Effect of water management, tillage options and phosphorus rates on rice in an arsenic-soil-water system

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Abstract
Arsenic (As) in rice could become an additional health hazard in Bangladesh. Field experiments were conducted to examine the effects of water management (WM) and Phosphorus (P) rates on As uptake and yields in rice. There were 6 treatments consisting of two tillage options [Permanent raised bed-PRB (aerobic WM) and conventional till on flat-CTF (anaerobic WM)] and three P levels (0%, 100% and 200% of recommended P) using two rice varieties, in an As-contaminated field at Gaibandha, Bangladesh in 2004 and 2005. Significantly, the highest grain yields (6.65 and 7.12 t/ha in winter season irrigated rice (*boro)* 6.36 and 6.40 t/ha in monsoon rice (*aman)* in both the years' trials) were recorded in PRB (aerobic WM: Eh = +360 mV) plus 100% P amendment. There was a 14% yield increase over CTF (anaerobic WM: Eh = -56 mV) at same P level. The As content in grain and straw were about 3 and 6 times higher in CTF compared to PRB, respectively. The furrow irrigation approach of the PRB treatments consistently reduced irrigation input by 29-31% for *boro* and 27-30% for *aman* rice relative to CTF treatments in 2004 and 2005, respectively, thus reducing the amount of As added to the soil.

Key Words
Rice, water management, permanent raised bed, phosphorus, arsenic.

Introduction
There is a growing concern in Bangladesh about arsenic contamination of rice (*Oryza sativa* L), the staple food crop, because of the high As levels found in irrigation waters and soils in many parts of the country (Panaullah *et al*. 2003). As solubility and mobility in the soil environment depends on several factors including redox potential (Eh), pH and other factors. Phosphate enhances the mobility of As in soils (Campos 2002). Addition of P to the soil might enhance downward movement of As (Peryea *et al.* 1997). On the other hand, Jahiruddin *et al.* (2004) reported that application of P enhanced the As accumulation in flooded rice. Under oxidizing conditions, As solubility is low with the major portion of soluble As present as organic species. Paddy rice in flooded soil is known to be very susceptible to As toxicity as compared to upland rice, since As^{+3} would be more prevalent under reducing conditions, creating phytotoxicity to the paddy rice. As a result rice yields were decreased 75% at 50 ppm of disodium methylarsenate in silty loam soils (Das 2000).

Irrigated rice in Bangladesh like Asia is typically transplanted into puddled paddy fields. Because of increasing water scarcity, there is a need to develop alternative systems that require less water. Aerobic water management through permanent raised bed in Bangladesh is a new technique of rice production without sacrificing yield (Talukder *et al.* 2002). In a bed planting system, all the crops are considered to be grown in aerobic conditions. The amount of irrigation water applied is just enough to fill the furrow. Raised bed may reduce irrigation water (Julie *et al.* 2008) and amount of added As and the sorption of As with different clay particles like iron oxide is more in compare with flood irrigation on the conventional flat. For this reason, in a conventional planting system there are a lot of chances for As in the form of arsenite to enter into the plant roots up to the grains through As-contaminated irrigation water. Little research has been conducted to minimize As uptake by the crops. In particular, the potential of P amendments and aerobic rice production to reduce As contamination of rice needs to be investigated. Therefore, the present research program was undertaken with the following objectives:

1. To determine the influence of water management through PRB on the growth and yield of rice in As contaminated soil-water system,
2. To evaluate the effects of phosphorus on the growth and yield of rice in As contaminated soil and water, and
3. To evaluate the effects of water management and phosphorus on As uptake by the rice plant.

Methods

Field experiments were undertaken in an arsenic-affected area of Gaibandha, Bangladesh ($25^0$05.169' N Latitude and $089^0$26.327' East Longitude, 30 m asl) where soil and irrigation water were already contaminated with arsenic (BGS 2000). During the *boro* crop the area received 930 mm and 277 mm total rainfall in 2004 and 2005, respectively, about 50% of which occurred in May in both the years. The total rainfall was 818 and 1678 mm during the *aman* crop in respective years. The experimental soil was sandy clay loam with sightly acidity (pH 6.), low organic matter (0.95 %), low available P (5.47 ppm), moderate soil As (8.12 ppm) and high As content in irrigation water (0.1 ppm). The experiment comprised two tillage options viz. Permanent Raised Bed-PRB (aerobic/near saturated condition) and Conventional Tillage on Flat-CTF (anaerobic/flooded condition) and three P doses viz. 0, 100 and 200% of recommended phosphorus. The experiments were laid out in split plot design with three replications. The width of the beds was 75 cm (furrow to furrow) and depth of furrows on the average was 12.5 cm. Two rows of rice (var. BRRI Dhan 29 and 32 for *boro* and *aman* rice, respecrtively) with a spacing of 30 cm were transplanted by hand on the beds. In CTF, rice were transplanted in 30 x 15 (row x plant). The lay-out was maintained up to transplanted *aman* rice during 2005 season. Raised beds were not broken down but reshaped manually before transplanting the next rice. Irrigation was done as soon as the furrows become empty. But in CTF, excess irrigation water was applied to create an over saturated condition (flooded/anaerobic; 7-8 cm depth) and was maintained up to grain filling stage. Depending on climatic conditions, pattern of rainfall and soil type 9 and 12 irrigations per month was given for *boro* in 2004 and 2005, respectively. But in *aman* only 3 and 2 supplemental irrigations per month was made in consecutive years. Grain and straw yield were determined on a 7.5 m^2 area in the centre of each plot. Data were analysed for variance (ANOVA) using MSTAT-C. Treatment means were compared by Duncan's Multiple Range Test (DMRT).

Results

Effects of tillage options and P

Effective management strategies are required to reduce As accumulation in rice under As contaminated soils and irrigation water. A significant reduction in grain yield of *boro* and *aman* rice was found in the CTF using As-contaminated irrigation water (0.1 ppm As /L water). The highest grain yields (6.65 and 7.12 t/ha in 2004 and 2005, respectively) of *boro* rice were recorded in PRB with 100% P level (26 kg P/ha), which was a 14% yield increase at the same level P under CTF. In *aman*, the highest grain yields (6.36 and 6.40 t/ha in 2004 and 2005, respectively) were found under PRB (aerobic WM) with recommended P level (20 kg P/ha), which was also a 14% yield increase (pooled yield) over CTF at same P level (Table 1). The plots without P amendment had reduced growth, reduction of effective tillers hil/L, fertile grains/panicle, panicle length and 1000-grain weight (data not presented). There are similar reports of rice grain yield reduction under CTF compared to PRB culture (Lauren *et al.* 2008).

Table 1. Interaction effects of tillage options and phosphorus levels on yield and yield contributing characters of transplanted *boro* and *aman* rice on a farmers' field of arsenic affected area of Bangladesh.

Interactions (T x P)[Д]	*Boro* (Winter Season Irrigated Rice)				*Aman* (Monsoon Rice			
	Grain yield (t/ha)[µ]		Straw yield (t/ha)		Grain yield (t/ha)		Straw yield (t/ha)	
	2004	2005	2004	2005	2004	2005	2004	2005
PRB								
$P_{0\%}$	5.03 d[¶]	5.48 d	6.99 e	7.20 c	5.23 cd	4.75 d	7.20 cd	7.10 c
$P_{100\%}$	6.65 a	7.12 a	8.15 a	8.80 a	6.36 a	6.40 a	8.17 a	8.10 a
$P_{200\%}$	5.43 c	5.89 c	7.46 c	7.35 c	5.45 bc	5.27 c	7.35 bc	7.25 c
CTF								
$P_{0\%}$	4.61 e	4.90 e	6.88 e	7.00 d	5.12 d	4.25 e	7.00 d	7.15 c
$P_{100\%}$	6.00 b	6.11 b	7.68 b	8.20 b	5.68 b	5.55 b	7.53 b	7.75 b
$P_{200\%}$	5.28 cd	5.72 c	7.17 d	7.21 c	5.42 c	5.17 c	7.40 bc	7.20 c
CV (%)	1.89	1.34	1.24	1.38	1.64	1.79	1.98	1.54
Level of sig.	**	**	*	*	**	**	*	*

[¶]Figures with the same letters are not significantly different as per Duncan's Multiple Range Test.

[Д] PRB- permanent raised bed [aerobic water management (near saturated)], CTF- conventional till on flat [anaerobic water management (flooded)]. P-phosphorus level (% of recommendation-26 and 20 kg/ha for *boro* and *aman* rice, respectively); * Significant at 5% level of probability; ** Significant at 1% level of probability. T- tillage options; P - phosphorus. µ- at 12% moisture content

Arsenic uptake by grain and straw in boro rice

The strongest relationship between As and tillage options was found under As contaminated farmer's field conditions. The data (Figure 1) for As concentration in grain (husked) and straw clearly showed that irrespective of tillage options and P levels, rice straw contained MUCH higher concentrations of As than grain. A significant reduction of As content in *boro* rice grain (husked) was observed at a higher P amendment (200% of recommended). But As content in *boro* rice straw with P amendment was the same at the highest P rate. The arsenic concentration in grain was 3 times and As content in straw was about 6 times higher in CTF compared to PRB. Under CTF, rice was transplanted in a waterlogged condition. For this reason in CTF system, there are more chances for As in the form of arsenite to enter into the grains through As-contaminated irrigation water compared to PRB. During whole growing period, the soil Eh values of PRB and CTF was observed oxidized [Eh = +302 to +395 mV (pH-6.50 at 24^0C)] and reduced (-56 mV), respectively. The aerobic status of the beds indicating that As availability in soil solution was less. Under flooded conditions, the anaerobic status of soil promoted greater As availability for the plant uptake site. As a result, plants uptake less As under PRB (Figure 2).

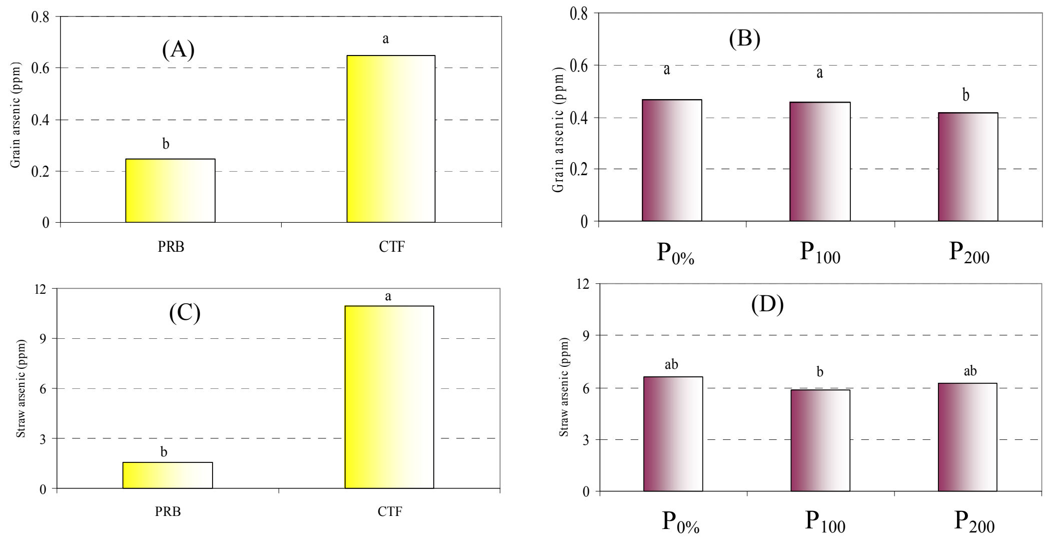

Figure 1. Arsenic uptake by *boro* rice as affected by tillage options and P levels (A to D) on a farmers' field in 2005
[Note: The bar having the same letters are not significantly different as per Duncan's Multiple Range Test]

There is much evidence to confirm these findings. The mobility of As in soils depends on several factors including redox potential, soil pH, the presence of other anions that compete with As for soil retention sites, for example, P. Phosphate enhances the mobility of As in soils by competing for adsorption sites. McGeehan *et al.* (1998) reported that prolonged flooding resulted in a decrease in soil redox potential an increased of As availability. As a result As is more available in soil water due to flooding (Onken *et al.*1995). Under this situation plant can take up more As.

Table 2. Redox potential (Eh) soil under different tillage options in transplanted *boro* and *aman* rice on a farmers' field of arsenic affected area of Bangladesh in 2005.

Soil depth (cm) #	Cultivation practices					
	Conventional till on Flat-CTF			Permanent Raised Bed-PRB		
	Eh value (mV)	pH	Temp. (^{0}C)	Eh value (mV)	pH	Temp (^{0}C)
10	-38	6.8	26.9	395	6.9	26.4
20	-60	6.7	25.5	385	6.35	25.6
30	-71	6.65	25.6	302	6.56	25.7
Mean	-56*	6.72	26	+361**	6.6	25.9

*anaerobic water management; **aerobic water management; # mean value of three replications.

Irrigation input

In the field study it was observed that during the irrigation, water advanced faster in untilled soil than in a tilled soil, and furrow irrigation is used as opposed to flood inundation, a substantial savings (30%) in water applications was expected with PRB as compared to CTF treatments (data not presented). The furrow irrigation approach of the PRB treatments consistently reduced irrigation inputs. As a result there was a

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reduced amount of As deposited to the soil in PRB by the As contaminated irrigation water (0.1 ppm). Yearly, 30% less As was deposited to the soil compared to CTF system through irrigation water during *boro* season. Lauren *et al.* (2008) observed that the furrow irrigated raised bed system consistently reduced irrigation inputs by 21-33% for wheat, 14-38% for rice and 16-33% for mungbean relative to CTF treatments. On a per hectare basis, these reductions translate into annual irrigation input savings of between 0.4 and 3.1 ML. Furthermore, farmers would likely have significant cost savings for fuel by pumping less water.

Conclusion

Arsenic has a negative impact on yield and yield components of rice. Phosphorus amendment and aerobic WM also had potential effects on grain yield. Aerobic WM reduced As toxicity compared to anaerobic WM for all P levels. Water management is a potential tool to reduce As contamination of grain and straw to levels safe for human and cattle consumption in the As affected areas of Bangladesh. The possibility of potential health hazards for As in foodstuffs are dependent on As species and its accumulation and metabolism in the body systems of human or cattle. So, it should be further studied. Aerobic rice culture might be the alternate option to maximize yields of rice, reduce or minimize As accumulation and toxicity in rice without access to irrigation in As contaminated areas of Bangladesh.

References

BGS (British Geological Servey) (2000). 'Groundwater Studies of Arsenic Contamination in Bangladesh' (British Geological Survey and Mott MachDonald (UK) for the Government of Bangladesh, Ministry of Local Government, Rural Development and Cooperatives, Department of Public Health Engineering and Department for International Development: UK).

Campos, V (2002). Arsenic in groundwater affected by phosphate fertilizers at São Paulo, Brazil. *Environ. Geol.* **42,** 83-87.

Das, HK (2000). 'Bangladesh Arsenic. Bhayabahata O Sambhabbya Protikar (Bengali)'. (Bangla Academy: Dhaka).

Jahiruddin M, Islam MR, Shah AL, Islam S, Ghani, MA (2004). Effects of Arsenic Contamination on Yield and Arsenic Accumulation in crops. In 'Proceedings for workshop on arsenic in the food chain: Assessment of arsenic in the water-soil-crop system'. (Ed MAL Shah, MA Rashid, MH Rashid, MR Mandal, MA Ghani) pp. 39-51. (BARI: Gazipur, Dhaka, Bangladesh).

Lauren JG, Shah G, Hossain MI, Talukder ASMHM, Duxbury JM, Meisner CA, Adhikari C (2008). Research station and on-farm experiences with permanent raised beds through the Soil Management Collaborative Research Support Program. In 'Proceedings of permanent beds and rice residue management for rice–wheat systems in the Indo-Gangetic Plain. Ludhiana, India 7-9 September 2006'. ACIAR Proceedings No. 127. (Eds E Humphreys, CH Roth) pp 124-132.

McGeehan SL, Fendorf SE, Naylor DV (1998). Alteration of arsenic sorption in flooded-dried soils. *Soil Sci. Am. J.* **62,** 828-833.

Onken BM, Hossner LR (1995). Plant uptake and determination of arsenic species in soil solution under flooded conditions. *J. Envirn. Qual.* **24,** 373-381.

Panaullah GM, Ahmed ZU, Rahman GKMM, Jahiruddin M, Miah MAM, Farid ATM, Biswas BK, Lauren JG, Loeppert RH, Duxbury JM, Meisner, CA (2003). The Arsenic Hazard in the Irrigation Water-Soil-Plant System in Bangladesh:A Preliminary Assessment. In 'Proceedings of 7th International Conference on the Biogeochemistry of Trace Elements. Uppsala, Sweden, June 10-15, 2003'.

Peryea FJ, Kammereck R (1997). Phosphate-enhanced movement of arsenic out of lead arsenate contaminated top soil and through uncontaminated subsoil. *Water Air Soil Pollut.* **93,** 243–254.

Talukder ASMHM, Sufian MA, Meisner CA, Duxbury JM, Lauren JG, Hossain ABS (2002). Rice, wheat and mungbean yields in response to N levels and management under a bed planting system. In 'Proceedings of the 17th World Congress of Soil Science, Bangkok, Thailand'. Vol no.1. Symposium no. 11, 351.