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Role of organics in reducing arsenic loading in soil-plant system under rice in the lower *Gangetic* plain of West Bengal

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ABSTRACT

Rice (Oryza sativa L.) is one of the major food crops in many countries. As the cultivation of rice requires huge volume of water, long term use of arsenic contaminated groundwater for irrigation may result in the increase of arsenic concentration in the agricultural soil and eventually accumulation in rice plants. In this context, an experiment has been conducted in the arsenic endemic area of village Ghentughachi (block Chakdaha, Nadia district, West Bengal, India) at farmer's field to explore the effect of selected organic manures (namely, mustard cake, vermicompost, municipal sludge and FYM) on minimization of arsenic uptake by rice. The arsenic status of the soil and irrigation water of the experimental site was 10.24- 19.17 kg ha^{-1} (total soil arsenic), 0.34 mg l^{-1} (arsenic in water discharged from shallow tube well) and 0.03 mg l^{-1} (arsenic in pond water). Arsenic accumulation in different plant parts of rice was monitored at different growth stages and it has been observed that highest arsenic concentration was found in root (34.84-75.25 mg kg^{-1}), and the lowest in the grain (0.44-1.33 mg kg^{-1}). Regardless of the growth stages the arsenic accumulation follows the order of root > leaf> shoot > grain. Both irrigation source and organic amendments significantly decrease crop arsenic uptake. Such favourable effects exerted by the selected organic matters in offloading arsenic from rice remained most pronounced with municipal sludge and farm yard manure when total uptake of arsenic by different plant parts was taken into account throughout the entire growth period.

Key words: Arsenic, organic manures, rice

Rice is the most important crop of India and second principal food crop of the world. In India, rice is predominantly grown in the Indo-Gangetic plains, on 13.5 million ha or 85 percent of the cultivated land area with ground water as a principal source of irrigation (Samra *et al.*, 2004).

Most of the shallow groundwater in southern Bangladesh and eastern part of West Bengal, India, is 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 Indian adult is approximately 100 mg As (NNMB, 2002) (400 g dry wt x 0.25 mg As kg^{-1}), which is 5 times the 20 mg As intake from consumption of 2 L of water as the WHO limit of 10 ug l^{-1} (WHO, 1993).

Arsenic contamination in groundwater in the state of West Bengal has assumed the proportion of 12 endemic districts, 111 endemic blocks and above 50 million people exposed to threats of arsenic related health hazard (Anon., 2006). It is only the agricultural sector which enjoys the major share (> 90%) of such contaminated groundwater as source of irrigation and received attention for quantifying the influence of arsenic in soil-plant system (Abedin *et al.*, 2002, Mukhopadhyay and Sanyal, 2004). In this context, an experiment has been conducted in the arsenic endemic area of village Ghentughachi (block Chakdaha, district Nadia, West Bengal) at farmer's field to explore the effect of selected organic manures (namely, mustard cake, phosphocompost, municipal sludge and FYM) on minimization of arsenic uptake by rice.

MATERIALS AND METHODS

The experiment was conducted at farmer's field in the Village Ghentugachhi, Geographical location: N $23^0 02'7.1''$, $E88^0 35'4.8''$, district Nadia, West Bengal, India for two years (2008 and 2009) during May to September. The crop autumn rice, variety *GS 3* which is widely grown in the arsenic affected area of West Bengal was selected for the study. The crop was sown during first week of May. Seed rate was 100 kg/ha and spacing maintained at 30×10 cm. Weeding has been done twice (@ 20 and 40 DAT. Rice fields have been irrigated both from shallow tube well water (As concentration ≅ 0.32 mg l^{-1}) and pond water (As concentration ≅ 0.03 mg l^{-1}). The experiment has been laid out in a 2 factor randomized block design with three replications. Factorial experimental treatments were two levels of irrigation (irrigation through shallow tube well water and irrigation through surface water) and four levels of organic manures namely FYM@10 t ha^{-1} ,vermicompost @3 t ha^{-1},municipalsludge @10t ha^{-1} and mustard cake@1.0 t ha^{-1}. The soils were amended with well decomposed FYM, vermicompost, municipalsludge and mustard cake in respective treated plots followed by a couple of ploughing operations 25 days before sowing. The recommended doses of N, P, K fertilizers (N: P_2O_5: K_2O:: 100 : 50 : 50 kg ha^{-1}) were applied to the soils irrespective of treatments. The entire P and K fertilizers were applied basally while N fertilizer has been applied in three splits (50% as basal and rest 50% top dressed at 30 DAT and 45 DAT). Weeding has been done twice (@

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20 and 40 DAT. The initial and post-harvest soil samples were collected through soil auger at a depth of 15 cm. At least 10 sub (core) samples were collected to have the composite sample from one replication. Plant samples (whole plant) were collected at different growth stages *i.e.* at 30, 60 and 90 DAT.

Soils were collected, tagged and packed in brown polythene packets and taken to the laboratory. The soil samples were air-dried, ground and sieved through 2 mm sieve and packed in air tight polythene containers. The plant samples were oven dried for 24 hours at 105°C, ground and packed in air tight polythene container. Soil samples were analyzed for detailed characterization with respect to the important physico-chemical properties (pH, organic carbon, available N, P_2O_5 and K_2O, total and extractable arsenic) following the standard methods (Page, 1982).

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, 1934), texture (Dewis and Freitas, 1984), olsen extractable As by 0.5 M $NaHCO_3$, pH 8.5 (Olsen and Sommers, 1982) and total As by tri-acid digestion (Sparks, 2006). Plant samples 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 total As measurement. Olsen extractable P was analyzed colorimetrically, ammonium acetate extractable K was analyzed by flame photometry. Sodium bicarbonate extractable As, total soil As and plant As were determined through atomic absorption spectrophotometer (PerkinElmer AAnalyst 200) coupled with flow injection system (FIAS-400).

The humic acid (HA) and fulvic acid (FA) fractions were extracted from the manures used with 0.5 M Na_2CO_3, followed by their fractionation into humic and fulvic acid constituents and the complexation equilibria between arsenic and the humic/fulvic substances were examined following the standard method (Schnitzer and Skinner, 1966) and the stability constants (Log k) of the arsenic-humic/fulvic complexes formed were recorded.

The leachate from soil or the digest of soil and plant samples collected after digesting 1 g of soil and plant sample and was diluted to 50 ml. 10 ml of the aliquot was taken in 50 ml volumetric flask, 5 ml of concentrated HCl and 1 ml of mixed reagent [5% KI (w/v) + 5% Ascorbic acid (w/v)] were added to it, kept for 45 minutes to ensure complete reaction and the volume was made up to 50 ml The resultant solution was analyzed in a PerkinElmer Atomic Absorption Spectrophotometer with Flow Injection Analysis System (FIAS 400) @ $\lambda_{max} \cong 193.7$ nm where the carrier solution was 10% v/v HCl, the reducing agent [to ensure all As species be reduced to AsH_3 and to be measured against a calibration with standard As^{+3} solution in 10% (v/v) HCl] was 0.2% $NaBH_4$ in 0.05% NaOH. The spectrometer technique is AA, integration time 15 sec, peak height- smoothing- 0.5 sec/19 points, lamp- EDL, slit- 0.7 nm, cell temperature- 900^0C.

RESULTS AND DISCUSSION

The selected physicochemical properties of the soil and the concentrations of arsenic in irrigation water, soil are presented in table-1. The results clearly indicate that the agricultural soil of the study area has become highly contaminated with arsenic (19.17 mg kg^{-1}) due to the excessive use of arsenic rich groundwater (0.32 mg l^{-1}) for irrigation. Long term use of arsenic contaminated groundwater for irrigation may result in the further increase of arsenic concentration in the agricultural soil and eventually hyper-accumulation in rice plants.

Table 1: Physico- chemical properties of experimental site

Properties	Observation
Soil	
pH	7.51
Organic C (%)	0.56
Textural class	Silty clay
%Sand	3.5
% Silt	46.7
% Clay	49.8
Available nitrogen (kg ha^{-1})	220.0
Available phosphorus (kg ha^{-1})	57.0
Available potassium (kg ha^{-1})	190.0
Total arsenic (kg ha^{-1})	19.17
Available arsenic (kg ha^{-1})	5.30
Water	
Arsenic in pond water (ppm)	0.03
Arsenic in shallow water (ppm)	0.32

The results of table-2 revealed that maximum accumulation of arsenic was observed in root (34.84-75.25 mg kg^{-1}), followed by leaf (4.56-18.63 mg kg^{-1}), shoot (2.28-18.00 mg kg^{-1}) and grain (0.44-1.33 mg kg^{-1}). Results revealed that the arsenic accumulation in different parts of rice remained in an order of root>leaf>shoot>grain in both experimental years (2008 and 2009) which has been found to increase with advancement of growth stages (Fig.1). Similar observations were also reported by Abedin *et al.,* 2002. Very little share of the total arsenic accumulation has been found to be translocated to grain (2-4%), although the level is alarming (0.44-1.33 mg kg^{-1}).

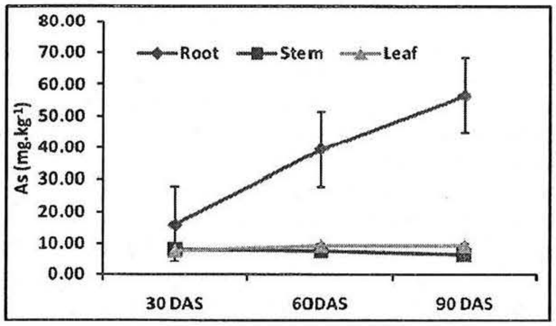

Fig. 1: Progressive changes in arsenic accumulation in different plant parts of *autumn* rice with advancement of growth

The results clearly indicated that incorporation of organic manures has marked effect on reduction of arsenic accumulation in different plant parts of *autumn* rice. It was observed that incorporation of organic manures significantly reduced the arsenic uptake by different plant parts of rice over the control counter part under both the irrigation regimes (STW and PW). Such beneficial role exerted by different organic sources has been found to be most pronounced and consistent with FYM and vermicompost. Das *et al.* (2005) also observed that available soil arsenic content decreases with the increase of organic matter application. Such changes in arsenic accumulation in rice manifested either through using surface water as irrigation source or through organic amendments, may be attributed to similar changes in soil available arsenic under similar situations, as reflected in significant correlation drawn between total arsenic uptake by rice at harvest and available arsenic in post-harvest soil of rice (Table 3). The magnitude of such decreases, however, varied with sources and levels of applied organic matter while such decrease remained most pronounced with vermicompost, which might be due to formation of insoluble arseno-organic complexes and its adsorption on to organic colloids.

Table 2: Arsenic accumulations in different plant parts of rice recorded at different growth stages as affected by intervention of organic manures and source of irrigation

Irrigation sources (I)	Organic matters (O)	Arsenic accumulation (mg kg^{-1})							
		2008				2009			
		Root	Shoot	Leaf	Grain	Root	Shoot	Leaf	Grain
Shallow tube-well water	C	67.67±1.53	18.00±0.19	18.63±0.10	1.33±0.04	75.25±0.25	4.94±0.06	12.15±0.12	0.92±0.08
	O_1	68.33±2.96	13.08±0.29	16.13±0.20	0.76±0.03	54.22±0.47	3.38±0.05	8.77±0.08	0.75±0.06
	O_2	65.75±0.74	8.53±0.17	7.46±0.09	1.08±0.06	42.41±0.17	4.46±0.08	6.13±0.05	0.90±0.05
	O_3	65.50±0.41	7.40±0.09	11.89±0.14	0.60±0.02	38.33±0.43	2.78±0.11	6.41±0.11	0.66±0.07
	O_4	63.92±1.31	9.03±0.19	13.50±0.10	0.67±0.08	49.45±0.13	3.01±0.05	6.75±0.09	0.68±0.04
	Mean	**66.23**	**11.21**	**13.52**	**0.89**	**51.93**	**3.71**	**8.04**	**0.78**
Pond water	C	65.33±0.77	13.92±0.21	10.84±0.15	1.17±0.14	69.21±0.33	3.68±0.09	9.77±0.11	0.82±0.06
	O_1	68.58±0.31	9.31±0.14	9.36±0.23	0.64±0.09	49.49±0.20	3.25±0.11	6.23±0.09	0.63±0.03
	O_2	56.33±0.72	7.97±0.11	8.54±0.18	0.48±0.06	37.68±0.22	2.28±0.06	4.56±0.05	0.62±0.05
	O_3	58.17±0.31	5.23±0.18	7.53±0.13	0.44±0.11	34.84±0.47	2.58±0.12	6.84±0.07	0.63±0.04
	O_4	59.75±0.41	6.36±0.08	9.39±0.17	0.51±0.07	41.32±0.79	2.85±0.06	6.28±0.04	0.68±0.03
	Mean	**61.63**	**8.56**	**9.13**	**0.65**	**46.51**	**2.93**	**6.74**	**0.68**
LSD (0.05)									
I		**1.19**	**0.15**	**0.11**	**0.01**	**0.34**	**0.04**	**0.05**	**0.02**
O		**1.87**	**0.24**	**0.18**	**0.02**	**0.54**	**0.06**	**0.08**	**0.03**
I × O		**2.65**	**0.34**	**0.26**	**0.03**	**0.77**	**0.09**	**0.12**	**0.04**

Note: C = Control, O_1 = Mustard cake@1 t ha^{-1}, O_2 = Farm Yard Manure @10 t ha^{-1}, O_3 = Vermicompost @3 t ha^{-1} and O_4 = Municipal sludge@10 t ha^{-1}

Organic amendments such as composts and manures which contain a high amount of humified organic matter can decrease the bioavailability of heavy metals through adsorption and by forming stable complexes with humic substances. (Chen *et al*, 2000). Jones (2000) reported that the reduced accumulation of arsenic in plants are due to low availability of the toxicant from soil due to amended through compost, manures etc. Rahaman *et al.* (2011) showed that combined applications of lathyrus +

vermicompost + poultry manure reduced arsenic transport in plant parts (root, straw, husk, whole grains and milled grain). Precipitation and flocculation of humic acids by heavy metals were observed in both acidic and calcareous soils (Clemente and Bernal, 2006). Humic acids have great capacity to retain and bind metals. Their molecular structure is usually larger than the soil pore size resulting in the low mobility and little leaching through soil profile. (Halim *et al.*, 2003).

The complexation studies of arsenic with humic acid and fulvic acid fractions isolated from the selected organic manures used in the present experiment revealed that HA-FA fractions extracted from vermicompost have the capacity of making strongest complexes with soil arsenic (as expressed in the computed log K values, table 4) which may be attributed to the reduction in available arsenic load in soil-plant system through respective interventions. This is in good agreement with the findings as obtained earlier by Mukhopadhyay and Sanyal (2004) who reported that there was an ability of native or added soil organic fractions to sorb arsenic, thereby moderating its toxicity in soil-plant system. Das (2007) also observed 18.30% and 14.01% decrease in 0.5 M $NaHCO_3$- extractable soil As from the control counterpart when the soil was amended with vermicompost and well-rotten FYM, due to formation of organo-As complexation.

Table 3: Correlation between available soil arsenic and total uptake of rice at harvest

Irrigation sources (I)	Treatment (T)	2008		2009	
		Available arsenic (kg ha^{-1})	Total uptake (mg kg^{-1})	Available arsenic (kg ha^{-1})	Total uptake (mg kg^{-1})
Shallow tubewell water	C	4.46	105.63	4.32	93.26
	O_1	4.19	98.3	4.14	67.13
	O_2	4.01	82.82	3.87	53.9
	O_3	3.97	85.43	3.49	48.18
	O_4	4.28	87.12	4.13	59.89
	Mean	**4.18**	**91.86**	**3.99**	**64.47**
Pond water	C	3.93	91.26	4.26	83.48
	O_1	3.66	87.85	3.71	59.6
	O_2	3.03	73.32	2.97	45.14
	O_3	3.31	71.37	3.22	44.87
	O_4	3.51	76.01	3.35	51.14
	Mean	**3.49**	**79.96**	**3.50**	**56.85**
Correlation		**0.8685****		**0.8466****	

Note: C = Control, O_1 *= Mustard cake@1 t ha*$^{-1}$*,* O_2 *= Farm Yard Manure @10 t ha*$^{-1}$*,* O_3 *= Vermicompost @3 t ha*$^{-1}$ *and* O_4 *= Municipal sludge@10 t ha*$^{-1}$

Table 4: Characterization of the selected organic manures

Feature	FYM	Vermicompost	Phosphocompost	Mustard cake
TOC (%)	25.9	25.0	17.0	12.0
N (%)	0.5	0.25	0.5	5.0
P (%)	1.5	1.0	1.5	2.0
K (%)	1.0	1.0	1.0	1.5
Zn (ppm)	52.0	48.0	80.0	39.0
Cu (ppm)	8.0	12.0	40.0	19.0
Fe (ppm)	1500	1025	1838	2705
Mn (ppm)	53.0	56.0	62.0	70.0
C: N	20:1	15:1	18:1	12:1
As (ppm)	3.54	3.02	3.64	0.38
Log k (HA)	4.12	4.86	4.54	2.67
Log k (FA)	8.65	10.27	8.97	4.95

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