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EFFECTS OF INDUSTRIAL EFFLUENTS ON THE CHANGES OF SOIL CHEMICAL PROIPERTIES AND HEAVY METAL AND NUTRIENT CONTENT OF BORO RICE

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Abstract

A pot experiment with Boro rice (BRRI dhan29) was conducted at the net-house of Sher-e-Bangla Agricultural University (SAU), Dhaka. The experiment was carried out with six soils (five polluted by industrial effluents and 1 non-polluted soil) and three fertilizer treatments (control, 100% RDF and 70% RDF; RDF means recommended dose of fertilizers). The effects of polluted soils and fertilizers on yield and metal accumulation in rice grain were determined. The highest organic carbon (2.26%) and available P (18.19 ppm) was observed in S_6 soils and the lowest in S_1 soil (non-polluted). The highest level of Cd, Pb and Zn was found in S_4 (1.26 ppm), S_5 (18.2 ppm) and S_6 (227 ppm) soils, respectively; these soils are located relatively near to waste carrying canals. The non-polluted soil S_1 contained lower concentrations of those elements. Boro rice yield was significantly influenced by different types of industrially polluted soils and fertilizer treatments. The highest grain yield (132.9 g pot^{-1}) was found in S_4T_2 and the lowest in the S_1T_0 treated pots. Application of lower amount of fertilizers to polluted soils increased the grain and straw yields. Similarly, the highest Pb accumulation in rice grain was found in S_5T_1 (1.305 ppm), and the lowest Pb (0.697 ppm) in S_4T_2. The highest rice Cd (0.495ppm) was noted in S_1T_1 which was close to that of S_6T_0 and the lowest grain Cd was observed in S_3T_2. These results indicate that higher levels of Pb and Cd were accumulated in rice grown on polluted soils. Higher level of grain S, K & Zn concentrations was observed in non-polluted soil receiving 100% recommended dose of fertilizers.

Keywords: Industrial pollution, Chemical properties, Boro rice, Plant nutrients, Heavy metal pollution.

1. Introduction

Heavy metals, whether from natural or human sources, can pollute soil, water, plants, and ecosystems, impacting human health. Heavy metal pollution of agricultural soil and crops is one of the most severe ecological problems on a world scale, especially in developing countries like Bangladesh (Ahmad and Goni, 2010). Industrial effluent contains waste materials from manufacturing, often with toxins and chemicals. When released into the soil, it harms soil quality, fertility, and biological activity. This pollution leads to issues like reduced fertility, increased pest attacks, skin diseases, and lower yields (Afrad *et al.* 2020). Industrial effluents, particularly from textile industries, often contain harmful heavy metals.

In countries like Bangladesh, poor management and disposal worsen the problem. Untreated effluents pollute water and soil, impacting crops, pests, animals, and humans (Hossain *et al.* 2010). Bangladesh has rapid growth in textile and dyeing industries. Bhaluka in Mymensingh district is a significant area with industrial clusters, mainly textile manufacturing, including dyeing and printing units (Chowdhury and Clemett, 2006). Textile industries release untreated effluents into the ecosystem, affecting local livelihoods and soil quality due to trace metal accumulation (Chen *et al.* 2005).

Industrial wastewater contains toxins, including trace elements like Cu, Mn, Ni, Se, and Zn, which are essential in small amounts for organisms. However, high concentrations can be toxic. Industrial effluent carries harmful substances, polluting water, soil, and air, disrupting ecosystems (Hossain *et al.,* 2010). Trace metals in soil are of growing concern for ecosystems, agriculture, and human health. Unregulated industrial effluent deposition contributes to the accumulation of elements like Cd, Cu, Zn, Cr, Ni, Pb, and Zn in surface soils (Mapanda et al. 2005). This metal buildup can impact food quality and safety (Sharma *et al.* 2007), potentially posing health risks when crops absorb and accumulate them. In Bangladesh, information of trace metal contamination in soil and its transfer to crops near industrial areas are limited. Hence, a study was undertaken to evaluate changes in soil chemical properties in the soils of industrially polluted areas, (ii) Assess the influence of polluted soils along with or without fertilizer management on rice yield and metal & nutrient accumulation in rice grain.

2. Materials and Methods

The experiment was conducted at the net-house of Sher-e-Bangla Agricultural University (SAU), Dhaka. The experiment was laid out in Randomized Complete Block Design with 18 treatment combinations (3 fertilizer treatments x 6 soils) having three replications. Six different soils were collected from Bhaluka industrially polluted areas considering the soil pollution intensity.

There were 54 pots [6 soils (5 industrially polluted and 01 non-polluted) x 3 fertilizer treatments) x 3 replications] altogether. An amount of 17 kg soil was taken into each pot. The initial soil samples were analyzed for different nutrient contents along with physico-chemical properties following standard methods. There were three fertilizer treatments, namely T_0: Control, T_1: 100% RDCF, T_2: 70% RDCF in combination with 6 soils (S_1: Non-polluted soil, S_2- S_6 polluted soil . Traditional irrigation i.e., continuous flooding (2-3 cm water) was imposed during whole crop growth period. The industrially polluted soils belong to the AEZ No. 28, Madhupur Tract. Soil texture, pH, %OC, nutrient and metal concentrations were determined. Soil pH was measured by glass electrode pH meter (McLean, 1982), organic matter by wet oxidation method (Nelson and Sommers, 1982) and total N content by micro-Kjeldahl method (Bremner and Mulvaney, 1982). Cadmium (Cd), Pb and Zn contents were determined by $HNO_3/HClO_4$ digestion method (Lindsay and Norvel, 1987). Phosphorus was extracted by sodium bicarbonate (0.5 M, pH 8.5) according to Olsen *et al.* (1954). Available S was determined by 0.15% $CaCl_2$ extraction method (Page *et al.,* 1982). The exchangeable potassium was extracted with 1N ammonium acetate and determined using the Flame photometer (Jackson, 1973). The soil texture, pH, %OC, nutrient and metal concentrations are mentioned in Table 1.

High yielding variety of Boro rice (BRRI dhan 29) was used in the experiment. Required amounts of fertilizers viz. TSP, MoP, gypsum, zinc sulphate and one-third urea were applied during final land preparation based on the fertilizer treatments and weight of pot soil. Two seedlings of rice was transplanted on 05 January 2021 and the crop at maturity was harvested on 27 May 2021. The yield and yield components were measured. The grain samples from every pot were determined for N, P, K, S, Cd, Pb, and Zn contents following standard methods. $HNO_3/HClO_4$ (87/13 v/v) (Jones and Case, 1990) digestion was followed for determining all the elements except N. The K, Cd, Pb, and Zn concentrations of the digests were determined by an atomic absorption spectrophotometer (Model: novAA400P, Brand: analytic jena). The collected data were analyzed using a two-way analysis of variance (ANOVA) and the significant differences between treatments were symbolized by different alphabetical letters according to DMRT at $p < 0.05$ using MStat-C software.

3. Results and Discussion

3.1 General soil properties and heavy metal contents of industrially polluted lands

Soils were collected from six different agricultural fields under industrial areas of Bhaluka, Mymensingh (AEZ 28). There soil were analyzed for different soil properties including some heavy metals. The results are displayed in Table 1.

Table 1. Basic soil properties, nutrients and heavy metals in the industrially polluted soils

Soils	pH	% OC	Soil texture	Total N (%)	Avail. P (ppm)	Avail. K (me%)	Avail. S (ppm)	Avail Zn (ppm)	Cd (ppm)	Pb (ppm)
S_1	6.40	1.65	Loam	0.110	7.50	0.159	14.7	85.8	0.95	12.5
S_2	6.00	1.91	Loam	0.116	7.58	0.164	18.0	71.4	0.52	11.9
S_3	6.33	2.18	Clay loam	0.157	10.1	0.238	48.1	114.3	0.56	10.7
S_3	6.43	2.16	Clay loam	0.112	15.2	0.058	9.5	116.8	1.26	17.9
S_5	6.42	1.72	Clay	0.114	14.9	0.315	6.1	146.7	0.71	18.2
S_6	6.50	2.26	Sandy clay loam	0.145	18.2	0.132	43.0	226.6	0.57	8.2

Soil 1 represents non-polluted soil and Soils 2-6 indicate industrially polluted soils.

Soil pH of industrial areas ranged from 6.0 to 6.5 lightly acidic in nature. Higher levels of organic carbon were found in S_3, $S_{4,}$ and S_6 soils showing 2.18%, 2.16% and 2.26%, respectively, and the lowest in non-polluted soil S_1 (1.65%). Possibly deposition and decomposition of huge quantities of solid wastes and sewage sludge were responsible for organic carbon enrichment in this soil. The highest available P content was observed in polluted soil S_6 (18.2 ppm), and the lowest in non-polluted soil S_1 (7.50 ppm). Higher level of available S was noted for S_3 (48.1 ppm) and S_6 (43.0 ppm) soils and lower level of S was in S_4 and S_5 soils having 9.5 ppm and 6.1 ppm respectively. Higher amount of available K was found in polluted S_3 and S_4 soils (0.238 me% and 0.315 me%), and the lower amount in S_5 soil (0.058 me%).

The highest Cd, Pb and Zn concentrations were found in polluted soils S_4 (1.26 ppm), S_5 (18.18 ppm) and S_6 (226.6 ppm), respectively which polluted soils were located relatively near to waste carrying canals and non-polluted soil S_1 showed lower concentrations of those elements indicating 0.95 ppm, 12.5 ppm and 85.8 ppm, respectively which non-polluted soil was situated comparatively far apart from industrial effluents carrying canals (Table 1).

3.2 Single and combined effects of soil and fertilizer on the yield of Boro rice

The 1000-grain weight, grain and straw yields of the Boro rice were significantly varied between the polluted soils and between fertilizer treatments (Table 2A). The highest 1000-grain weight (18.8 g) was found in S_4 soil and the lowest in S_3 (17.6 g) soil. The highest grain yield (104.0 g pot^{-1}) was found in S_5 which was statistically similar to S_4 and the lowest (50.6 g pot^{-1}) was found in S_3. The maximum straw yield (99.3 g pot^{-1}) was noted for soil S_5 which was statistically similar to soil S_4 and S_6 and the minimum straw yield was in soil S_3. The higher and statistically similar grain and straw yields were obtained from industrially polluted soils S_5 and S_4 and lowest in polluted soil S_3. Considering that rice production in industrial area, the highest 1000-grain weight, straw, and grain yield were observed in rice in non-polluted soil and lower values were recorded in polluted soils (Latif *et al.,* 2020).

The highest 1000-grain weight (18.3 g pot^{-1}) was found in T_2 treatment (100% RDF) which was statistically similar to T_0 (control) and T_1 (70% RDF) treatments. The highest grain yield (95.3g pot^{-1}) was obtained in T_1 treatment which was statistically identical with T_2 treatment and the lowest yield (46.2 g pot^{-1}) was noted in T_0 treatment. The single effect of fertilizer treatments shows that T_2 (70% RDF) was a suitable treatment for industrially polluted soils.

The grain and straw yields of Boro rice were significantly influenced by soil and fertilizer factors (Table 2B). The highest grain (132.9 g pot^{-1}) and straw yield (130.7 g pot^{-1}) were found in S_4T_2 (Polluted soil 3 and 70% RDF) and the lowest grain yield (34.6 g pot^{-1}) in S_1T_0 treatment combination. These results indicate that application of lower rate of fertilizers on polluted soils increased the grain and straw yields of Boro rice. The highest 1000-grain weight (10.5 g pot^{-1}) was found in S_4T_2 treatment combination which was statistically similar to other all soil-fertilizer combinations.

Table 2. Effects of soil and fertilizer on1000-grain weight, grain yield and straw yield of Boro rice

A) Single effects

Factors	1000 - grain wt. (g)	Grain yield (g pot^{-1})	Straw yield (g pot^{-1})
Soil:			
S_1	18.0 ab	85.7 bc	80.8 b
S_2	17.8 b	76.1 cd	84.0 b
S_3	17.6 b	50.6 e	60.7 c
S_4	18.8 a	90.9 ab	90.6 ab
S_5	18.2 ab	104.0 a	99.3 a
S_6	18.4 ab	65.5 d	87.4 ab
SE	0.26	3.87	3.79
Fertilizer:			
T_0	18.0	46.2 b	42.1 b
T_1	18.2	95.3 a	103.0 a
T_2	18.3	94.9 a	106.2a
SE	NS	2.73	2.68

B) Combined effects

Soil × Fertilizer	1000-grain wt. (g)	Straw yield (g)	Grain yield (g)
S_1T_0	17.7	34.0g	34.6h
S_1T_1	18.4	108.5abc	115.1abc
S_1T_2	17.9	100.0cd	107.5bcd
S_2T_0	17.6	42.0fg	44.9gh
S_2T_1	17.9	107.3bc	93.1cde
S_2T_2	17.8	102.7bc	90.4de
S_3T_0	17.6	42.0fg	45.3gh
S_3T_1	17.3	60.0ef	53.3gh
S_3T_2	18.0	80.0de	53.1gh
S_4T_0	18.4	30.7g	36.4gh
S_4T_1	18.8	110.3abc	103.4cd
S_4T_2	19.2	130.7a	132.9a
S_5T_0	17.7	52.5fg	56.5fgh
S_5T_1	18.4	122.0abc	128.9ab
S_5T_2	18.6	123.3ab	126.6ab
S_6T_0	18.6	51.7fg	59.6fg
S_6T_1	18.5	110.0abc	78.2ef
S_6T_2	18.1	100.7bcd	58.8fg
SE	NS	6.57	6.69

Soil 1 represents non-polluted soil and Soils 2-6 indicate industrially polluted soils.
T_0 = Control, T_1 = 100% RDF, T_2 = 70% RDF, RDF = Recommended dose of fertilizers
In a column the values having similar letter(s) do not differ significantly at 5% level by DMRT.

3.3 Single and combined effects of soil and fertilizer on P, K, S, Zn, Pb and Cd

The grain N, P, S, K, Zn, Pb, and Cd concentrations were significantly varied due to soil variation (polluted and non-polluted) and fertilizer treatments (Table 3). Higher levels of P, K, and S concentrations of rice grains were recorded for non-polluted soils. The highest grain P (0.191%) concentration was found in S_3 soil and the lowest was found in S_2 soil. The highest grain S (0.141%) concentration was found in S_1 soil which was statistically similar to all soils except S_6 and the lowest grain S was noted for S_6 soil. The highest K (0.31%) concentration was found in the S_1 (non-polluted soil) which was statistically similar to S_3 and S_4 soil, and the lowest K (0.272%) was got in the S_6 soil. The highest grain P (0.181%) was found in the T_2 (70% RDF) treatment and the highest S and K concentrations were in the T_1 treatment, and the lowest P, S, and K concentrations were documented in the T_0 treatment.

The highest Zn concentration (23.95 ppm) was found in S_1 (non-polluted soil) which was statistically comparable to S_2, S_3, and S_6 soils, and the lowest grain Zn was found in S_4 soil. The highest Pb concentration (1.01 ppm) was found in S_5 soil which was statistically identical to S_2 and S_6 soils and the lowest (0.791ppm) in S_4 soil. The highest grain Cd concentration (0.325 ppm) was found in S_6 soil which was statistically similar to S_1 soil and the lowest Cd concentration (0.043 ppm) was in S_3 soil (Table 3).

Table 3. Effects of soil and fertilizer on P, K, S, Zn, Pb and Cd accumulation in rice grain

Soil:	P conc. (%)	S conc. (%)	K conc. (%)	Zn conc.(ppm)	Pb conc.(ppm)	Cd conc.(ppm)
S_1	0.150d	0.141a	0.310a	23.95a	0.843b	0.322a
S_2	0.125c	0.134a	0.272c	21.82ab	0.907ab	0.219b
S_3	0.191a	0.134a	0.300ab	22.19a	0.881b	0.043e
S_4	0.186b	0.135a	0.299ab	17.64c	0.791b	0.160c
S_5	0.154c	0.117b	0.297b	18.09bc	1.01a	0.110d
S_6	0.118f	0.099c	0.272c	21.25abc	0.887ab	0.325a
SE	0.005	0.005	0.005	1.0	0.033	0.01
Fertilizer:						
T_0	0.135c	0.087c	0.277b	17.79b	0.888	0.249a
T_1	0.145b	0.154a	0.306a	22.91a	0.90	0.199b
T_2	0.181a	0.138b	0.291b	21.77ab	0.871	0.141c
SE	0.004	0.003	0.004	0.71	NS	0.007

Soil 1 represents non-polluted soil and Soils 2-6 indicate industrially polluted soils.
T_0 = Control, T_1 = 100% RDF, T_2 = 70% RDF, RDF = Recommended dose of fertilizers
In a column the values having similar letter(s) do not differ significantly at 5% level by DMRT.

Similarly higher grain Pb concentrations were obtained in polluted soil in comparison to non-polluted soils. The higher concentrations of rice grain Pb and Cd were found in the soils of industrially polluted areas due to high contents of metals in the soil as caused by irrigation with metal-contaminated water released from industries. The highest rice grain Zn (22.9 ppm) concentration was found in T_1 (100% RDF) which was statistically comparable to T_2 (70% RDF) and the lowest Zn in the T_0 (control) treatment (Table 3). The highest grain Pb concentration (0.90 ppm) was found in T_1 (100% RDF) treatment which was close to that of the treatment T_2 (70% RDF) and control (T_0) treatments. The highest grain Cd concentration (0.249 ppm) was found in the T_0 (Control) treatment where fertilizer was not applied and the lowest in the T_2 (70% RDF) treatment. The increased gain Cd in control treatment misht be due to lower availability of nutrients for no application of fertilizer.

The grain P, K, S, Zn, Pb, and Cd concentrations were significantly affected by combined effects of different soils and fertilizers (Table 4). The highest P concentration (0.207%) was recorded in the S_5T_0 treatment combination which was almost similar to S_3T_1 S_4T_1 $S_4T_{2,}$ and S_3T_2 treatment combinations. The highest S concentration (0.175%) was recorded in the S_1T_1 treatment combination which was statistically similar to $S_3T_{2,}$ S_4T_1, $S_4T_{1,}$ and S_2T_1 treatment combinations. The highest K concentration (0.329%) was recorded in the S_1T_1 treatment combination which was statistically similar to S_1T_2, S_3T_0, S_4T_2 $S_5T_{1,}$ and S_5T_2 treatment combinations. Higher levels of grain S and K were accumulated in non-polluted soil due to the residual effects of applied fertilizers during previous crop cultivation and application of 100% recommended dose of fertilizer but higher levels grain P accumulated from polluted soils due to presence of higher levels of available P in industrially polluted soils and application of 100% recommended dose of fertilizer (Table 4). The highest rice Zn concentration (30.8 ppm) was found in S_2T_1(polluted soil-1 and 100% RDF) which was statistically similar to S_1T_2 (non-polluted soil and 70% RDF) and S_1T_1 treatment combinations and the lowest Zn accumulation was observed in S_2T_0 treatment combination. This result shows higher rice accumulation of Zn in non-polluted soil (Table 4).

Table 4. Combined effects of soil and fertilizer on P, K, S, Zn, Pb and Cd accumulation in rice grain

Soil × Fertilizer	P conc. (%)	S conc. (%)	K conc (%)	Zn conc. (ppm)	Pb conc. (ppm)	Cd conc. (ppm)
S_1T_0	0.108j	0.086de	0.272de	16.17e	0.856bcd	0.235b
S_1T_1	0.153h	0.175a	0.329a	25.31ab	0.836cd	0.495a
S_1T_2	0.189de	0.161ab	0.329a	30.36a	0.837cd	0.236b
S_2T_0	0.099k	0.103d	0.262ef	14.70e	0.850bcd	0.282b
S_2T_1	0.104jk	0.171a	0.298bc	30.83a	0.829cd	0.259b
S_2T_2	0.173f	0.130c	0.257ef	19.94bcde	1.041b	0.115cd
S_3T_0	0.174f	0.104d	0.322a	23.56bcd	1.043b	0.092def
S_3T_1	0.201b	0.127c	0.297bc	19.16cde	0.771cd	0.035fg
S_3T_2	0.198bc	0.172a	0.283cd	23.85bcd	0.828cd	0.002g
S_4T_0	0.166g	0.087de	0.282cd	16.94e	0.842bcd	0.251b
S_4T_1	0.200b	0.171a	0.298bc	18.06de	0.835cd	0.104cde
S_4T_2	0.194cd	0.145bc	0.316ab	17.91de	0.697d	0.125cd
S_5T_0	0.207a	0.063f	0.254ef	16.79e	0.836cd	0.161c
S_5T_1	0.110j	0.155ab	0.318a	19.57bcde	1.305a	0.048efg
S_5T_2	0.145i	0.132c	0.319a	17.91de	0.885bcd	0.121cd
S_6T_0	0.059l	0.080ef	0.273de	18.60cde	0.901bc	0.472a
S_6T_1	0.108j	0.127c	0.299bc	24.52bc	0.821cd	0.256b
S_6T_2	0.186e	0.090de	0.243f	20.63bcde	0.939bc	0.247b
SE	0.009	0.008	0.009	1.75	0.058	0.018

Soil 1 represents non-polluted soil and Soils 2-6 indicate industrially polluted soils.
T_0 = Control, T_1 = 100% RDF, T_2 = 70% RDF, RDF = Recommended dose of fertilizers
In a column the values having similar letter(s) do not differ significantly at 5% level by DMRT.

The highest Pd concentration (1.305 mg kg^{-1}) was found in S_5T_1 treatment combination and the lowest Pb accumulation was observed in the S_4T_2. The second highest Pb concentration (1.043 ppm) was recorded in S_3T_0 which was closely similar to S_2T_2 treatment combination. The grain Cd accumulation varied with the interaction of soil and fertilizer. The higher levels of grain Cd concentrations were obtained in S_1 (non-polluted soil), S_2, and S_6 soils with different fertilizer treatments. The highest Cd concentration (0.495 mg kg^{-1}) was found in the S_1T_1 (non-polluted soil and 100% RDCF) treatment combination which was statistically and closely similar to S_6T_0 treatment combination and the lowest Cd accumulation was observed in S_3T_2 treatment combination. These results indicate that higher Pb accumulated in rice of industrially polluted soils with different fertilizer treatments. The higher Cd concentrations in rice grain were found in different industrially polluted soils and soil of one non-polluted agricultural land with different fertilizer treatments.

4. Conclusions

This study examined soil physicochemical changes in the industrial areas of Bhaluka Upazila under Mymensingh district. Industrial wastewater impacted soil properties, including contaminants like N, P, K, S, and heavy metals. Soil near waste discharge canals had the highest pollution levels. The pot-culture experiment showed that boro rice yielded the best in certain polluted soils with reduced amount of fertilizer (70% RDF) application. Higher Pb and Cd concentrations were observed in rice grown on polluted soils. These findings focuses the need for monitoring toxic heavy metals in rice to prevent their accumulation in the food chain and emphasize the importance of raising awareness among farmers in the industrial areas.

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Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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