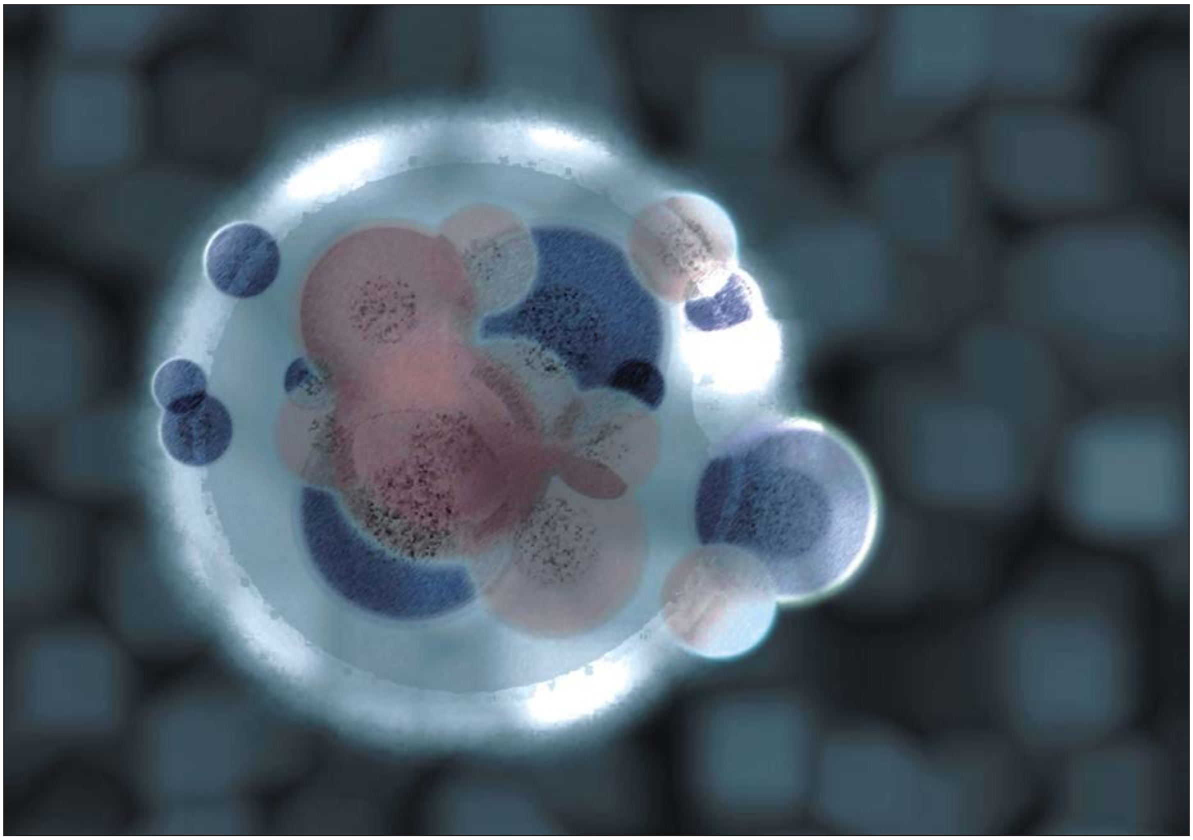

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Effects of Irrigation Water Arsenic in the Rice-rice Cropping System

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Abstract: A pot culture experiment was carried out at Bangladesh Agricultural University (BAU), Mymensingh to see the effects irrigation water arsenic (As) on Boro rice (February to June) and the residual effect on T. Aman rice (August-November). There were eight treatments consisting of Control, 0.10, 0.25, 0.50, 0.75, 1.00, 1.50 and 2.00 ppm As added through irrigation water. A total of 56 L of irrigation water having different concentrations of As was needed for the Boro rice (Cv. BRRI dhan 29). After harvest of Boro rice, T. Aman rice (Cv. BRRI dhan 33) was grown in the same pots with monsoon rain. Nutrients such as N, P, K and S @ 100, 25, 40 and 25 ppm, respectively were added to sustain normal growth of both Boro and T. Aman rice. The irrigation water added As up to 0.25 ppm enhanced the plant height, panicle length, filled grains/panicle, 1000-grain weight and finally the grain yield of Boro rice and the further doses of depressed the plant growth, yield and yield components. The concentration of As in rice grain or straw of Boro rice increased significantly with increasing As concentrations in the irrigation water, the values for grain As for every As treatment were below the Maximum Permissible Level (1.0 ppm). Application of As added to the first crop (Boro rice) had significant residual effects on the second crop (T. Aman rice) in respect of plant height, panicle length, grains/panicle, grain and straw yields. Arsenic concentrations were always higher in Boro rice grain and straw compared to T. Aman rice. The grain As of Boro rice was almost double the As levels in T. Aman rice grain over the treatments. The As treatments had an adverse effect on the N, P, K and S concentration of rice grain.

Key words: Rice, arsenic, irrigation, grain yield, grain-As, straw-As

INTRODUCTION

Groundwater contamination by arsenic (As) has been reported form many countries, with the most severe problems occurring in Asia, namely Bangladesh[1,2], India[3], China[4] and Taiwan[5]. In Bangladesh, 80 million people in 59 out of 64 districts across the country are exposed to arsenic poisoning and 10,000 people have already shown the symptoms of arsenicosis[6]. The people of Bangladesh are using the arsenic contaminated groundwater not only for drinking purpose and also for irrigating the crops as groundwater is the main irrigation source. Rice grain is the main staple food for the people and rice straw is used as cattle feed in this country. A large amount of groundwater is being used for irrigating rice crop especially in the dry season. Presently, 75% of the total cropped area and 83% of the total irrigated area are under rice cultivation[7]. All activities related with rice cultivation such as germination, raising of seedling, transplanting and growing rice in the main field are mostly done by groundwater irrigation. In some areas of Bangladesh, groundwater As concentrations reach 2 ppm[8]. Thus, arsenic accumulation of the surface soil through irrigation is likely to be increase and is being transported to plant systems and ultimately contaminating the food chain. The accurate contamination levels of arsenic in rice plant parts are not well established in Bangladesh. In a rice-rice cropping system, irrigation water is applied during the Boro rice and the following T. Aman rice is grown with natural rainfall. The application of water contaminated with As may affect the immediate Boro rice and the accumulated As in soil may have residual effects on the following crop (T. Aman rice). Under the circumstance, the present research was undertaken to see the effect of different concentrations of As in irrigation water on Boro rice and their residual effects on the following T. Aman rice.

MATERIALS AND METHODS

This study was conducted at the net-house of the Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh during the cropping season of 2002. The soil was collected from BAU farm at 0-15 cm depth. Texturally the soil was silt loam having pH 6.5, organic matter 1.61%, total N 0.1%, available P 10.2 ppm, available S 13 ppm, available Zn 0.7 ppm, available B 0.25 ppm, available Mn 11.6 ppm,

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available Fe 51.2 ppm, exchangeable K 0.12 mE%, exchangeable Ca 5.03 mE%, exchangeable Mg 2.20 mE%, exchangeable Na 10.35 mE% and total As 2.6 ppm. Twelve kilogram of air dry soil was taken into each pot having size of 43 cm in diameter and 40 cm height. There were eight treatments Control, 0.10, 0.25, 0.5, 0.75, 1, 1.5 and 2 mg As L^{-1} irrigation water, arranged in a Completely Randomized Design with three replications. The source for As was sodium arsenate ($Na_2HAsO_4.7H_2O$). The variety for Boro rice was BRRI dhan 29 and for T. Aman rice was BRRI dhan 33. For both Boro and T. Aman rice, every pot received an equal amount of N, P, K and S at the rate of 100 ppm from urea, 25 ppm from P from potassium biphosphate, 40 ppm K from MP and 25 ppm S from gypsum. Irrigation with different concentrations of As was applied to the pots when required. A total of 56 L of irrigation water was added to each pot for raising the first crop. The crop was harvested at full maturity. After harvest of Boro rice, all the pots were brought under T. Aman rice cultivation in the following season. T. Aman rice was grown under natural rainfall condition; supplemental irrigation was needed three times during the growth period. Data on yield and yield parameters were recorded for both rice crops. The As content in rice grain and straw was determined by digesting the sample with di-acid mixture followed by flow injection hydride generation atomic absorption spectrophotometer with Perkin-Elmer model 2380 and MHS-10 hydride generator assembly using matrix-matching standard[9]. All the plant data were statistically analyzed following F test and the difference between treatment means was adjudged by Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

First crop (BRRI dhan 29)

Yield contributing characters: There was significant effect of the As treatments on the yield contributing characters of Boro rice (Table 1). Higher concentrations of As (>0.75 ppm) significantly increased the total number of tillers/pot, however the number of effective tillers remained unchanged. Plant height, panicle length and number of grains/panicle were significantly increased due to the application of 0.25 ppm As (T_2) and there after at higher concentrations of As (>0.25 ppm As) resulted a gradual decrease in plant height and panicle length. The result that lower concentrations of As through irrigation water was stimulatory for rice plants was also reported by Xie and Huang[10], Abedin *et al.*[11]. Thousand grain weight of Boro rice was increased progressively with increase in As concentration through irrigation water up to 0.5 ppm As (T_5) and then slightly decreased with further increase in As concentration.

Yield: Different concentrations of As in irrigation water significantly affected the grain yield of BRRI dhan 29. The grain yield of BRRI dhan 29, the grain being 49.77 g in T_7 (2.0 ppm As) to 108.96 g in T_2 (0.25 ppm As). The grain yield increased up to 0.25 ppm As application and then tended to decrease with further increase in As concentration. The grain yield obtained in 0.25 ppm As (T_2) was statistically superior to that found in control (T_0) treatment. The highest grain yield obtained with T_2 (0.25 ppm As) was statistically comparable to that found in T_3 (0.5 mg As) and T_4 (0.5 mg As) and T_1 (0.1 ppm As) treatments. The grain yield decreased by 0.9, 25.9 and 50.1% compared to control due to application of irrigation water containing 1, 1.5 and 2 ppm As, respectively. Onken and Hossner[12] reported rice yield a reduction by 66% when arsenic concentration was 1.5 ppm compared to As control. Decrease in rice yield due to As toxicity has been reported by a number of workers in the past[11,13,14]. Like grain yield, the straw yield was significantly increased due to the application of 0.25 ppm As (T_2) and 0.50 ppm As (T_3) compared to As control pot. Further increase in As concentration decreased the straw yield significantly. The straw yields decreased by 3.3, 20 and 31.2% over control due to application of 1, 1.5 and 2 ppm As, respectively (Table 1). Reduction in straw yield of rice due to As application was also reported by Milam *et al.*[15] and Tang and Miller[16].

Nutrient concentration: The N concentration in rice grain decreased while the straw-N concentration increased with increase in As concentrations in irrigation water (Table 2). Phosphorus concentration in rice grain was significantly affected with the addition of different concentrations of As in irrigation water but the straw-P concentration remained unaffected. The grain-K concentration decreased significantly with increasing As concentration in irrigation water while in straw it increased up to the 0.25 ppm As and then decreased gradually. Sulphur concentration in rice grain and straw increased generally with increasing As concentrations. Arsenic concentrations in both rice grain and straw were significantly increased with increasing As concentrations in irrigation water. Arsenic concentration in rice grain ranged from 0.239 to 0.622 ppm and its concentration in rice straw varied from 2.292 to 10.83 ppm over the treatments. The grain-As content adversely affected the grain-N ($r = -0.95^{**}$), grain-P ($r = -0.60^{ns}$) and grain-K ($r = -0.70^{*}$) contents of rice. Grain-As level was positively associated with straw-As level ($r = 0.86^{**}$).

Table 1: Effects of added arsenic through irrigation water on the yield components of the first rice crop (BRRI dhan 29)

Treatments	Total tillers/ pot (no.)	Effective tillers/ pot (no.)	Plant height (cm)	Panicle length (cm)	Grains/ panicle (no.)	1000-grain weight (g)	Grain yield (g/pot)	Straw yield (g/pot)
T_0: 0 ppm As	39.60bc	38.30a	91.00b	23.00b	136.20d	20.54c	99.87b	119.10c
T_1: 0.1 ppm As	36.00d	35.00ab	92.80ab	23.40b	146.20cd	20.81a-c	103.73ab (3.8%)	122.50c (3.4%)
T_2: 0.25 ppm As	34.30d	34.00ab	96.30a	26.70a	178.00a	21.02ab	108.9a (9.0%)	148.00a (28.9%)
T_3: 0.5 ppm As	38.00cd	33.30ab	90.90b	22.20bc	171.90ab	21.96a	106.60ab (6.7%)	148.83a (29.7%)
T_4: 0.75 ppm As	39.00d	30.00c	88.70bc	21.20c	160.00ab	20.32cd	101.97ab (2.0%)	133.57b (14.5%)
T_5: 1 ppm As	43.00bc	36.00ab	87.10bc	20.30c	153.40bc	20.61bc	99.02b (-0.9%)	115.77c (-3.3%)
T_6: 1.5 ppm As	45.00ab	32.70bc	83.30c	18.50cd	136.10d	21.78ab	74.01c (-25.9%)	99.07d (-20.0%)
T_7: 2 ppm As	50.30a	33.70ab	79.80d	17.90d	113.20e	19.24d	49.77d (-50.1%)	87.90e (-31.2%)
Cv (%)	8.11	7.88	7.87	8.94	6.85	3.10	4.54	6.64
SE (±)	1.16	1.56	1.94	2.31	5.91	0.37	1.49	2.85

In a column, figures having same letter(s) do not differ significantly at 5% level

Table 2: Effects of added arsenic through irrigation water on N, P, K, S and As concentrations in rice grain and straw of the first rice crop (Cv. BRRI dhan 29)

	Grain					Straw				
Treatments	N (%)	P (%)	K (%)	S (%)	As (ppm)	N (%)	P (%)	K (%)	S (%)	As (ppm)
T_0: 0 ppm As	1.20a	0.355cd	0.45a	0.26a-c	0.23e	0.50e	0.23	0.94a	0.06	2.29g
T_1: 0.1 ppm As	1.17a	0.359b-d	0.34c	0.25bc	0.33d	0.55de	0.23	0.97a	0.04	4.83f
T_2: 0.25 ppm As	1.16a	0.415ab	0.42ab	0.23bc	0.34cd	0.56de	0.24	1.00a	0.04	6.53e
T_3: 0.5 ppm As	1.13a	0.441a	0.40ab	0.21c	0.39c	0.56de	0.26	0.98a	0.06	7.06de
T_4: 0.75 ppm As	1.12a	0.403a-c	0.37bc	0.22c	0.44b	0.58cd	0.28	0.98a	0.06	7.49cd
T_5: 1 ppm As	1.10a	0.347cd	0.40a-c	0.28ab	0.48b	0.63bc	0.24	0.77a	0.12	7.86c
T_6: 1.5 ppm As	0.96b	0.310de	0.343c	0.29ab	0.57a	0.67ab	0.25	0.75b	0.10	9.008b
T_7: 2 ppm As	0.91b	0.277e	0.346c	0.31a	0.62a	0.69a	0.25	0.69b	0.12	10.83a
Cv (%)	7.07	6.91	6.06	10.56	5.62	6.11	9.34	6.43	18.33	5.69
SE (±)	0.04	0.01	0.01	0.02	0.01	0.02	NS	0.03	NS	0.19

In a column, figures having same letter(s) do not differ significantly at 5% level

Table 3: Residual effects of added arsenic on the yield and yield components of second rice crop (Cv. BRRI dhan 33)

Treatments	Total tillers/ pot (no.)	Effective tillers/ pot (no.)	Plant height (cm)	Panicle length (cm)	Grains/ panicle (no.)	1000- grain weight (g)	Grain yield (g/pot)	Straw yield (g/pot)
T_0: 0 ppm As	24.30b	21.60	107.50ab	25.50ab	166.00bc	25.73	56.33bc	61.26b
T_1: 0.1 ppm As	22.70b	21.30	107.10ab	25.20ab	176.50ab	23.37	58.76b (2.5%)	66.68b (5.4%)
T_2: 0.25 ppm As	25.00b	23.30	113.50a	26.10a	181.90a	26.29	71.50a (15.2%)	83.52a (22.2%)
T_3: 0.5 ppm As	23.00b	21.40	101.90bc	24.60ab	163.90bc	23.88	56.54bc (0.3%)	67.39b (6.1%)
T_4: 0.75 ppm As	25.30b	23.00	97.60cd	23.50bc	155.80cd	23.51	53.71bc (-2.6%)	62.16b (1.2%)
T_5: 1 ppm As	24.30ab	23.60	94.80cd	23.10cd	144.90d	24.00	50.28cd (-6.1%)	61.38b (0.1%)
T_6: 1.5 ppm As	26.00ab	22.60	93.90d	22.80d	146.30d	24.40	45.19de (-11.1%)	59.91b (-0.1.4%)
T_7: 2 ppm As	30.30a	25.60	92.20d	22.60d	144.40d	24.75	42.64e (-13.6%)	57.42c (-3.90%)
Cv (%)	11.14	12.89	4.96	5.88	4.38	5.51	7.38	9.59
SE (±)	1.62	NS	2.31	0.68	4.05	0.78	1.87	3.60

In a column, figures having same letter(s) do not differ significantly at 5% level

Second crop (BRRI dhan 32)

Yield contributing characters: The application of different concentrations of As in irrigation water had significant residual effects on several yield contributing characters of T. Aman rice viz., total tillers, plant height, panicle length, grains/panicle (Table 3). The number of fertile tillers/pot and 1000-grain weight did not follow a definite trend with As application in the previous crop. The application of different concentrations of As in the previous Boro rice had beneficial effect on the plant height of T. Aman rice. The application of 0.25 ppm As (T_2) in the previous rice recorded the tallest plant of

Table 4: Residual effects of As on N, P, K, S and As concentration in grain and straw of the second rice crop (Cv. BRRI dhan 33)

	Grain					Straw				
Treatments	N (%)	P (%)	K (%)	S (%)	As (ppm)	N (%)	P (%)	K (%)	S (%)	As (ppm)
T_0	1.25a	0.41a	0.40a	0.12a	0.09e	0.64ab	0.25a	1.02a	0.09	1.48g
T_1	1.11ab	0.40ab	0.38ab	0.11ab	0.10de	0.62b	0.20ab	0.97ab	0.10	2.64f
T_2	1.19a	0.37a-c	0.37ab	0.11ab	0.13c-e	0.72a	0.19b	0.97ab	0.10	2.74ef
T_3	1.12ab	0.34b-d	0.35abc	0.10bc	0.13c-e	0.61bc	0.19b	0.92bc	0.09	3.08de
T_4	1.04a-c	0.33cd	0.33abc	0.09bc	0.15b-d	0.59bc	0.18b	0.87c	0.10	3.26d
T_5	0.92b-d	0.28de	0.31bc	0.09bc	0.17bc	0.63c	0.17b	0.77d	0.10	3.84c
T_6	0.82cd	0.24ef	0.28c	0.09bc	0.20b	0.44d	0.16b	0.72de	0.10	4.60b
T_7	0.74cd	0.19f	0.25d	0.08c	0.29a	0.41d	0.15b	0.68e	0.10	5.02a
Cv (%)	10.90	8.26	10.29	5.46	12.39	7.55	9.48	7.92	8.56	7.06
SE (±)	0.07	0.02	0.06	0.10	0.01	0.03	0.01	0.01	NS	0.14

In a column, figures having same letter(s) do not differ significantly at 5% level

T. Aman rice which was statistically similar to those found in T_1 and T_0 treatments. Plant height decreased significantly when the previous crop was irrigated with the As concentrations of more than 0.25 ppm. Panicle length decreased with increase in As concentrations beyond 0.25 ppm As. The highest number of grains/panicle was found when 0.25 ppm As (T_2) was applied. The number of grains/panicle decreased steadily with increase of As concentration beyond 0.25 ppm in irrigation water applied to the previous Boro rice.

Yield: There was significant residual effect of the arsenic on the grain yield of T. Aman rice (Table 3). Application of 0.25 ppm As (T_2) in the Boro rice had significant residual effects on the grain yield of T. Aman rice showing 15.2% yield increase over controls, further increase in As application in Boro rice significantly reduced the yield of T. Aman rice. The grain yields due to T_3, T_4 and T_5 treatments were statistically identical and again, the grain yields obtained in T_5, T_6 and T_7 were statistically similar. The grain yields decreased by 2.6, 6.1, 11.1 and 13.6% compared to control due to the application of irrigation water having As concentrations of 0.75, 1.0, 1.5 and 2.0 ppm in the previous Boro rice. Like grain yield, straw yield of T. Aman rice was also significantly affected by the application of different concentration of As in the previous Boro rice. The application of 0.25 ppm As (T_2) in the Boro rice resulted in significantly higher straw yield of T. Aman rice and thereafter the As treatments significant reduced the straw significantly (Table 3).

Nutrient concentration: The concentrations of N, P, K and S in T. Aman rice grain were significantly decreased with increase in As application through irrigation water during the previous Boro rice (Table 4). Thus, the nutrient concentrations were highest in the As control treatment (T_0) and the lowest in 2 ppm treatment (T_7). The application of As in the first crop (Boro rice) had significant residual effects on the concentrations of N, P, K and As in rice straw of the second crop (T. Aman rice). Increase in As concentrations beyond 0.25 ppm applied to the previous crop significantly decreased the straw N concentrations of the following crop. The highest P and K concentrations in straw of T. Aman rice were found in control (T_0) treatment and their concentrations decreased with increase in As concentration in the previous Boro rice. Arsenic concentrations in T. Aman rice straw increased significantly with increase in As concentrations of irrigation water applied to the previous Boro rice. The grain-As content of T. Aman rice was inversely related to the grain-N ($r = -0.92^{**}$), grain-P ($r = -0.96^{**}$), grain-K ($r = -0.96^{**}$) and grain-S ($r = -0.83^{**}$) contents. There was significant positive relationship between grain-As and straw- As levels ($r = 0.92^{**}$).

It appears from this study that lower concentrations of As (<0.25 ppm) were stimulatory while higher concentrations were detrimental for the growth and yield of Boro rice. The application of irrigation water having more than 1.0 ppm As decreased the grain yield of rice compared to that obtained with As free irrigation water. The applied As had significant residual effects on the growth, yield and nutrient concentration of T. Aman rice (second crop). The arsenic concentration in T. Aman rice grain was much lower than that in Boro rice grain. However, grain-As contents of both Boro and T. Aman rice were below 1 ppm (Maximum Permissible Limit), but the straw-As concentration far exceeded 1 ppm which might be unfit as feed for animal consumption.

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