# Effects of Arsenic Contamination on Rice Crop (*Oryza sativa* L.)

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**Abstract**

*A pot-culture experiment was conducted at Bangladesh Agricultural University (BAU), Mymensingh during February to October 2002 in order to examine the adverse effect in rice, if any, due to arsenic (As) contamination of soil. Boro rice (dry season rice) and T. Aman rice (wet season rice) were grown in sequence. The soil had 2.6 mg $kg^{-1}$ background As. Arsenic was added to soil at various rates viz. 0, 5, 10, 15, 20, 25, 30, 40 and 50 mg $kg^{-1}$ for the first crop only. No addition of As was made to the second crop. Arsenic was added as $Na_2HAsO_4.7H_2O$ in solution. The As contamination of soil significantly affected the yield and yield components of Boro and T. Aman rice. Generally, the values decreased as the doses of arsenic increased. There was more than 45% yield reduction due to use of As at 10 mg $kg^{-1}$ or above doses. The concentrations of N, P, K and S in grain and straw of both the rice crops were negatively correlated with the As concentrations. The grain-As concentration did not exceed 1 mg $kg^{-1}$ (the maximum permissible limit) all over the As treatments while the straw-As concentration in all cases went well above 1 mg $kg^{-1}$. Thus, a soil having more than 10 mg $kg^{-1}$ As may cause a great yield loss of rice with a concomitant loss of straw quality as animal feed.*

**Key words**: Arsenic, rice, yield, grain-As, straw-As

## Introduction

Arsenic contamination of groundwater is a severe problem in Bangladesh. At present, 59 out of 64 districts and 60% of lands across the country are affected by arsenic contamination. Consequently, 80 million people are now exposed to arsenic poisoning and 10,000 people have shown the symptoms of arsenicosis. Background levels of arsenic in soils can be between 4 and 8 mg As $kg^{-1}$ but in the areas irrigated with As contaminated water, the soil level can reach up to 83 mg As $kg^{-1}$ (Ullah 1998). Jahiruddin *et al.*, (2000) reported that the arsenic content of non-calcareous soils ranged from 4.85 to 12.2 mg $kg^{-1}$ and that of calcareous soils from 11.6 to 24.4 mg $kg^{-1}$. The maximum acceptable limit of As in agricultural soils as stated by Kabata-Pendias and Pendias, (2001), is 20 mg $kg^{-1}$. In countries where rice is the staple food, the dietary exposure to arsenic through rice is highly important. Levels of arsenic in rice grain are typically between 0.05 – 0.4 µg $g^{-1}$ for North America, Europe and Taiwan (Schoof *et al.* 1998). In Bangladesh, irrigation is principally used in dry season for Boro rice cultivation. Irrigation of rice and other crops with arsenic contaminated groundwater is likely to increase accumulation of As in the surface soil from where it may be transported to plant systems and consequently contaminate the food chain. Thus, a pot-culture experiment was carried out to assess the effects of arsenic contamination on the growth, yield and nutrient concentration of Boro rice and its residual effects on T. Aman rice.

## Materials and Methods

The experiment was conducted at Bangladesh Agricultural University, Mymensingh (Latitude 24°43.407′ and Longitude 90° 26.22′) with rice as the test crop. Two crops, Boro and T. Aman were grown in sequence during the cropping season of 2002. The soil was collected from 0-15 cm depth. Texturally the soil was silt loam having pH of 6.5, organic matter content of 1.61%, total N of 0.1%, available P of 10.2 mg $kg^{-1}$, available S of 13 mg $kg^{-1}$, available Fe of 51.2, exchangeable K 0.12 me%, and total As of 2.6 mg $kg^{-1}$. Twelve kg of air dried soil was taken into each pot having size of 43 cm diameter and 40 cm height. There were nine treatments consisting of 0, 5, 10, 15, 20, 25, 30, 40 and 50 mg $kg^{-1}$ of As (soil basis), each treatment was replicated thrice. Only the first crop received the As treatment. Arsenic was added as sodium arsenate ($Na_2HAsO_4.7H_2O$) in solution. All the pots received a blanket dose of 100 mg $kg^{-1}$ N, 25 mg $kg^{-1}$ P, 40 mg $kg^{-1}$ K and 25 mg $kg^{-1}$ S from urea, potassium biphosphate, muriate of potash and gypsum, respectively. The first of the three doses of urea with all other fertilizers were applied as basal during final pot preparation. The remaining amount of urea was top dressed in two equal splits at active tillering and panicle initiation stages for both Boro and T. Aman rice. Healthy seedlings at thirty five days old were transplanted into the pots on 23 February 2002 for Boro rice and 18 July 2002 for T. Aman rice. Intercultural operations such as weeding and irrigation water maintaining 5-6 cm depth were done to support normal plant growth. The crops were harvested at maturity. Grain and straw yields per pot were recorded. Plants of all three hills from each pot were measured and averaged to record the yield contributing parameters. Grain and straw samples were analyzed for N, P, K, S, Fe and As contents. The As contents in rice grain and straw were determined by digesting the sample with di-acid mixture ($HNO_3$+ $HClO_4$) followed by flow injection hydride generating atomic absorption spectrophotometer (Perkin-Elmer model 2380) and MHS-10 hydride generator assembly using matrix-matching standard (Welsch *et al.* 1990). All the plant data were statistically analyzed following F-test and the difference between treatments means were adjudged by Duncan's Multiple Range Test (DMRT).

## Results and Discussion

### First crop (Boro rice)

Arsenic contamination of soil significantly affected plant height, tillering, grains per panicle and 100-grain weight of Boro rice (Table 1) and the values for most of the parameters were found to decrease as arsenic doses increased. The grain and straw yields of Boro rice were also markedly affected by As contamination to soil. The grain yield varied from 0.7 to 70.8 g $pot^{-1}$ with no grain in the 50 mg $kg^{-1}$ As treatment (Table 1). The highest grain yield was recorded in the control treatment (0 mg $kg^{-1}$ As). There was 5.5-100% grain yield reduction due to use of 5-50 mg $kg^{-1}$ As, compared to the control. Similar to the effect on grain yield, the As treatment had negative effect on the straw yield of Boro rice. The highest straw yield of 78.4 g pot $^{-1}$ was found in the control and the lowest yield of 5.6g pot $^{-1}$ in 50 mg $kg^{-1}$ As treated pots. There was no significant yield difference between 0 and 5 mg $kg^{-1}$ As treatments. The reduction of straw yield due to various As treatments was 7.4 to 92.9% over control. Reduction in rice yield due to As toxicity has been reported by a number of previous workers (Liu and Goa 1987, Tang and Miller 1991; Abedin *et al.* 2002).

**Table 1. Effects of added arsenic on the growth and yield components of Boro rice (cv. BRRI dhan 29)** (Values having same letter in each column do not differ significantly at 5% level by DMRT).

| As added (mg $kg^{-1}$) | Plant height (cm) | Tillers $pot^{-1}$ (no.) | Panicles $pot^{-1}$ (no.) | Grains $panicle^{-1}$ (no.) | 100 grain weight (g) | Grain yield g $pot^{-1}$ | Straw yield g $pot^{-1}$ |
|---|---|---|---|---|---|---|---|
| 0 | 86.8a | 36.0a | 32.7a | 83.9ab | 2.2ab | 70.8a | 78.4a |
| 5 | 87.0a | 32.0ab | 27.3ab | 92.7a | 2.3a | 66.9a | 72.6ab |
| 10 | 70.7b | 24.7abc | 20.7bc | 80.8ab | 2.1abc | 38.3b | 56.7b |
| 15 | 67.5b | 33.0ab | 24.3b | 62.4b | 2.0bc | 37.5b | 39.7c |
| 20 | 47.6c | 29.0abc | 17.3c | 17.2cd | 1.9cd | 5.8c | 29.4cd |
| 25 | 43.7cd | 25.0abc | 8.3d | 30.7c | 1.9cd | 4.5c | 10.4e |
| 30 | 36.4d | 20.7bcd | 9.0d | 4.5d | 1.7e | 0.7c | 14.4de |
| 40 | 44.8cd | 16.3cd | 9.0d | 14.2cd | 1.8de | 2.6c | 14.5de |
| 50 | 23.9e | 8.3d | 1.7e | 0.0 | 0f | 0.0c | 5.6e |
| SE (±) | 2.83 | 3.95 | 2.16 | 7.48 | 0.07 | 4.91 | 5.3 |

The concentration of nutrients viz. N, P, K, S and Fe in the grain of Boro rice was significantly affected by As addition to soil (Table 2). Straw concentrations of N and S remained unaffected by As treatments. The control treatment (0 mg $kg^{-1}$ As) recorded the highest concentration of all the nutrients except for Fe in both the grain and straw and the lowest concentration was observed in 40 mg $kg^{-1}$ As treatment. In most cases, the concentration of a nutrient was higher in grain than in straw. The grain concentration of As in all the As treated pots was below 1 mg $kg^{-1}$, which is considered to be the maximum permissible limit. Straw, concentration of As in all the treatments was above 1 mg $kg^{-1}$ with 6.25 mg $kg^{-1}$ as the maximum. The grain concentration of As adversely affected the grain-P ($r=-0.720^{*}$) and grain-K ($r=-0.736^{*}$) contents of rice.

**Second Crop (T. Aman rice)**

There was a significant residual effect of the added As on the growth, yield and yield parameters of T. Aman rice (Table 3). Generally, the highest results of the parameters tested were observed in the control and the lowest in 50 mg $kg^{-1}$ As treatment. The grain yield varied from 8.7 to 53.6 g pot $^{-1}$ over the treatments (Table 3). The grain yield decreased steadily as the As addition increased. There was no significant yield difference for 0, 5, 10, and 15 mg $kg^{-1}$ As doses. The yield declined markedly when added As was mg kg-1 or more. The grain yields reduction in T. Aman rice from residual effect of As treatments was as high as 83.9%, compared to the control treatment. The straw yield varied between 13.5 and 65.6 g $pot^{-1}$ with the lowest result in 50 mg $kg^{-1}$ As and the highest in the control treatment. The reduction in straw yield due to different As doses against control treatment was between 21.9 -79.8%.

**Table 2. Effects of added arsenic on N, P, K, S, Fe and As concentrations in grain and straw of Boro rice (cv. BRRI dhan 29).** (Values having same letter in the same column do not differ significantly at 5% level by DMRT).

| As added (mg kg$^{-1}$) | Grain | | | | | | Straw | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N (%) | P (%) | K (%) | S (%) | Fe (mg kg$^{-1}$) | As (mg kg$^{-1}$) | N (%) | P (%) | K (%) | S (%) | Fe (mg kg$^{-1}$) | As (mg kg$^{-1}$) |
| 0 | 1.49a | 0.45a | 0.42a | 0.095ab | 49.6c | 0.262c | 1.01 | 0.17c | 0.98a | 0.084 | 303.8d | 2.556b |
| 5 | 1.07b | 0.38abc | 0.38ab | 0.075ab | 75.0bc | 0.628b | 0.91 | 0.20bc | 0.92ab | 0.071 | 472.2cd | 3.864b |
| 10 | 1.12b | 0.39ab | 0.33abc | 0.071ab | 130.3a | 0.956a | 1.18 | 0.21abc | 0.68bc | 0.10 | 485.0bcd | 4.942a |
| 15 | 1.02b | 0.28c | 0.30bc | 0.063b | 150.9a | 0.982a | 1.11 | 0.25abc | 0.55cd | 0.108 | 673.8abc | 6.250a |
| 20 | 0.86b | 0.28c | 0.19de | 0.074ab | 124.5ab | 0.996a | 1.18 | 0.30a | 0.47cd | 0.092 | 623.5abc | 5.332a |
| 25 | 0.92b | 0.29c | 0.19de | 0.082ab | 80.4bc | 0.720b | 1.15 | 0.26ab | 0.59cd | 0.102 | 768.1a | 5.217a |
| 30 | 0.92b | 0.33bc | 0.27cd | 0.108a | 118.9ab | 0.652b | 1.35 | 0.22bc | 0.34d | 0.088 | 637.0abc | 5.860a |
| 40 | 0.85b | 0.33bc | 0.16e | 0.102a | 75.5bc | 0.514b | 1.24 | 0.25abc | 0.43cd | 0.113 | 735.5ab | 6.181a |
| 50 | - | - | - | - | - | - | 1.01 | 0.26ab | 0.42cd | 0.113 | 712.2abc | 6.248a |
| SE (±) | 0.104 | 0.032 | 0.029 | 0.008 | 12.42 | 0.079 | NS | 0.024 | 0.084 | NS | 75.24 | 0.593 |

**Table 3. Residual effects of added arsenic on the growth and yield components of T. Aman rice (cv. BRRI dhan 33).** Values having same letter in each column do not differ significantly at 5% level by DMRT.

| *As added (mg $kg^{-1}$) | Plant height (cm) | Tillers $pot^{-1}$ (no.) | Panicles $pot^{-1}$ (no.) | Grains $panicle^{-1}$ (no.) | 100 grain weight (g) | Grain yield g $pot^{-1}$ | Straw yield g $pot^{-1}$ |
|---|---|---|---|---|---|---|---|
| 0 | 94.6a | 27.3ab | 24.7a | 88.4a | 2.39a | 53.6a | 65.6a |
| 5 | 92.9a | 28.0ab | 22.3ab | 86.3ab | 2.33a | 49.1ab | 51.2ab |
| 10 | 88.4a | 28.0ab | 26.7a | 69.5bc | 2.46a | 41.1abc | 46.3bc |
| 15 | 81.5ab | 33.0a | 27.7a | 56.5cd | 2.22a | 38.4abc | 44.6bc |
| 20 | 80.3ab | 23.7bc | 22.3ab | 54.3cd | 2.24a | 33.1bc | 37.8bcd |
| 25 | 82.5ab | 22.7bc | 22.7ab | 56.2cd | 2.37a | 27.7c | 33.9cd |
| 30 | 77.3ab | 22.3bc | 21.0ab | 46.1de | 2.35a | 33.2cd | 25.5de |
| 40 | 70.4b | 19.7bc | 17.7bc | 32.9ef | 1.94b | 9.3d | 14.2e |
| 50 | 56.3c | 15.3c | 13.7c | 21.9f | 1.92b | 8.7b | 13.5e |
| SE (±) | 4.34 | 2.62 | 2.02 | 5.78 | 0.083 | 5.71 | 4.80 |

***** As was added in the previous rice crop but not in this crop

There was no significant residual effect of As on grain N, S and Fe concentrations, while the P, K and As concentrations in grain were significantly affected by the arsenic doses (Table 4). The control treatment recorded the highest nutrient concentrations in grain while the opposite result was obtained in case of grain As content. As for N and S concentrations in grain, there was no residual effect of As on straw N and S concentrations. Further, like grain K and As contents, the added As to the first crop (Boro rice) significantly affected the straw K and As contents. Unlike grain result, the straw concentration of Fe was significantly affected by As added to the first crop. The As concentration in the T. Aman rice adversely affected the S content of grain ($r=-0.719^{*}$). There was significant positive relationship ($r=0.891^{**}$) between grain and straw concentration of As.

Application of As at 10 mg $kg^{-1}$ or more to the soil (2.6 mg $kg^{-1}$ background As) reduced the grain yield by more than 40%. The grain concentration of As for every As treatments did not exceed 1 mg $kg^{-1}$ (the maximum permissible limit) but the straw concentration of As far exceeded this limit indicating that this straw might be unfit for animal consumption as feed. Thus, it can be concluded that high arsenic accumulation in soil through inherent minerals, irrigation water or any other source may result in a yield loss of rice accompanied with deterioration in straw (animal feed) quality.

**Table 4 Residual effects of added As on N, P, K, S, Fe and As concentrations in grain and straw of T. Aman rice (cv. BRRI dhan 33).** (Values having same letter in each column do not differ significantly at 5% level by DMRT).

| *As added (mg kg-1) | Grain | | | | | | Straw | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N (%) | P (%) | K (%) | S (%) | Fe (mg $kg^{-1}$) | As (mg $kg^{-1}$) | N (%) | P (%) | K (%) | S (%) | Fe (mg $kg^{-1}$) | As (mg $kg^{-1}$) |
| 0 | 1.24 | 0.41a | 0.41a | 0.122 | 74.85 | 0.148d | 0.64 | 0.195 | 1.01a | 0.081 | 90.8ef | 1.89f |
| 5 | 1.12 | 0.38ab | 0.38a | 0.117 | 75.53 | 0.193cd | 0.64 | 0.187 | 1.04a | 0.090 | 104.3de | 3.74e |
| 10 | 1.17 | 0.32cd | 0.32b | 0.114 | 90.55 | 0.354b | 0.62 | 0.185 | 0.99a | 0.085 | 112.8cde | 4.74cde |
| 15 | 1.06 | 0.32cd | 0.28bc | 0.105 | 111.97 | 0.308bc | 0.63 | 0.191 | 0.86ab | 0.077 | 121.4bcd | 4.78cde |
| 20 | 1.19 | 0.31d | 0.24cd | 0.104 | 107.85 | 0.376b | 0.59 | 0.187 | 0.87ab | 0.074 | 140.2b | 6.82b |
| 25 | 1.12 | 0.30bc | 0.26cd | 0.105 | 112.27 | 0.308bc | 0.61 | 0.186 | 0.89ab | 0.073 | 138.0bc | 4.02de |
| 30 | 1.23 | 0.35bc | 0.22de | 0.103 | 72.83 | 0.285bc | 0.62 | 0.185 | 0.75bc | 0.074 | 72.3f | 5.47bcd |
| 40 | 1.22 | 0.31d | 0.20de | 0.104 | 86.76 | 0.308bc | 0.61 | 0.189 | 0.65c | 0.092 | 90.8ef | 5.95bc |
| 50 | 1.11 | 0.31d | 0.19e | 0.105 | 81.88 | 0.583a | 0.59 | 0.187 | 0.58c | 0.082 | 182.1a | 9.10a |
| SE (±) | NS | 0.012 | 0.018 | NS | NS | 0.04 | NS | NS | 0.054 | NS | 9.28 | 0.427 |

* As was added in the previous rice crop but not in this crop

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