Mhathre and Chaphekar (1984) observed damage to plants even at 1 ppb Hg concentration in the nutrient solution. Dry weight reductions of straw and root at the highest rate of Hg application (2.00 mg kg^{-1} soil) from the control were 13-29% and 27-49%, respectively in the present study. Du *et al*. (2005) found that Hg^{2+} at concentrations of 1.0 and 2.5 mg L^{-1} caused a 50% reduction in root biomass of rice and a 50% reduction in shoot boimass occurred at Hg^{2+} concentrations of around 0.5 mg L^{-1}. It was observed that compared to the values obtained with control for grain, straw and root, the adverse effects of Hg application at 2.00 mg kg^{-1} soil was in the order : root > straw > grain; which might be due to the larger accumulation of Hg in roots and its subsequent effect on the root growth of rice plants. The uptake of Hg in rice roots was found to be higher compared with that in shoots in both field and laboratory conditions (De La Cruz, 2000). Steinnes (1995) reported that the fraction of Hg retained in the roots of higher plants from solution culture was about 20 times that observed in the shoots. Kahle (1993) proposed that since heavy metals tend to inhibit growth and function

Table 2. Effects of mercury (Hg) on height, tiller, panicle and grain of rice

Treatment (mg Hg kg^{-1} soil)	Plant height (cm)	Number of tillers pot^{-1}	Number of panicles pot^{-1}	Number of grains $Panicle^{-1}$	Number of unfilled grains $Panicle^{-1}$	Average unfilled grains (%)	1000-grain weight (g)
Clay Loam Soil							
0.00	79.67 a*	52 a	36 a	120 ab	21 c	17.30 d	23.21 a
0.25	76.67 ab	53 a	35 a	123 a	23 bc	19.08 d	22.80 ab
0.50	74.67 abc	52 a	36 a	115 ab	24 bc	20.88 cd	22.41 ab
1.00	75.00 abc	49 ab	35 a	107 bc	25 bc	23.74 bc	21.91 bc
1.50	72.67 bc	46 b	34 a	107 bc	27 ab	25.44 b	21.64 bc
2.00	69.67 c	46 b	33 a	100 c	31 a	31.16 a	21.00 c
Significance of F values (p)	0.01	0.05	NS	0.05	0.01	0.001	0.01
Sandy Clay Loam Soil							
0.00	70.33 a	32 ab	29 a	137 a	20 c	15.10 d	22.64 a
0.25	67.67 ab	33 a	25 b	128 a	22 c	16.96 cd	22.40 ab
0.50	64.00 bc	31 abc	25 b	126 a	27 bc	21.16 bcd	21.78 abc
1.00	63.00 bc	29 bc	24 b	120 a	28 abc	23.67 abc	21.32 bc
1.50	63.67 bc	28 bc	22 b	118 a	31 ab	26.36 ab	21.33 bc
2.00	61.00 c	27 c	23 b	115 a	35 a	30.99 a	20.87 c
Significance of F values (p)	0.01	0.05	0.05	NS	0.01	0.01	0.05
Sandy Loam Soil							
0.00	66.67 a	26 a	22 a	89 ab	16 c	18.42 c	23.24 a
0.25	67.33 a	25 a	23 a	92 a	18 bc	19.15 c	22.59 ab
0.50	64.00 a	25 a	21 ab	85 ab	19 abc	22.75 c	22.47 ab
1.00	62.67 a	25 a	20 ab	75 abc	20 abc	27.43 bc	22.24 ab
1.50	62.33 a	23 a	19 ab	69 bc	23 ab	33.00 b	21.81 bc
2.00	60.33 a	24 a	18 b	58 c	25 a	44.66 a	20.96 c
Significance of F values (p)	NS	NS	0.05	0.01	0.05	0.01	0.01

*Mean values followed by the same letter(s) in vertical direction are not significantly different according to DMRT ($p \leq 0.05$).

in roots, this might limit the uptake and translocation of Hg to other plant parts. Further, Hg may also bind itself to root materials (e.g. to structural component), which results in significantly higher root levels (De La Cruz, 2002). Du *et al.* (2005) reported that Hg accumulated in rice roots and the mercuty concentration factors in roots reached nearly 1900 at 2.5 mg Hg L^{-1} in solution culture.

Conclusions

Growth and yield, in general, was better in the clay loam soil and poorer in the sandy loam soil. The application of mercury resulted significant decrease in plant height, tiller number , panicle number, grains $panicle^{-1}$. The number of unfilled grains $panicle^{-1}$ showed the opposite trend of change to that of grains $panicle^{-1}$, the highest being observed with the highest rate of Hg application. Grain yield gradually decreased from control to the highest rate of Hg application indicating unfavourable effects of Hg on grain filling process.

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