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Mitigation options of arsenic uptake by rice plant in arsenic endemic area

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ABSTRACT

A study was initiated with selected organic and inorganic amendments to restrict arsenic mobilization in soil-plant system under differential water sources as well as to examine the variability of arsenic uptake as the irrigation sources differ. The study was conducted in a arsenic endemic area, namely Nonaghata-Uttarpara village of Haringhata block of Nadia district, West Bengal with rice cv. IET 4786 during 2006-2007. The result indicated that among the organics, vermicompost gave the best result followed by farm yard manure, whereas $FeSO_4 > ZnSO_4 > CaSiO_3$ *in case of inorganic amendments in minimizing arsenic uptake in soil-plant system. Pond water irrigated plots received less arsenic in soil-plant system compared to shallow tube well irrigated plots. The arsenic concentration in different plant parts were significantly correlated to the degree of arsenic contamination of soil at different growth stages of rice.*

Key words: *rice, irrigation water, arsenic, organic and inorganic amendments*

Rice is grown in Indo-Gangetic plains, in 85 percent of the cultivated land area with ground water as a principal source of irrigation. Most of the shallow groundwater in Indo-Gangetic plains are geogenicaly contaminated with arsenic (As), exposing more than 40 million people at risk of As in drinking water (World Bank, 2005). Arsenic contamination of water and soil can also adversely affect food safety. A global normal range of 0.08 to 0.2 mg As kg^{-1} has been suggested for rice (Zavala and Duxbury, 2008), but values as high as 0.25 mg As $kg.^{-1}$ have been found in rice (Mandal *et al.*, 2007). The average daily intake of As from rice for an adult in India is approximately 100 mg As, which is 5 times the 20 mg As intake from consumption of 2 L of water (Williams *et al.,* 2006) as against the WHO limit of 10 ugL^{-1} (WHO, 1993). The present study has been undertaken to take an account of arsenic accumulation in rice from arsenic contaminated irrigation water, and to adjudge the efficiencies of selected organic and inorganic amileorants in offloading arsenic in soil-plant system.

MATERIALS AND METHODS

The study was undertaken in farmers' fields irrigated with shallow tube well (STW) located in Nonaghata-Uttarpara of Haringhata block in Nadia district, an arsenic affected area of Gangetic plain of West Bengal, India. The soil was characterized to be silty clay loam (clay 32.2%, silt 49.6%), neutral in reaction (pH 6.65), moderate in organic matter (oxidizable organic C 4.0 g kg^{-1}), low in available N (126 kg ha^{-1}), low-medium in available P_2O_5 (45.0 kg ha^{-1}), and moderate in available K_2O (115.0 kg ha^{-1}).

The extractable Si (27.62 mg kg $^{-1}$), Fe (3.36 mg kg^{-1}) and Zn (0.28 mg kg^{-1}) were also determined. The range of total and olsen extractable arsenic contents of the experimental soil were 16.52 and 2.37 mg kg^{-1}, respectively (Table 1). The levels of arsenic contamination in shallow tube well (STW) and pond water (PW) were 0.39 and 0.07 mg l^{-1}, respectively.

The experiment was laid out in a thrice replicated factorial design with three replications to adjudge the effects of three levels of organic amileorants e.g. control, farm yard manure (FYM) and vermicompost (VC) (@ 0, 10.0 and 2.5 $t.ha^{-1}$), four levels of inorganic amileorants e.g. control, $FeSO_4$, $ZnSO_4$ and $CasiO_3$ (@ 0, 30, 20 and 400 kg ha^{-1}. Sampling was done at 55, 110 and 150 days after transplanting. Two regimes of irrigation e.g. shallow tube well and pond water irrigation, alone and in combination, on arsenic loading in root, shoot, grain of summer rice cv. IET 4786 and arsenic build-up in

Table 1. Properties of the experimental soil, applied organic matters and irrigation water

Properties Experimental soil	Observations
Soil taxonomy	Typic Haplustepts
pH	6.65
EC (dS m-1)	0.14
Cation exchange capacity (CEC)	
[cmol (p+) kg-1]	10.5
Oxydizable organic carbon (g kg-1)	4.0
Textural composition	
Sand (%)	18.2
Silt (%)	49.6
Clay (%)	32.2
Textural class	Silty clay-loam
Exchangeable Ca + Mg [cmol (p+) kg^{-1}]	9.57
Amorphous Fe (%)	0.49
Amorphous Al (%)	0.28
Available nitrogen (kg ha^{-1})	126
Available P_2O_5 (kg $ha^{-1)}$	45.0
Available K_2O (kg ha^{-1})	115.0
Available Fe (mg kg^{-1})	3.36
Available Zn (mg kg^{-1})	0.28
Available Cu (mg kg^{-1})	0.51
Available Mn (mg kg^{-1})	2.86
Available Si (mg kg^{-1})	27.62
Olsen extractable As (mg kg^{-1})	2.37
Total As (mg kg^{-1})	16.52
Vermicompost	
Total N (%)	1.52
Total P (%)	0.41
Total K (%)	0.72
Total As (mg kg^{-1})	2.62
FYM	
Total N (%)	0.65
Total P (%)	0.22
Total K (%)	0.31
Total As (mg kg^{-1})	2.04
Shallow tube well water	
Total As (mg L^{-1})	0.39
Pond water	
Total As (mg L^{-1})	0.07

experimental soils. The N, P_2O_5 and K_2O were applied at their recommended doses (100:50:50 kg ha^{-1}). The organic manures were applied 15 days before transplanting whereas inorganic amendments and fertilizers were applied at the time of final land preparation. The 21 days rice seedlings were transplanted into each plot at 20 x 20 cm spacing. The crop was sampled at different growth stages like vegetative 55 days after sowing, reproductive (110 DAS) and harvesting (150 DAS) stages. The data were statistically analyzed following the principle of strip plot design and conclusions were drawn with the software package MSTATC.

Available N content of soil was determined by the Kjeldahl method (Subbiah and Asija, 1956), available P by 0.5 M $NaHCO_3$ (pH 8.5) (Olsen and Sommers, 1982), exchangeable K by 1M NH_4OAc (pH 7.0) (Knudsen et al. 1982), oxydizable organic C (Walkley and Black, 1937), extractable Si by 0.5 mol L^{-1} acetic acid (Corey and Jackson, 1953), texture (Dewis and Freitas, 1984), available Fe and Zn (Lindsay and Norvell, 1978), olsen extractable As by 0.5 M $NaHCO_3$ (pH 8.5) and total As by tri-acid digestion (Sparks, 2006). Plant samples (root, straw and grain) were digested with a mixture of acids i.e. HNO_3, $HClO_4$ and H_2SO_4 in a proportion of 10:4:1 (v/v) for As determination. Extractable P and Si were analyzed colorimetrically, extractable K was analyzed by flame photometry, extractable and total soil As and plant As were determined through atomic absorption spectro-photometer (PerkinElmer Analyst 200) coupled with flow injection (FIAS-400) hydride generation system.

RESULTS AND DISCUSSION

Accumulation of arsenic in different plant parts of rice gradually decreased from root > shoot > grain while significant increase in arsenic loading in root and shoot was observed with advancement of growth stages of rice. However, insignificant amount of arsenic was found to be translocated to grain, the highest recovery of arsenic was to the tune of 0.94 mg.kg^{-1} of rice grain (in control under irrigation from STW). Significantly lower recoveries of arsenic from soil and different plant parts of rice in different growth stages were obtained when exposed to irrigation from pond water (Table 2 and 3).

Vermicompost remained more efficient in ameliorating arsenic in soil and plant than FYM (Sinha and Bhattacharyya, 2011), while such efficiencies of the selected inorganic amendments came in the order of $FeSO_4$ > $ZnSO_4$ > $CaSiO_3$ regardless of growth stages of rice. The enhanced iron (Fe^{2+}) in the soil solution due to application of $FeSO_4$ may be responsible for reducing extractable As through sorption/co-precipitation as insoluble Fe-As complexes (Al-Abed

Table 2. Effect of selected organic-inorganic ameliorants on root, straw and grain arsenic content at different growth stages of *boro* rice cv. IET 4786

Treatments	Root As (mg kg^{-1})			Straw As (mg kg^{-1})			Grain As (mg kg^{-1})
	55 DAS	110 DAS	150 DAS	55 DAS	110 DAS	150 DAS	Harvest
$W_1O_1I_1$	15.34	21.07	20.73	9.56	10.42	10.26	0.94
$W_1O_1I_2$	12.54	17.52	17.22	5.84	7.02	6.90	0.53
$W_1O_1I_3$	12.91	18.87	18.67	6.15	8.67	8.38	0.66
$W_1O_1I_4$	14.05	19.82	19.26	7.54	9.55	9.44	0.77
$W_1O_2I_1$	12.05	19.48	19.05	7.45	9.01	8.61	0.87
$W_1O_2I_2$	10.98	15.66	15.37	5.01	5.86	5.52	0.49
$W_1O_2I_3$	11.22	16.25	16.04	5.55	7.12	6.92	0.55
$W_1O_2I_4$	11.39	18.21	18.16	6.89	8.65	8.50	0.66
$W_1O_3I_1$	11.16	18.39	18.01	6.88	8.22	8.19	0.82
$W_1O_3I_2$	9.88	14.62	14.24	4.41	5.21	5.02	0.42
$W_1O_3I_3$	10.09	15.94	15.61	4.68	6.39	6.17	0.48
$W_1O_3I_4$	10.68	17.66	17.48	6.52	8.06	7.81	0.67
$W_2O_1I_1$	12.26	18.99	18.76	8.85	9.49	9.36	0.86
$W_2O_1I_2$	10.11	15.84	15.45	5.32	6.21	6.02	0.44
$W_2O_1I_3$	10.67	16.35	15.98	5.78	7.78	7.67	0.58
$W_2O_1I_4$	11.51	17.52	16.99	8.02	8.84	8.59	0.74
$W_2O_2I_1$	10.35	17.37	17.15	6.98	7.89	7.67	0.76
$W_2O_2I_2$	8.82	14.92	13.57	4.82	4.52	4.35	0.41
$W_2O_2I_3$	8.97	15.26	14.71	4.99	6.07	5.90	0.56
$W_2O_2I_4$	9.64	15.92	15.68	5.37	7.01	6.81	0.65
$W_2O_3I_1$	10.01	17.26	17.13	5.46	7.15	6.98	0.67
$W_2O_3I_2$	7.78	13.45	13.26	4.69	4.36	4.18	0.38
$W_2O_3I_3$	7.92	13.82	13.48	4.88	5.22	5.02	0.46
$W_2O_3I_4$	8.65	15.34	14.93	5.18	5.92	5.45	0.54
SD	1.83	1.95	2.01	1.39	1.66	1.68	0.16

CD at 5%	Root	Straw	Grain
D	0.024	0.16	
W	0.020	0.13	0.001
D × W	0.034	0.22	
O	0.011	0.13	0.003
D × O	0.019	NS	
W × O	0.019	0.19	0.008
D × O × W	0.034	NS	
I	0.014	0.14	0.004
D × I	0.024	0.24	
W × I	0.019	0.20	0.005
D × W × I	0.033	NS	
O × I	0.024	0.24	0.006
D × O × I	0.041	0.42	
W × O × I	0.033	0.34	0.009
D × W × O × I	0.058	NS	

W - Irrigation sources (W_1- Shallow tube well, 0.21 to 0.26 mg L^{-1} As; W_2- Pond water, 0.09 to 0.18 mg L^{-1} As); O- Levels of organics (O_1- Control, O_2- Farm yard manure @ 10 t ha^{-1}, O_3- Vermicompost @ 2.5 t ha^{-1}); I- Levels of inorganics (I_1- Control, I_2- $FeSO_4$ @ 30 kg ha^{-1}, I_3- $ZnSO_4$ @ 20 kg ha^{-1}, I_4-$CaSiO_3$ @ 400 kg ha^{-1}). DAT – Days after transplanting, D – Days of sampling

et al., 2007). The reduction of extractable As manifested through application of $ZnSO_4$ may come out through precipitation/fixation of As as Zn–arsenate (Das *et al.*, 2008). The application of silica reduced the extractable As in soil-plant system throughout the growth period. Bogdan and Schank (2008) observed that there was an inhibitory effect of indigenous silicic acid in soil on As uptake by rice. The interactions of organic-inorganic interventions also remained efficient in significantly offloading arsenic in soil and plant among which the vermicompost-$FeSO_4$ interactions performed best in reducing arsenic concentration in root, shoot and grain of rice regardless of growth stages and irrigation regimes. The arsenic recoveries in rice grain were substantially (significantly at the same time) reduced to the tune 0.42 and 0.38 mg.kg^{-1} in STW and PW irrigated rice administered with vermicompost and $FeSO_4$ manifesting 55 per cent reduction over corresponding control (Table-2). The beneficial role

Table 3. Effect of selected organic-inorganic ameliorants on olsen extractable arsenic in soils at different growth stages of *boro* rice cv. IET 4786.

Treatment	Soil As (mg kg^{-1})		
	55 DAS	110 DAS	Post-Harvest
$W_1O_1I_1$	2.94	3.87	3.61
$W_1O_1I_2$	2.41	3.08	2.62
$W_1O_1I_3$	2.75	3.46	2.96
$W_1O_1I_4$	2.76	3.70	3.49
$W_1O_2I_1$	2.84	3.61	2.50
$W_1O_2I_2$	2.44	2.94	1.62
$W_1O_2I_3$	2.52	3.40	1.72
$W_1O_2I_4$	2.70	3.49	2.41
$W_1O_3I_1$	2.71	3.50	2.05
$W_1O_3I_2$	2.35	2.78	1.46
$W_1O_3I_3$	2.45	3.14	1.59
$W_1O_3I_4$	2.60	3.29	1.69
$W_2O_1I_1$	2.85	3.02	2.48
$W_2O_1I_2$	2.12	2.25	1.67
$W_2O_1I_3$	2.38	2.45	1.90
$W_2O_1I_4$	2.52	2.74	2.04
$W_2O_2I_1$	2.61	2.75	1.87
$W_2O_2I_2$	1.94	2.13	1.31
$W_2O_2I_3$	1.86	2.32	1.41
$W_2O_2I_4$	2.35	2.47	1.68
$W_2O_3I_1$	2.43	2.58	1.77
$W_2O_3I_2$	1.46	1.80	1.18
$W_2O_3I_3$	1.67	1.88	1.28
$W_2O_3I_4$	2.18	2.37	1.52
SD	0.38	0.59	0.66
CD at 5%			
D	0.007	I	0.013
W	0.006	D × I	0.023
D × W	0.010	W × I	0.019
O	0.014	D × W × I	0.033
D × O	0.025	O × I	0.023
W × O	0.015	D × O × I	0.040
D × O × W	0.026	W × O × I	0.032
D × W × O × I	0.056		

W - Irrigation sources (W_1- Shallow tube well, 0.21 to 0.26 mg L^{-1} As; W_2- Pond water, 0.09 to 0.18 mg L^{-1} As); O- Levels of organics (O_1- Control, O_2- Farm yard manure @ 10 t ha^{-1}, O_3- Vermicompost @ 2.5 t ha^{-1}); I- Levels of inorganics (I_1- Control, I_2- $FeSO_4$ @ 30 kg ha^{-1}, I_3- $ZnSO_4$ @ 20 kg ha^{-1}, I_4-$CaSiO_3$ @ 400 kg ha^{-1})

manifested through organic interventions in reducing As accumulation in rice may be attributed to formation of insoluble organo-As complex through enriched organic fractions due to incorporation of organic matters in rice soils (Das *et al.*, 2008). This has been further substantiated by correlation obtained at different growth stages between As content in different plant parts and extractable soil As (Table-5).

The relative efficacy of different organic & inorganic amendments in increasing rice yield was in order of FYM > vermicompost in case of straw yield and vermicompost > FYM in grain yield was observed. A positive effect of use of vermicompost and FYM application on growth and productivity of rice have been also cited by Benik and Bhebaruah (2004), Adhikari and Mishra, (2002). Increase in grain and straw yields through inorganic amendments appeared in an order of $CaSiO_3$ > $FeSO_4$ > $ZnSO_4$ (Table 4) as also observed by earlier workers (Jawahar and Vaiyapuri, 2010; Sarwar, 2011). The lowering of yields in plots receiving water from STW may be attributed to several reasons, one of which might be due to higher As concentration of the irrigation sources (Table 1) which caused decreased iron concentration in leaves resulting poor formulation or reduction of chlorophyll in rice leaf, leading to poor yield of rice (Shaibur *et al.* 2006).

Table 4. Effect of different organic-inorganic ameliorants on yield of *boro* rice cv. IET 4786

Treatment	Straw yield (t ha^{-1})			Grain yield (t ha^{-1})		
	O_1	O_2	O_3	O_1	O_2	O_3
W_1I_1	3.94	5.14	5.16	2.95	4.35	4.40
W_1I_2	4.05	5.32	5.24	3.29	4.62	4.81
W_1I_3	4.02	5.41	5.25	3.23	4.58	4.70
W_1I_4	4.45	5.56	5.61	3.45	4.71	4.85
W_2I_1	5.36	6.39	6.44	4.08	5.43	5.64
W_2I_2	5.74	6.65	6.52	4.76	5.88	6.05
W_2I_3	5.68	6.60	6.49	4.67	5.80	5.84
W_2I_4	6.02	6.95	6.88	4.96	5.95	6.15
SD	0.88	0.72	0.70	0.79	0.67	0.69
CD at 5 %		Straw yield			Grain yield	
W		0.013			0.041	
O		0.011			0.029	
W × O		0.028			0.042	
I		0.023			0.018	
W × I		0.032			0.025	
O × I		0.040			0.031	
W × O × I		0.056			0.044	

W - Irrigation sources (W_1- Shallow tube well, 0.21 to 0.26 mg L^{-1} As; W_2- Pond water, 0.09 to 0.18 mg L^{-1} As); O- Levels of organics (O_1- Control, O_2- Farm yard manure @ 10 t ha^{-1}, O_3- Vermicompost @ 2.5 t ha^{-1}); I- Levels of inorganics (I_1- Control, I_2- $FeSO_4$ @ 30 kg ha^{-1}, I_3- $ZnSO_4$ @ 20 kg ha^{-1}, I_4-$CaSiO_3$ @ 400 kg ha^{-1})

Based on the results, it may be concluded that use of surface water (pond water) for irrigation may be a safer alternative to underground water with regard to arsenic ingestion in food-web. Adoption of appropriate management practices (such as recycling

Table 5. Correlations drawn between arsenic accumulation in different plant parts and Olsen extractable arsenic in soil at different growth stages of *boro* rice (cv. IET 4786)

Plant parts of rice	Different stages of rice		
	55 DAT	110 DAT	Harvest
Root	0.877**	0.953**	0.906**
Shoot	0.777**	0.895**	0.858**
Grain	-	-	0.728**

*** indicates significant at 1 % level of significance*

of crop residues, incorporation of organic manures, etc.) to improve the soil organic matter stock and hence arsenic retention in the arsenic-affected soils as well as incorporation of inorganic amendments especially micronutrients like Zn, Fe, Si etc. in deficient areas could be an efficient management option in arsenic endemic areas.

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