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Impact of Water Management on the Arsenic Content of Rice Grain and Cultivated Soil in an Arsenic Contaminated Area of Bangladesh

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Abstract
A study was conducted in an arsenic (As) contaminated area of Faridpur, Bangladesh with a view to observe the effect of reduced irrigation on the As concentration of rice grain. Rice yield of BRRI dhan28 was found to be slightly higher in alternate wetting and drying (AWD) method than in continuous standing water (CSW) method of irrigation although not significant. The highest grain As conc. (0.65 mg/kg) was observed in the plots irrigated with ground water by CSW method. Significant reduction in grain As conc. was observed in AWD plots irrigated with contaminated ground water. Partial aeration of soil in AWD may have hindered the entrance of water As to rice roots. No significant reduction of soil As conc. was observed due to the application of AWD method. Reduction in grain As in AWD method implies that this technique can be devised as tool for mitigation of As in the As contaminated areas for irrigation of rice.

Key words: Arsenic contamination, Grain arsenic, Irrigated rice

Introduction

Contamination of shallow ground water with arsenic (As) in Bangladesh is well recognized since 1990s and has become a major public health issue. The use of As-contaminated ground water has resulted in elevated levels of As in paddy soils (Alam and Sattar, 2000; Ali *et. al.,* 2003; Ullah, 1998) and subsequent increased uptake to rice grain (Duxbury *et al.,* 2003; Meharg and Rahman, 2003; Norra *et al.,* 2005). The As content of lowland paddy-rice grain is generally much higher than that of upland rice because of the high availability of soil As under anaerobic (lowland, flooded) conditions as compared to upland (aerobic) rice (Talukdar *et al.,* 2012). Alternate wetting and drying (AWD) is a method of irrigation in which the paddy soil is drained intermittently during the growing period of rice to save the water. The AWD method has been proposed for As mitigation due to reduced water input to soil (Brammer, 2009). The philosophy behind As mitigation by AWD method is that if water input could be reduced to make the soil more aerobic, the solubility of As and the uptake of As will be minimized (Heikens, 2006). The mobility of solution As is closely related to soil texture and oxalate extractable Fe content (Khaled *et al.,* 2005). A remarkable reduction (48%) of total As content in soil pore-water was found in aerobic water management compared to anaerobic management (Talukdar *et al.,* 2012). The objective of the study was to compare two water management techniques, AWD and continuous standing water (CSW) with two sources of water, namely contaminated ground water (GW) and uncontaminated surface (pond) water (SW) to find suitable water management practices to mitigate As content in the contaminated soils.

Materials and Methods

The experiment was conducted at Bangladesh Rice Research Institute (BRRI) farm Bhanga, Faridpur in two consecutive *boro* seasons (2012 and 2013). The texture of the soil was clayey (78% clay) and the pH was neutral (6.8). The As content of the farm soil was 12.7 mg/kg. The experimental design was factorial RCBD (2×2) with three replications. Two water management methods: AWD and continuous standing water (CSW) were maintained with two sources of water, namely, GW and surface (pond) water (SW) containing 419 ppb and 25 ppb As, respectively. The unit plot size was 3×6 m^2. The plots were separated with polythene sheets placed vertically to a depth of 45 cm to resist the entrance of seepage water. Forty days old seedlings of BRRI dhan28 were transplanted. The rates of fertilizers were N, P, K, S and Zn @ 115-20-60-12-3 kg/ha from urea, TSP, MP, gypsum and zinc sulfate, respectively. Irrigation water was continuously applied during the first 2 weeks in all the plots. However, after 2 weeks, AWD plots received irrigation water only after the recession of the standing water to 15 cm depth. From PI to maturity, standing water was kept again in all plots. Both initial and post-harvest soil samples were collected for As analysis. At maturity, the crop was harvested and grain and straw yields were recorded. Collected plant and soil samples were dried and processed before digestion in tri-acid mixture (HNO_3+$HClO_4$+H_2SO_4) for As-analysis in hydride generation atomic absorption spectrophotometer (Perkin Elmer A Analyst 100) (Rahman *et al.,* 2010). Reduction of plot soil As due to treatment effects was determined by deducting the treated soil As conc. from the initial soil As conc. (12.7 mg/kg). Analysis of variance and the variation in means for the treatment effect were analyzed using SAS software version 9.0.

Results and Discussion

Grain yield

In 2012, grain yield of BRRI dhan28 was not affected significantly by either of the method of irrigation or the source of water (Table 1), although the yield was slightly higher in AWD system. Similarly, in 2013, there was no significant effect of AWD on grain yield. Significant effect of water source was observed only in CSW method as depicted by the highest yield (7.58 t/ha) of the treatment with continuous standing surface water. Except in that treatment the average grain yield was higher in AWD method than CSW method of irrigation although not significant.

Table 1. Effect of irrigation method and source of water on grain yield of BRRI dhan28 during *Boro* season 2012 and 2013 in BRRI Bhanga, Faridpur

Methods of irrigation[a]	Grain yield (t/ha)					
	2012			2013		
	GW[b]	SW	Difference	GW	SW	Difference
AWD	6.38	6.27	0.11 ns	7.21	6.40	0.81 ns
CSW	5.63	5.38	0.25 ns	6.21	7.58	-1.37*
Difference	0.75 ns	0.89 ns		1.00 ns	-1.18 ns	

[a] AWD = alternate wetting and drying; CSW = continuous standing water. [b] GW =ground water; SW =surface water. * difference significant at 5% level

***Grain* As**

In both years of the study, significant reduction in grain As conc. was observed in AWD plots irrigated with (contaminated) ground water although the effect was not found in surface water treated plot (Table 2). On the other hand, grain As conc. was significantly higher in CSW plots irrigated with ground water than that with surface water. The highest grain As conc. (0.65 mg/kg) was observed in the plot irrigated with ground water by CSW method.

Table 2. Effect of irrigation method and source of water on rice grain As conc. of BRRI dhan28 during *Boro* season 2012 and 2013 in BRRI Bhanga, Faridpur

Methods of irrigation[a]	Grain As (mg/kg)					
	2012			2013		
	GW[b]	SW	Difference	GW	SW	Difference
CSW	0.46	0.35	0.11*	0.65	0.40	0.25**
AWD	0.37	0.29	0.08 ns	0.41	0.45	-0.04 ns
Difference	0.09*	0.06 ns		0.24**	-0.05 ns	

[a] AWD = alternate wetting and drying; CSW = continuous standing water. [b] GW =ground water; SW =surface water. **, * difference significant at 1% and 5% levels respectively

Thus, irrespective of the source of water, the average grain As conc. reduced more in AWD method than in CSW method. A possible explanation of the finding is that the mobility and grain uptake of As was comparatively higher in CSW method in which the rice plant remained flooded throughout the crop period. It was found that flooded conditions of soil leads to As mobilization and enhanced bioavailability to rice plant (Takahashi *et al.*, 2004, Xu *et al.*, 2004). The oxidized conditions can result in the precipitation of FeOOH around the rice plant roots, also known as Fe-plaque, that may influence As speciation, bioavailability and uptake and Fe reducing and oxidizing bacteria are likely to play a major role (Fitz and Wenzel, 2002; Meharg, 2004; Weiss *et al.*, 2003; Weiss *et al.*, 2004).

***Soil* As**

The significant effect of surface water irrigation was observed in the As conc. of the post harvest soils both in 2012 and 2013 (Table 3). Plots that were irrigated with ground water showed higher soil As than those with surface water although the effect was not significant in case of CSW. This was expected since the As conc. of surface water was quite negligible (25 µg/l). Effect of irrigation method was not observed in soil As during 2012. In 2013, a reverse pattern was observed, where the soil As conc. was significantly higher (10.80 mg/kg) in AWD irrigated with ground water than that in CSW plot (9.90 mg/kg). Similar finding was also observed in 2012 although the difference (0.76 mg/kg) was not significant. The exact reason for higher As in the AWD plot soil is not known. However, it is assumed that high conc. of soil As is not of immediate concern since soil As is not directly up taken by the plants (van Geen *et al.*, 2006). In our study there was no correlation among the soil and rice grain As conc. (Fig. 1).

Table 3. Effect of irrigation method and source of water on As conc. of irrigated plot soil during *Boro* season 2012 and 2013 in BRRI Bhanga, Faridpur

	Soil As (mg/kg)					
	2012			2013		
Methods of irrigation[a]	GW[b]	SW	Difference	GW	SW	Difference
CSW	10.47	9.91	0.56	9.90	9.12	0.78
AWD	11.23	9.20	1.03*	10.80	9.28	1.52**
Difference	-0.76	0.71		-0.90*	-0.16	

[a] AWD = alternate wetting and drying; CSW = continuous standing water.[b] GW =ground water; SW =surface water. **, * difference significant at 1% and 5% levels respectively.

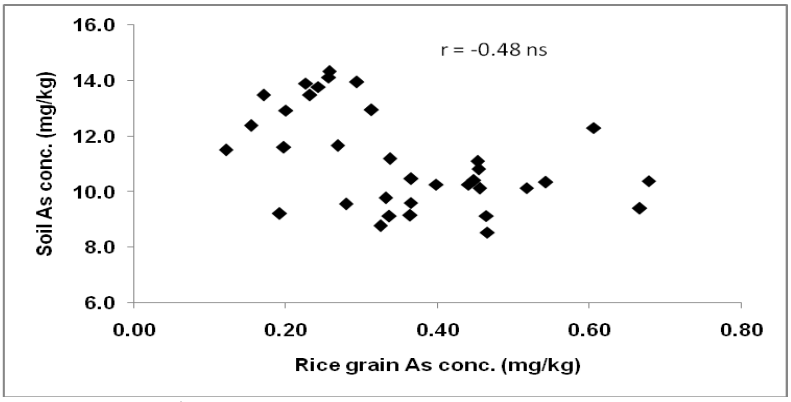

Fig. 1. Correlation between grain As of BRRI dhan28 and the corresponding soil As in BRRI Bhanga Faridpur, 2012-2013

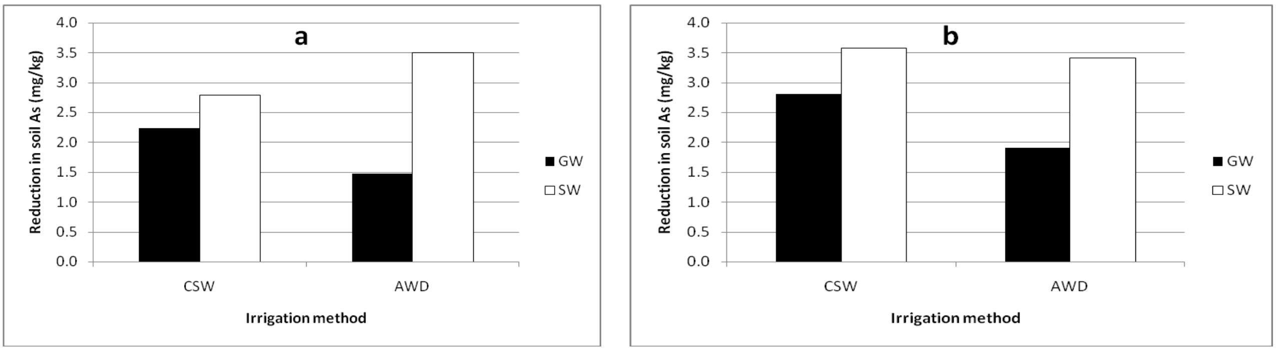

Fig. 2. Reduction in soil As as affected by methods of irrigation and source of water on the reduction of soil As conc. (mg/kg) during a) *Boro*, 2012 and b) *Boro*, 2013 in BRRI Bhanga, Faridpur

Variability was also observed in the reduction in post harvest soil As conc. from that of the initial soil content due to application of different irrigation methods and water sources (Fig. 2). In *Boro* season 2012, the plots treated with surface water reduced more soil As than those with ground water. The AWD method showed higher capacity to reduce soil As when irrigated with surface water. However, the reverse was true for CSW with ground water i.e. higher reduction was observed in ground water treated plots than surface water in CSW method. Similarly, in 2013, CSW performed better than AWD in reducing soil As. Thus, in this year, AWD method was not found to be advantageous over CSW with respect to reduction of soil As. Research findings shows that not only soil aeration, but soil texture and other soil physico-chemical properties are responsible for variability of soil As (Ahmed *et al.,* 2012).

Conclusions

The result of the two years of the study shows that the grain As conc. of BRRI dhan28 was significantly lower in plots irrigated in AWD method than that in CSW method. This might have been due to reduced mobility of As in intermittent drained condition compared to continuously flooded condition of CSW method. Also the oxidized conditions in AWD can help develop Fe-plaque which in turn reduce bioavailability of As. However, the methods of irrigation did not influence soil As conc. significantly. Since the effect of AWD was favorable in increasing rice yield and reducing rice grain As, this technique can be proposed for the mitigation of As in the As-contaminated rice growing areas of Bangladesh. However, further study involving soil physico-chemical properties will help confirm the findings.

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