J. Sher. Agric. Univ., 1(1): 1-7, July 2007

EFFECTS OF IRRIGATION WATER AND SOIL ADDED ARSENIC ON GROWTH AND YIELD OF CROPS IN RICE-RICE CROPPING PATTERN

M. A. Khan[1], M. R. Islam[2], G. M. Panaullah[3], J. M. Duxburry[4] & M. Jahiruddin[5]

ABSTRACT

A field Experiment was conducted at Bangladesh Agricultural University Farm during January 2004 to December 2005 in order to examine the adverse effect of As in rice. Boro-T. Aman-Boro-T. Aman rice crops were grown in sequence. There were five treatments consisting of 0, 1, 2 ppm As added with irrigation water, 10 and 20 ppm As added to soil. Arsenic treatments were applied in Boro crops. The As contamination of soil either through irrigation water or directly to soil significantly affected the yield and yield components of Boro and T. Aman rice. Application of As added to the Boro rice had significant residual effects on the T. Aman rice. The irrigation water and soil added As depressed the plant height, number of tillers, filled grains panicle^{-1}, 1000-grain weight, straw and grain yields of Boro and T. Aman rice. The grain yield reduction over the cropping seasons and treatments varied from 8.2 to 80% as compared to control treatment.

Key words: Arsenic, yield parameters, yield, rice

INTRODUCTION

Arsenic in groundwater and its fate and transport in the environment appear to be a great concern in Bangladesh. Presently, 61 districts out of 64 and about 60% land of this country are affected by arsenic contamination. This element contamination poses a serious threat to man and agricultural sustainability in this country. Besides domestic use, significant quantities of water from shallow aquifers are being used in the dry season particularly for irrigating Boro rice. About 86% of the total groundwater withdrawn is used for irrigating crops mainly Boro rice (WRI, 2000). Irrigated water borne As from contaminated shallow tube-wells is being accumulated in the soils (Panaullah *et al.*, 2003). The dependency on groundwater irrigation results in a large quantity of arsenic being cycled through the environment each year with a major implication for public health and the environment. Arsenic contaminated irrigation water in Bangladesh is most likely responsible for high As levels in soils used for growing rice. High arsenic concentrations in soils and water may lead to elevated concentrations of As in rice grain or in rice straw, which is used as cattle feed. Groundwater As concentrations are certainly important factors in predicting rice grain As levels. Rice grown in the regions where arsenic is building up in the soil had high As concentrations (Meharg and Rahaman, 2003). Rice obtained from districts with contaminated irrgation water (> 50 μg As L^{-1}) were clearly more elevated than rice from uncontaminated districts (<50 μg As L^{-1}) (Duxbury *et al.*, 2003; Williams *et al.*, 2006). There are reports of reduced plant height, number of effective tillers, filled grains panicle^{-1}, 1000-grain wt. and yields (Kang *et al.*, 1996; Islam *et al.*, 2004) due to the application of As contaminated water.

MATERIALS AND METHODS

The experiment was set up at the Soil Science Field Laboratory of Bangladesh Agricultural University (BAU) Farm, Mymensingh during the period from February, 2004 to November 2005. The experiment field is located at 24.75^{0}N latitude and 90.50^{0}E. The land is medium high and it belongs to the 'Old Brahmaputra Floodplain' agro ecological zone (UNDP and FAO, 1988).

[1]Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka 1207; [2&5]Department of Soil Science, Bangladesh Agricultural University, Mymensingh 2202 ; [3]CIMMYT Bangladesh, P.O. Box 6057, Dhaka 1212; [4]Cornell University, USA.

The soil falls into the 'Sonatola Soil Series. The initial soil was collected from 0-15 cm depth. Texturally the soil was silt loam having pH 6.5, organic matter content 1.40%, available P 6.3 ppm, total Fe 29.87 g kg^{-1}, total Mn 0.484 g kg^{-1} and total As 3.19 mg kg^{-1}. Two rice crops such as Boro and Transplant Aman were grown in a sequence of Boro-T. Aman- Boro-T. Aman during 2004 and 2005. The varieties used were BRRI dhan 29 and BRRI dhan 33, respectively. There were five treatments of T_0 (As-control), T_1 (1 ppm As with irrigation water), T_2 (2 ppm As with irrigation water), T_3 (10 ppm soil added As) and T_4 (20 ppm soil added As), each treatment was replicated four times. Arsenic treatments were applied in Boro season of 2004 and 2005. Twenty PVC cylinders (30 cm diameter and 30 cm length) were installed up to 20 cm depth in the middle of the 1m x 1m plot. Five treatments (Irrigation water containing 0, 1 & 2 μg As mL^{-1} and 10 & 20 μg As g^{-1} soil) were applied to the soils of the cores in each Boro season. Soil applied arsenic was mixed uniformly with the soils up to 15 cm depth of the ring before transplanting the seedlings. The land was puddled in each crop transplantation. The total number of hills/plot were 25 including 2 hills within the ring and 2 seedlings were used in each hill following a spacing of 20 cm x 20 cm. Seedling age was 40-45 days. Arsenic was added through sodium arsenate. Irrigation water was collected after 15 minute of starting pump and the water was analysed for As contents. Then stock solution of As was mixed to the collected irrigation water to get 1 and 2 ppm solution for application. The total amounts of 150 and 300 mg As were added in 1 and 2 ppm irrigation As treatments. Treatment wise irrigation water was applied and other management practices were done as required. In As-control and 2 soil applied As treatments, normal irrigation water (free from As) was applied. Fertilizer application (N, P, K & S) and intercultural operations were done as required to maintain normal crop growth. The rates of N, P, K and S for Boro rice were 120, 25, 60 and 20 kg ha^{-1}. The crop was harvested at maturity. The yield and yield components were recorded. Total tillers, effective tillers, non effective tillers, plant height, panicle length, filled grains $panicle^{-1}$, unfilled grains $panicle^{-1}$, 1000 grain wt., grain and straw yields were recorded. After harvest of Boro rice, the cores were kept properly during the fallow period then the second crop T. Aman rice (cv. BRRI dhan 33) was grown in the same rings and plots to observe the residual effects of As applied to the previous crop (Boro rice). During T. Aman cultivation, the crop was grown without any arsenic application. Fertilizer application (N, P, K & S) and intercultural operations were done as required to maintain normal crop growth. The rates of N, P, K and S for T. Aman rice were 100, 15, 45 and 10 kg ha^{-1}. After harvest, the yield and yield components were also recorded. In the same way, Boro (3^{rd} crop) and T. Aman (4th crop) crops were grown during 2005 and yield and yield components were recorded. 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

Effects of As on yield components of Boro and T. Aman rice

There was significant effect of As treatments on the yield contributing characters of Boro and T. Aman rice. The yield components (viz. effective tillers $core^{-1}$, plant height, panicle length, grains $panicle^{-1}$) were significantly influenced by As addition to soil either through irrigation water or directly to soil (Tables1-3). The application of different concentrations of As in irrigation water and soil to Boro rice had significant residual effects on several yield contributing characters of following T. Aman rice. It was noticed that in treatment T_4 (20 ppm soil added As) the yield parameters of the rice crops were drastically reduced. In maximum cases, the yield parameters observed in T_1 (1 ppm irrigation As) treatment were not significantly different from T_0 treatment.

The number of effective tillers $core^{-1}$ decreased significantly with increasing As concentration in irrigation water or added directly to soil. In all the crops, the higher number of effective tillers $core^{-1}$ was observed with T_0 treatment and the lowest number with T_4 treatment (Table 1).

In Boro rice of 2005, the number of effective tillers (21.3core^{-1}) found in T_1 treatment was comparable to those observed in T_2 and T_3 treatments. In T. Aman rice of 2005, the lowest number of effective tillers core^{-1} found in treatment T_4 which was statistically identical to treatment T_3. Kang *et al.* (1996); Hossain *et al.* (2005) found reduced number of effective tillers of rice with application of irrigation having as in soil.

Table 1. Effects of soil and irrigation water added arsenic on the effective tillers core^{-1} and plant height of Boro and T. Aman rice during 2004 and 2005

Treatment	Effective tiller core^{-1}(no.)				Plant height (cm)			
	Boro 2004	T. Aman 2004	Boro 2005	T. Aman 2005	Boro 2004	T. Aman 2004	Boro 2005	T. Aman 2005
T_0: control	22.0b	22.3	23.8a	17.0a	82.6a	80.5a	83.6a	99.3a
T_1: 1 ppm irrigation water applied As	24.5a	22.0	21.3ab	17.0a	83.4a	71.8b	79.7ab	97.2ab
T_2: 2 ppm irrigation. water applied As	20.0b	20.0	20.0b	14.8a	78.7a	69.2b	78.4b	88.7c
T_3: 10 ppm soil added As	13.0c	20.5	18.8b	8.3b	64.5b	70.6b	81.1ab	90.1bc
T_4: 20 ppm soil added As	10.5d	17.5	13.8c	7.0b	63.3b	61.7c	72.9c	80.5d
CV (%)	7.99	15.60	10.07	15.01	4.17	4.74	3.21	5.47
SE (±)	0.79	NS	0.992	0.961	1.553	1.677	1.271	2.493

Means followed by same letter are not significantly different at 5% level by DMRT, NS-Not significant. Irrigation water & soil added as were applied in Boro crops.

The height of the plant decreased with increasing As concentration in irrigation water or directly to soil. In all crops, the tallest rice plant was recorded in T_0 (As-control) treatment and the shortest plant was observed in T_4 (20 ppm soil added As) treatment (Table 1). In T. Aman rice 2004, the plant height recorded with 1 ppm irrigation As treatment (T_1) was not significantly different from 2 ppm irrigation (T_2) and 10 ppm soil added As (T_3) treatments. In Boro rice 2005, the height of the plant found in 1 ppm As was comparable to those observed in 2 ppm irrigation and 10 ppm soil added As treatments. In T. Aman rice 2005, the tallest plant obtained in control treatment which was statistically identical to that found in 1 ppm irrigation As treatment. Similarly, the plant height recorded with 2 ppm irrigation As treatment was comparable to that recorded with 10 ppm soil added As treatment. Kang *et al.* (1996); Marin *et al.* (1992); Islam *et al.* (2004). in their experiments, observed shorter rice plants when grown with As treatment.

Panicle length decreased in all crops with increasing As concentration in irrigation water or added directly to soil. In all the crops, the highest and lowest panicle length were observed in T_0 (As-control) and T_4 (20 ppm soil added As) treatments, respectively (Table 2). In Boro rice 2004, the highest panicle length (23.5 cm) was obtained in T_0 treatment which was statistically comparable to those treated with T_1 and T_2 treatments (Table 2). The lowest panicle length (16.8 cm) was recorded with 20 ppm soil added As treatment (T_4) which was statistically identical to that found in 10 ppm soil added As (T_3) treatment. In T. Aman rice of 2004, the highest panicle length of 21.7 cm was noted with 0 ppm As (T_0) which was statistically identical to those obtained with the rest of the treatments except T_4 treatment. In T. Aman rice of 2005, the panicle length varied from 20.4 cm in 20 ppm soil added As (T_4) treatment to 24.3 cm in control (T_0) treatment which was statistically identical to that recorded in 1 ppm irrigation As (T_1) treatment. The panicle length obtained with 2 ppm irrigation As (T_2) treatment was statistically identical to that obtained with 10 ppm soil added As (T_3) treatment. The thousand grain weight was reduced at higher arsenic treatments compared to the control or when arsenic was applied at a lower dose (Table 2).

Table 2. Effects of soil and irrigation water added arsenic on the plant height and 1000-grain weight of Boro and T. Aman rice during 2004 and 2005

Treatment	Panicle length (cm)				1000-grain wt. (g)			
	Boro 2004	T. Aman 2004	Boro 2005	T. Aman 2005	Boro 2004	T. Aman 2004	Boro 2005	T. Aman 2005
T_0: control	23.5a	21.7a	23.2a	24.3a	24.5	26.8	25.7	25.5
T_1: 1 ppm irrigation. water applied As	23.4a	20.4a	22.8a	24.3a	24.2	25.7	25.0	25.7
T_2: 2 ppm irrigation. water applied As	22.1a	20.6a	22.7a	22.6b	23.9	26.1	24.5	26.0
T_3: 10 ppm soil added As	18.0b	19.8ab	22.6a	22.7b	22.9	26.0	25.4	24.9
T_4: 20 ppm soil added As	16.8b	17.9b	20.5b	20.4c	22.1	25.5	24.8	24.2
CV (%)	7.31	6.91	3.91	3.75	5.56	2.66	4.25	4.10
SE (±)	0.758	0.695	0.4371	0.428	NS	NS	NS	NS

Means followed by same letter are not significantly different at 5% level by DMRT, NS- Not significant. Irrigation water & soil added as were applied in Boro crops.

The highest number of filled grains panicle^{-1} in all the crops was observed with T_0 (As-control) treatment and the lowest number with T_4 (20 ppm soil added As) treatment. In Boro rice of 2004, the highest number of filled grains panicle^{-1}(106.8) was found in 0 ppm As (T_0) which was statistically identical to that found in 1 ppm irrigation As (T_1) treatment (Table 3). Similarly, the lowest number of filled grains panicle^{-1} (48.7) found in 20 ppm soil added As (T_4) treatment was comparable to that observed in 10 ppm soil added As (T_3) treatment. In T. Aman rice of 2004, the highest number of filled grains panicle^{-1} (85.2) obtained with 0 ppm As (T_0) was comparable to those obtained with the rest of the treatments except 20 ppm soil added As (T_4). Islam *et al.* (2004) in their experiment found reduction of panicle length and reduced number of filled grains panicle^{-1} when grown with different As treatments. In T. Aman rice of 2004, the number of unfilled grains panicle^{-1} increased with increasing As concentration in irrigation water and in other crops there were no significant effect of As on the number of unfilled grains panicle^{-1}(Table 3).

Table 3. Effects of soil and irrigation water added arsenic on filled and unfilled grains panicle^{-1} of Boro and T. Aman rice during 2004 and 2005

Treatment	Filled grains panicle^{-1} (no.)				Unfilled grains panicle^{-1} (no.)			
	Boro 2004	T. Aman 2004	Boro 2005	T. Aman 2005	Boro 2004	T. Aman 2004	Boro 2005	T. Aman 2005
T_0: control	106.8a	85.2a	100.6a	105.2a	23.6	19.8b	25.7	29.4
T_1: 1 ppm irrigation. water applied As	104.9ab	82.4a	83.9bc	85.6b	27.5	19.3b	27.4	28.2
T_2: 2 ppm irrigation. water applied As	93.4b	79.4a	84.2bc	65.9c	25.9	21.2b	37.4	39.5
T_3: 10 ppm soil added As	56.2c	72.4a	93.3ab	70.1c	25.5	26.3a	25.9	46.4
T_4: 20 ppm soil added As	48.7c	58.9b	76.2c	42.3d	23.0	28.3a	26.2	39.9
CV (%)	9.34	10.66	11.05	11.18	27.53	6.89	22.12	27.73
SE (±)	3.829	4.031	4.8431	4.124	NS	0.791	NS	NS

Means followed by same letter are not significantly different at 5% level by DMRT, NS- Not significant. Irrigation water & soil added as were applied in Boro crops yield reduction observed in T. Aman rice of 2005 due to the residual effects of As applied to Boro rice of 2004 and 2005 (Table 4).

Table 4. Effects of soil and irrigation water added arsenic on grain and straw yields of Boro and T. Aman rice during 2004 and 2005

Treatment	Grain yield (g core^{-1})				Straw yield (g core^{-1})			
	Boro 2004	T. Aman 2004	Boro 2005	T. Aman 2005	Boro 2004	T. Aman 2004	Boro 2005	T. Aman 2005
T_0: control	57.2a	48.6a	68.7a	43.0a	60.5a	49.5a	69.4a	47.9a
T_1: 1 ppm irrigation water applied As	60.8a (+6.3%)	44.6ab (-8.2%)	52.7b (-23.3%)	36.2b (-15.8%)	63.6a (+5.1%)	46.1a (-6.9%)	54.0b (-22.2%)	43.4a (-9.4%)
T_2: 2 ppm irrigation water applied As	45.5b (-20.5%)	43.6ab (-10.2%)	47.8c (-30.4%)	24.1c (-44.0%)	51.0b (-15.7%)	44.4a (-10.3%)	52.6b (-24.2%)	30.1b (-37.2%)
T_3: 10 ppm soil added As	24.9c (-56.5%)	42.2b (-13.2%)	48.8bc (-29.0%)	14.5d (-66.3%)	28.5c (-52.9%)	45.1a (-8.9%)	55.0b (-20.7%)	20.8c (56.6%)
T_4: 20 ppm soil added As	14.8d (-74.1%)	29.8c (-38.7%)	31.6d (-54.0%)	8.6e (-80.0%)	16.8d (-72.2%)	31.2b (-37%)	32.9c (-52.6%)	17.1c (-64.3%)
CV (%)	7.06	7.76	5.79	8.53	9.35	7.46	7.49	10.43
SE (±)	1.435	1.619	1.445	1.078	2.069	1.614	1.964	1.66

Means followed by same letter are not significantly different at 5% level by DMRT, NS- Not significant. Irrigation water & soil added As were applied in Boro crops

In Boro rice of 2005, the straw yield recorded with 1 ppm irrigation As (T_1) was comparable to those recorded with 2 ppm irrigation As (T_2) and 10 ppm soil added As (T_3) treatments. In T. Aman rice of 2005, the highest straw yield (47.90 g core^{-1}) was comparable to that observed in 1 ppm irrigation As treatment (T_1). Considerable reduction in straw biomass in the higher As treatment recorded in this experiment primarily as a result of lower number of tillers core^{-1} and stunted rice plant. Exposure to arsenic, causing a reduction in shoot biomass and/ or growth, was also reported by Milam *et al.* (1988); Tsutsumi (1980); Tang and Miller (1991) and Marin *et al.* (1993) for rice. Islam *et al.* (2004) reported in their study that application of as added to the first crop (Boro rice) had significant residual effects on the second crop (T. Aman rice).

Acknowledgement

The authors gratefully acknowledge financial support from US-AID funded CIMMYT- Arsenic project

REFERENCES

Abedin, M. J., Cresser, M. S. J., Meharg, A. A., Feldmann, J. and Cotter, H. J.. 2002. Arsenic accumulation and metabolism in rice (*Oryza sativa* L.). *Environ. Sci. Technol.* 36: 962-968.

Duxbury, J. M., Mayer, A. B., Lauren, J.G. and. Hassan, N. 2003. Food chain aspects of arsenic contamination in Bangladesh: Effects on quality and productivity of rice. *J. Environ. Sci. Health.* 38: 61-69.

Hossain, K. M. D., Yoshida, I., Harada, M., Sarkar, A. A., Miah, M. N. H., Razzaque, A. H. M., Imtiazuddin, M., Adhna, K. and Parveen, M. F.. 2005. Growth and uptake of arsenic by rice irrigated with As contaminated water. *J.Food.Agric.Environ.* 3(2): 287-291.

Islam, M. R., Islam, S., Jahiruddin, M. and . Islam, M. A. 2004. Effects of irrigation water As in the rice-rice cropping system. *J. Biol. Sci.* 4(4): 542-546.

Jahiruddin, M., Islam, M. A., Islam, M. R. and Islam, S. 2004. Effects of As contamination on rice crop (*Oryza sativa* L). *Environtropica*. 1(2): 104-110.

Kang, L. J., . Li, X. D., Liu, J. H. and . Zang, X. Y. 1996. The effect of As on the growth of rice and residues in a loam paddy soil. *J. Jilin. Agril. Univ*. 18(3): 58-61.

Marin, A. R., . Masscheleyn,P. H and Patrick, W. H. Jr. 1992. The influence of chemical form and concentration of arsenic on rice growth and tissue arsenic concentration. *Plant and Soil* 139: 175-183.

Marin, A. R., . Masscheleyn, P. H and Patrick, W. H. Jr. 1993. Soil redox-pH stability of arsenic species and its influence on arsenic uptake by rice. *Plant and Soil* 152: 245-253.

Meharg, A. A. and Rahman, M. M. 2003. Arsenic contamination of Bangladesh paddy field soils; implications for rice contribution to arsenic consumption. *Environ. Sci. Technol.* 15; 37(2): 229-234.

Milam, M. R., Marin, A., Sedbery, J. E. Jr., Bligh, D. P. and Sheppard, R. 1988. Effect of water management, arsenic, zinc on selected agronomic traits and rice grain yield. In Annual Progress Report, Northeast Research Station and Macon Ridge Research Station, Baton Rouge, USA, pp 105-108.

Onken, B. M. and Hossner, L. R. 1995. Plant uptake and determination of arsenic species in soil solution under flooded conditions. *J. Environ. Qual.* 24: 373-381.

Panaullah,G. M., Ahmed, Z. U., Rahman, G. K. M. M., Jahiruddin, M., Miah, M. A. M., Farid, A. T. M., Biswas, B. K., Lauren, J. G., Loeppert, R. H., Duxburry, J. M. and Meisner, C. A. 2003. The arsenic hazard in the irrigation water-soil-plant system in Bangladesh: A preliminery assessment. Proc. 7^{th} International Conference on the Biogeochemistry of Trace Elements, Ed. Gobran, G.R and Lepp N.

Tang, T. and Miller, D. M. 1991. Growth and tissue composition of rice grown in soil treated with inorganic copper, nickel and arsenic. Commun. *Soil Sci. Plant Anal.* 22: 2037-2045.

Tsutsumi, M.1980. Intensification of arsenic toxicity to paddy rice by hydrogen sulphide and ferrous iron I. Induction of bronzing and accumulation in rice by arsenic. *Soil Sci. Plant Nutr.* 26: 561-569.

UNDP and FAO, 1988. Land Resources Appraisal of Bangladesh for Agricultural Development. Report 2. Agroecological Regions of Bangladesh. United Nations Development Programme and Food and Agricultural Organization. pp. 212-221.

Williams, P. N., Islam, M. R., Adomako, E. E., Raab, A., Hossain, S. A., Zhu, Y. G., Feldmann, J. and Meharg, A. A. 2006. Increase in rice grain As for regions of Bangladesh irrigating paddies with elevated arsenic in ground waters. *Environ. Sci.Technol.* 40: 4903-4908.

WRI (World Resources Indicator). 2000. Peoples and Ecosystem: The Fraying Web of Life World Resources Institute, Washington D.C.