

Experiment for Arsenic Accumulation into Rice Cultivated with Arsenic Enriched Irrigation Water in Bangladesh

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Abstract A green house field experiment of rice (*Oryza sativa* L) with arsenic amended irrigation water was conducted at Institute of Environmental Science of Rajshahi University to observe the trend of arsenic (As) accumulation into rice and soil. Sodium arsenate (Na_2HAsO_4) amended irrigation water (0.0, 0.1, 0.5, 1.0, 2.0 and 4.0 mg/l As) was used for cultivating a popular HYV-aman rice variety named BR-11. Arsenic accumulation of rice straw, grain and soil were investigated. A significant ($p \leq 0.01$) increasing trend of arsenic accumulation in straw, grain and soil was found with increase of arsenic in irrigation water. The highest level of arsenic in straw, grain and soil was observed in the treatment of 4.0 mg/l As containing irrigation water and lowest level in control treatment. Arsenic in irrigation water showed a strong positive correlations with arsenic accumulation into soil, straw and grain, and the trend of accumulation was found as water > soil > straw > grain.

Keywords: arsenic, water, soil, rice

1. Introduction

Rice is the staple food for nearly 50% of the world population [1] and Asia represents about 90% of global rice production and consumption. Bangladesh is the world's 6th largest rice producer where people get more than 70% of their calorie from staple food rice, providing carbohydrate, and some other proteins, vitamins and minerals [2]. The agricultural economy of Bangladesh is deeply dependent on rice. It is estimated that almost three-quarters of total cropped land in Bangladesh is devoted to paddy cultivation, and per capita rice consumption is one of the highest in the world. Based on national surveys, food grain consumption for an average person in urban and rural areas in Bangladesh is shown to have stabilized over time at about 160 and 180 kg per person per year, respectively [3]. Rice is the main food grain product and it is estimated that rice expenditures make up 40% of total food expenditures [3]. In order to cope with the increasing population, food security, nutrition, urbanization, climate change, Bangladesh Rice Research Institute (BRRI) has introduced many high yielding rice varieties and till today they have released 57 new varieties which are growing in three different seasons namely Aush, Aman and Boro. Aman is the main monsoon season in Bangladesh (July to November) and Aush is a short season (April to May) that follows the dry season or Boro (November/December to April/May) [2]. Significant changes have happened to rice cultivation in Bangladesh over time. Aman acreage has

changed little over time, but Boro acreage has increased substantially and Aus acreage has declined accordingly [4]. Production of rice overall has increased significantly over the last 40 years. Due to the proliferation of shallow tube wells and the development of high-yielding dry-season rice varieties (Boro rice), rice yields have increased dramatically and the share of dry-season rice has increased from 10% of the country's rice production in 1966–67 to 61% in 2008 [5]. The country has shifted from chronic food shortages to self sufficiency by the mid-1990's [6]. Rice covers about 83% of the irrigated area in Bangladesh [7]. Sixty of 64 districts are affected by groundwater arsenic contamination [8]. Geographically four unaffected districts are located in the old alluvial and mountain terrace soil area. Whereas soils of sixty districts of Bangladesh form by the process of alluvial deposition during monsoon river water. This young soil is badly affected with arsenic. Therefore, the Occurrences of arsenic (As) in the Bengal Basin of Bangladesh show close relationships with depositional environments and sediment textures [9]. The enrichment of groundwater by As is restricted mainly to the Holocene alluvial and deltaic plains of the Bengal Basin, whereas groundwater abstracted from the older Plio-Pleistocene aquifers are characteristically low in As. The Holocene shallow aquifers at the lower reach of the Ganges-Brahmaputra-Meghna (GBM) river system are most severely affected compared to other geological settings which show the distinct regional pattern of Arsenic [10]. Mobilisation of As into the groundwater of shallow alluvial aquifers in the Bengal Basin through natural processes involving

reductive dissolution of Fe-oxyhydroxide is widely accepted as the principal mechanism [11]. The farmers of Bangladesh irrigate their crops with arsenic contaminated ground water. The use of arsenic contaminated ground water in irrigation for a prolong period of time may increase the concentrations of arsenic in soil and crops [12]. The paddy soil gets contaminated from the irrigation water and thus enhancing the bioaccumulation of arsenic in rice plants [13]. Elevated arsenic concentrations in rice grain were found from many parts of Bangladesh [14]. Variation in rice grain arsenic concentration in Bangladesh was largely controlled by rice genetics [15]. The accumulation of arsenic in rice plants also varied with different variety of rice [16]. Mean arsenic concentration for boro rice (183 µg/kg) was 1.5 times higher than aman rice (117 µg/kg) [17]. Rice grain accumulated relatively large amounts of arsenic from soils which not contaminated by arsenic [18].

However, limited research has been done on the trend of arsenic accumulation into soil and rice in Gangetic soil condition of Bangladesh. Detailed information is needed for the conclusive assessment on the use of arsenic contaminated irrigation water and its accumulation into rice. The aim of this study was to assess the accumulation of arsenic into rice in Gangetic soil condition. Therefore, this research work was carried out to find out the trend of arsenic accumulation into soil and rice as well as to find out a safe level of arsenic in irrigation water for rice cultivation in Bangladesh.

2. Materials and Methods

2.1. Experimental Site

This field experiment was conducted in a green house made of transparent poly-ethylene paper, situated within 24°22'10.2" to 24°22'10.3" N and 88°38'21.7" to 88°38'21.8" E at Institute of Environmental Science of Rajshahi University in north-western part of Bangladesh during August to December 2011. The study site has sub-tropical and humid climate with adequate sunshine during day time.

2.2. Soil Condition

The experiment was conducted in gangetic soil condition. The properties of soil were total Nitrogen 0.04±0.02%, available P 25.3±0.04 ppm, available K 0.21±0.03 mol/kg, available S 15.7±0.05 ppm, available Z 0.68±0.04 ppm, pH 7.7±0.03, organic matter 0.80±0.05 and background total arsenic (As) 5.60±0.05 ppm.

2.3. Rice Variety

Rice variety, BR-11 is very popular aman variety in Bangladesh. This rice variety was cultivated for this experiment.

2.4. Seedling Transplantation

Thirty-five days old seedlings were uprooted carefully from the seedbed in the morning from the Bangladesh Rice Research Institute, Rajshahi station and four seedlings for each hill with three replications were transplanted on the same day in experimental field on 7th

August 2011. The seedlings which died within 6 days of transplantation were discarded and new seedlings were replaced.

2.5 Intercultural Application

2.5.1. Fertilizer Application

To support the plant growth, urea, triple super phosphate (TSP), murate of potash (MP) and gypsum fertilizer were applied for nitrogen, phosphorus, potassium, and sulfur, respectively. The first split (one third of the dose) of urea and full doses of all other fertilizers were incorporated into the soil by hand before two days of seedling transplantation. The second and third splits of urea were applied after 30 (maximum tillering stage) and 70 (panicle initiation stage) days of transplantation, respectively. One insecticide named fighter was applied into the soil to kill the insects and aphids those attacked the rice plants.

2.5.2. Arsenic Source

Sodium arsenate (Na₂HAsO₄) was used for arsenic source.

2.5.3. Irrigation and Treatment

Six arsenic treatments 0.0, 0.1, 0.5, 1.0, 2.0, and 4.0 mg/L As containing irrigation water were used in this experiment. After transplantation of rice seedlings, 3-4 cm water above soil level was maintained in each treatment throughout the growth period. Irrigation was stopped before 10 days of harvest.

2.6. Sample Collection and Preservation

The rice plants were cut at 4 cm above the soil. Rice grain was harvested at their maturity stage (120 days after transplantation) on 7th December 2011. Then the collected samples (straw and rice grain) from each treatment were tagged properly and sun dried for 3 days and then keeping the samples on a wooden table. The sun dried samples were stored in a drying cabinet at 45°C.

2.7. Chlorophyll Measurement

The chlorophyll from rice leaves during flowering stage was extracted in 80% acetone and chlorophyll contents were measured at 663nm and 645 nm in a spectrophotometer. From the absorption coefficients, the amount of chlorophyll was calculated.

2.8. Arsenic Analysis

Soil, rice straw and grain samples were digested separately following the heating block digestion procedure [19]. Rice straw and grain samples were digested by HNO₃-HClO₄ and soil samples by HNO₃-H₂SO₄-HClO₄ for measuring arsenic concentrations in hydride generation atomic absorption spectrophotometer in BCSIR Laboratory, Dhaka.

2.9. Statistical Analysis

The analysis of variance (ANOVA) was done following the F-statistics. Duncan's multiple range test (DMRT) was used for mean comparisons of the treatment at 5% level of

probability. Pearson correlation coefficients among the parameters were also calculated.

3. Results and Discussion

3.1. Chlorophyll Contents

Soil arsenic concentrations showed negative correlations with the chlorophyll-a and chlorophyll-b contents in rice leaf [20]. We found that chlorophyll-a and chlorophyll-b content in rice leaf was decreased significantly ($p = 0.0022$ and $p = 0.0006$, respectively) with increase of arsenic concentration in irrigation water. The highest and lowest chlorophyll-a and chlorophyll-b contents in leaves of BR-11 rice were found in 0.1 mg/l and in 4 mg/l As treatment, respectively (Table 1). Moreover, we observed a significant ($p < 0.01$) strong negative correlation ($r = -0.78$) between chlorophyll-a content and irrigation water arsenic. A significant ($p < 0.01$) strong negative correlation ($r = -0.77$) between chlorophyll-b content and irrigation water arsenic was also found.

Table 1. Effect of arsenic amended irrigation water on chlorophyll contents of BR-11 rice leaves.

Arsenic added in water (mg/l)	Chlorophyll contents (mg/g)	
	Chlorophyll-a	Chlorophyll-b
0.0	20.27 ± 1.70ab	17.00 ± 1.84b
0.1	24.84 ± 0.39a	21.57 ± 0.73a
0.5	20.18 ± 1.14ab	15.53 ± 0.47bc
1	16.11 ± 2.68bc	12.29 ± 2.04cd
2	15.90 ± 2.97bc	12.16 ± 2.04cd
4	10.91 ± 0.66c	08.46 ± 0.03d
F-test	**	**

Same letters in a column did not differ significantly at $p \leq 0.05$ by DMRT; ** indicate significant at 0.01 level of probability.

3.2. Spikelet Number

The number of filled spikelet pot-1 decreased significantly ($p < 0.001$) with the level of arsenate contaminated irrigation water [21]. We also found that filled spikelet number of BR-11 rice decreased significantly ($p = 0.0019$) with increase of arsenic concentration in irrigation water. The highest filled spikelet number (678.33 ± 78.81) was found in control treatment and the lowest (197.33 ± 97.58) in 4 mg/l As treatment (Table 2). The highest filled spikelet number was also observed in control treatment [21]. A significant ($p < 0.05$) negative correlation ($r = -0.552$) between filled spikelet number and irrigation water arsenic was detected.

Empty spikelet number was increased insignificantly with increase of arsenic concentration in irrigation water (Table 2). Empty spikelet number showed an insignificant positive correlation ($r = 0.127$) with irrigation water arsenic. Total spikelet number was decreased insignificantly with increase of arsenic concentration in irrigation water (Table 2). Total spikelet number showed an insignificant negative correlation ($r = -0.315$) with irrigation water arsenic.

Table 2. Effect of arsenic amended irrigation water on Spikelet number of BR-11 rice

Arsenic added in water (mg/l)	Filled spikelet number	Empty spikelet number	Total spikelet number
0.0	1091.67 ± 206.10a	1083.33 ± 123.47a	2172.00 ± 332.07a
0.1	678.33 ± 78.81b	945.00 ± 120.45a	1623.33 ± 81.67a
0.5	270.00 ± 116.21c	1203.33 ± 26.82a	1473.33 ± 126.07a
1	243.33 ± 138.51c	1208.00 ± 212.28a	1451.33 ± 131.13a
2	216.33 ± 108.41c	1230.00 ± 599.88a	1446.33 ± 616.68a
4	197.33 ± 97.58c	1185.00 ± 80.47a	1382.33 ± 107.54a
F-test	**	-	-

Same letters in a column did not differ significantly at $p \leq 0.05$ by DMRT; ** indicate significant at 0.01 level of probability.

3.3. Arsenic Accumulation in Soil

The arsenic concentration in soil of BR-11 paddy field was 5.60 mg/kg. Arsenic accumulation in paddy soil was increased significantly ($p \leq 0.01$) with increase of arsenic concentration in irrigation water (Table 3). The average arsenic concentration in Faridpur district of Bangladesh was more than three times higher than the world standard (10 mg/kg) [22]. We found that up to 1 mg/l As in irrigation water, the soil arsenic did not exceed the world standard but thereafter arsenic concentration in paddy soil was found higher than the world standard for soil (Table 3). A significant ($p < 0.01$) strong positive correlation ($r = 0.90$) between irrigation water arsenic and arsenic accumulation in paddy soil was observed (Table 4).

3.4. Arsenic Accumulation in Straw

A significant increase of arsenic in rice straw with increase of arsenate concentrations in irrigation water was reported [23]. In this study arsenic accumulation in straw of BR-11 rice was found to increase significantly ($p \leq 0.01$) with increase of arsenic concentration in irrigation water (Table 3). An elevated arsenic concentration in rice straw (up to 149 mg/kg As by dry weight) was detected when rice was grown in soil amended with sodium arsenate at different levels (0–312.5 mg/kg As) [24]. Rice-straw arsenic content increased with increasing of soil-arsenic concentration was also reported [25]. Straw accumulated twice as much arsenic than the grain [26]. We also found that arsenic accumulation in straw was much higher than grain. The highest arsenic accumulation was found in straw (4.69 ± 0.14 mg/kg) in 4 mg/l treatment and lowest (1.72 ± 0.16 mg/kg) in control (Table 3). As like as soil a significant ($p < 0.01$) strong positive correlation ($r = 0.90$) between irrigation water arsenic and arsenic accumulation in straw of BR-11 rice was observed (Table 4).

3.5. Arsenic Accumulation in Grain

From the arsenic uptake study of T-aman rice, it was found that the arsenic in rice grain increases with increase of arsenic in soil, but did not vary significantly up to 20mg/kg As treatment [26]. Arsenic uptake and accumulation

was greatly affected by arsenic contamination in soil and increased greatly with increasing levels of arsenic [27]. Arsenic in rice grain (0.30 mg/kg dry weight) was found when the rice was grown with 2.0 ppm arsenic contaminated irrigation water [23]. We also found that arsenic accumulation in grain of BR-11 rice was increased significantly ($p < 0.01$) with increase of arsenic concentration in irrigation water (Table 3). The highest level of arsenic accumulation in grain (0.47 ± 0.03 mg/kg) and the lowest level of arsenic accumulation in grain (0.06 ± 0.01 mg/kg) was observed in 4 mg/l and control treatments, respectively (Table 3). Rice grain generally has lower arsenic concentration and the concentration remains much below the maximum permissible limit of 1 mg/kg As [28]. Moreover, a significant ($p < 0.01$) strong positive correlation ($r = 0.804$) between arsenic in irrigation water and arsenic accumulation in grain of BR-11 rice was found (Table 4).

Table 3. Arsenic accumulation in soil, straw and grain of BR-11 rice

Arsenic added in water (mg/l)	Arsenic in soil (mg/kg)	Arsenic in straw (mg/kg)	Arsenic in grain (mg/kg)
0.0	$3.67 \pm 0.39a$	$1.72 \pm 0.16a$	$0.06 \pm 0.01a$
0.1	$6.11 \pm 0.46b$	$2.96 \pm 0.14b$	$0.19 \pm 0.01b$
0.5	$7.23 \pm 0.40b$	$3.04 \pm 0.16b$	$0.33 \pm 0.01c$
1	$9.85 \pm 0.49c$	$3.48 \pm 0.16bc$	$0.34 \pm 0.0c$
2	$13.68 \pm 0.35d$	$3.63 \pm 0.13d$	$0.44 \pm 0.02d$
4	$14.61 \pm 0.24d$	$4.69 \pm 0.14d$	$0.47 \pm 0.03d$
F-test	**	**	**

Same letters in a column did not differ significantly at $p \leq 0.05$ by DMRT; ** indicate significant at 0.01 level of probability.

Table 4. Matrix of arsenic accumulation correlation coefficient among water, soil, straw and grain arsenic

		Arsenic added in water (mg/l)	Arsenic in soil (mg/kg)	Arsenic in straw (mg/kg)	Arsenic in grain (mg/kg)
Arsenic added in water (mg/l)	Pearson Correlation	1	.900**	.864**	.804**
	Sig. (2-tailed)		.000	.000	.000
Arsenic in soil (mg/kg)	Pearson Correlation	.900**	1	.919**	.943**
	Sig. (2-tailed)	.000		.000	.000
Arsenic in straw (mg/kg)	Pearson Correlation	.864**	.919**	1	.921**
	Sig. (2-tailed)	.000	.000		.000
Arsenic in grain (mg/kg)	Pearson Correlation	.804**	.943**	.921**	1
	Sig. (2-tailed)	.000	.000	.000	

** indicate correlation is significant at the 0.01 level (2-tailed). N=18

4. Conclusions

From the overall observations of this study we may conclude that the trend of arsenic accumulation in Gangetic soil condition is as follows: irrigation water > soil > straw > grain. For rice cultivation the level of arsenic in irrigation water should be within 1mg/l. The findings of this research will help the farmers of Bangladesh for cultivating rice with lowest arsenic contamination.

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