Available online at www.sciencedirect.com

ScienceDirect

Journal of Environmental Sciences 2011, 23(4) 633–639

JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Effect of water regimes and organic matters on transport of arsenic in summer rice (*Oryza sativa* L.)

Sefaur Rahaman[1,*], Ashim Chandra Sinha[2], Dibyendu Mukhopadhyay[3]

1. Senior Research Fellow, Department of Agronomy, Faculty of Agriculture, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal-736165, India. E-mail: sefauragro@gmail.com
2. Department of Agronomy, Faculty of Agriculture, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal-736165, India
3. Reader and Head, Department of Soil Science & Agricultural Chemistry, Faculty of Agriculture, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal-736165, India

Received 04 May 2010; revised 08 October 2010; accepted 12 October 2010

Abstract

The arsenic contamination in soil-water-plant systems is a major concern of where, the groundwater is being contaminated with arsenic (above 0.01 mg/L) in the Indian subcontinent. The study was conducted with organic matter to find out the reducing effect on arsenic load to rice (cv. Khitish). It was observed that intermittent ponding reduced arsenic uptake (23.33% in root, 13.84% in shoot and 19.84% in leaf) at panicle initiation stage, instead of continuous ponding. A decreasing trend of arsenic accumulation (root > straw > husk > whole grain > milled grain) was observed in different plant parts at harvest. Combined applications of lathyrus + vermicompost + poultry manure reduced arsenic transport in plant parts (root, straw, husk, whole grains and milled grain) which was significantly at par ($p > 0.05$) with chopped rice straw (5 tons/ha) + lathyrus green manuring (5 tons/ha) in comparison to control and corresponding soils. A significant negative correlation of arsenic with phosphorus (grain P with arsenic in different parts R^2= 0.627–0.726 at $p >$ 0.01) was observed. Similarly, soil arsenic had a negative correlation with soil available phosphorus (R^2 = 0.822 at $p > 0.001$) followed by soil nitrogen (R^2= 0.762 at $p > 0.01$) and soil potassium (R^2 = 0.626 at $p > 0.01$). Hence, effective management of contaminated irrigation water along with organic matter could reduce the arsenic build up to plants and soil.

Key words: arsenic; intermittent ponding; lathyrus; organic nutrients; poultry manure; saturation and vermicompost

DOI: 10.1016/S1001-0742(10)60457-3

Citation: Rahaman S, Sinha A C, Mukhopadhyay D, 2011. Effect of water regimes and organic matters on transport of arsenic in summer rice (*Oryza sativa* L.). Journal of Environmental Sciences, 23(4): 633–639

Introduction

Arsenic (As) hazards in soil-water-plant are of international concern due to the potential health risks and widespread distribution in South East Asia, namely, Bangladesh (Dhar et al., 1997; Biswas et al., 1998; Nickson et al., 1998), West Bengal in India (Mandal et al., 1996), China (Huang et al., 1992) and Taiwan (Chen et al., 1995). The arsenic problem is of much concern because of the documented cases of arsenic poisoning of human beings (Smedley and Kinniburgh, 2002), leading to several carcinogenic diseases, including cancer. Contamination of groundwater by arsenic in the deltaic region, particularly in the Gangetic alluvium region, has become one of the world's most important natural calamities (Imamul Huq and Naidu, 2005). A large part of Ganga-Megna-Brahmaputra plain with an area of 569,749 km^2 and population over 500 million is at risk (Chakrabarty et al., 2004). In West Bengal, 111 blocks of 12 districts with 8–9 million people are arsenic affected (Adhikary et al., 2009). Hence As-contaminated groundwater when used for irrigation, led to the accumulation of arsenic in soil and the eventual exposure of the food chain through plant uptake and animal consumption (Imamul Huq and Naidu, 2005), poses long term risk to human health (Duxbary et al., 2003). *Boro* (summer) rice (*Oryza sativa*) being the major food crops of arsenic contaminated river basin of Malda district, requires a largest volume of irrigation water (1500–2100 mm) in agriculture sector (Thakur et al., 2009) during March–May, is amenable to the notable accumulation of arsenic in grains (0.20–0.25 mg/lit), through contaminated irrigation water (Pati and Mukhopadhyay, 2009) and a substantial amount of arsenic build up in topsoil (Jahiruddin et al., 2000; Meharg and Rahman, 2003). Rice is especially susceptible to arsenic toxicity compared to upland crops, because of an increase in both the bioavailability and toxicity of arsenic under the submerged soil of paddy fields (Horswell and Speir, 2006). About 90% of the inorganic arsenic present in groundwater

* Corresponding author. E-mail: sefauragro@gmail.com

has been found to be in the arsenite form (Imamul Huq and Naidu, 2003). While under aerobic conditions, arsenate dominates. Rice has been reported to accumulate arsenic up to 1.8 mg/kg in grains and up to 92 mg/kg in straw (Abedin et al., 2002), much higher than other cereals *viz*, wheat, maize, barley etc. Thus, arsenic from rice is an important pathway of exposure in the food chain system. However, Das et al. (2008) reported that concentration of arsenic in rice plant parts decreased with the application of intermittent irrigation in comparison to continuous ponding, organic sources (vermicompost and farm yard manure) and the amount of organic matter influenced the degrees of uptake rather than native organic substances in the form of humic/fulvic substance, a good accumulator of arsenic (Mukhopadhyay and Sanyal, 2004) and formed a arsenic-humic complexes with different degrees of stability. Management strategies to reduce arsenic uptake by rice are, therefore, very pertinent and urgent.

Based on the above perspective, an attempt has been made to find out the remedial measures in minimizing arsenic load in rice and gradual accumulation in surface soil with minimal utilization of arsenic contaminated groundwater for rice and also to restrict entry of arsenic into the growing plant parts through binding of exchangeable arsenic with organic amendments alone or in combination.

1 Material and methods

1.1 Study site

The study site was selected on the basis of arsenic contamination in groundwater. The trials were set at the farmers' field in Manikchak block (Jalalpur Village) of Malda District, West Bengal, India. The georeference of the experimental site is 24°40′20″–25°30′08″N latitude and 87°45′50′–88°28′10′E longitude. The soil was silty clay in texture and the physiochemical properties are shown in Table 1. Malda district has about 2 million populations consuming contaminated water ranging from 50 to 500 μg/kg arsenic (Das et al., 1996). In this area, sub surface water is being extracted from shallow tube wells through simple indigenous technology from minimum depth of about 3 m near the Ganges River progressively increasing to the tune of 100 m near the Mahananda River (Madhavan and Subramanian, 2004).

Table 1 Physiochemical properties of the experimental site

Soil properties	Value	Soil properties	Value
Sand	5.97%	Total nitrogen	1.1 g/kg
Silt	64.36%	Available nitrogen	250–300 kg/ha
Clay	29.67%	Total P	0.4 g/kg
Texture	Silty clay	Available P	22–39 kg/ha
pH	8.3	Total K	1.5 g/kg
EC	0.21 dS/m	Available K	194–225 kg/ha
CEC	31.59 cmol (p+)/kg	Exchangeable arsenic	10–15 mg/kg
Organic carbon	4.12 g/kg	Organic carbon status	Low

CEC: cation exchange capacity.

1.2 Collection and preparation of soil sample:

Initially, the bulk soil samples (0–0.15 m) from the experimental site at harvest were collected for composite soil samples. The collected soil samples were air dried, visible roots and debris were removed and discarded and screened through a 0.2 mm stainless steel sieve. The sieved samples were then mixed thoroughly to make the composite sample. These soil samples were used for various analyses. For soil arsenic analysis, 5 g soil samples was taken in a 100 mL conical flask and 50 mL of 0.5 mol/L $NaHCO_3$ solution was added. Then the whole materials was shaken for 1 hr in a "to and fro" horizontal shaker and after completion of shaking, the suspension was filtered through Whatman filter paper No 42. The filtered was collected for arsenic analysis with atomic absorption spectrophotometer (Model AAnalyst 200, PerkinElmer, USA) coupled with hydride-generator unit after reducing with 2 mL of 10% KI solution and 2 mL of 35% HCl, $NaBH_4$ solution and 4 mol/L HCl solution separately from three containers were allowed passing to a mixing manifold by a peristaltic pump. From the mixing manifold by argon (inert gas) carrier, AsH_3 (arsine) generated in the reaction loop. The arsenic was then atomized in a flame of air-acetylene and the direct arsenic concentration in the sample was measured (Johnston and Barnard, 1979). The pH of the soil was determined by using soil suspension in water in the ratio of (soil:water, 1:2.5, *m/V*). The soil samples were treated with neutral normal ammonium acetate solution (pH 7.0) in (soil:extractant, 1:10, *m/V*) after 1 hr shaking, followed by filtration, the leachate was used for the determination of K^+ and measure by using a Flame photometer, whereas, available nitrogen by $KMnO_4$ and P_2O_5 by Olsen method (Olsen et al., 1954).

1.3 Experimental set up

The trial was conducted with rice (cv *Khitish*) during the year of 2007–2009 at arsenic contaminated area of Manikchak block of Malda District (India). The experimental design was set as three main plot treatments with water regimes *viz* I_1-continuous ponding (CP) or farmers practice (5 ± 2 cm), I_2-intermittent ponding (3 days after disappearance of irrigation water (DAD) 5 ± 2 cm) from 15–35 days after transplanting (DAT) followed by CP and I_3-saturation from 15–35 DAT followed by CP and subplot treatments were sources of organic nutrient as, OS_0-control (with out nitrogen), OS_1-lathyrus green manuring 10 tons/ha (fresh weight basis), OS_2-vermicompost 5 tons/ha, OS_3-poultry manure 5 tons/ha, OS_4-chopped rice straw 5 tons/ha (rainy season rice straw) + lathyrus green manuring 5 tons/ha, and OS_5-lathyrus green manuring 5 tons/ha + vermicompost 2.5 tons/ha + poultry manure 2.5 tons/ha and OS_6-inorganic fertilizer (120:60:60 kg/ha of $N:P_2O_5:K_2O$). The experiment was carried out with the split plot design having three replications. The selected plots were occupied by "lathyrus" as green manuring crop at least 50 days before the transplanting of *boro* (summer) rice and treated with chemical fertilizer N, P_2O_5 and K_2O of 20:60:40 kg/ha, respectively. For achieving of 5 and

10 tons/ha, lathyrus was grown with the seed rate of 60 and 100 kg/ha. All the organic sources of nutrients were added in to the soil one week prior to the submergence. Before incorporation of organic matter N:P and K were analyzed. To fulfill the 120:60:40 kg/ha recommended dose of N, P_2O_5 and K_2O, treatment wise organic manure were applied and rest of the nitrogen, phosphorus and potassium were applied as basal and top dressing in the form of urea, single super phosphate (S.S.P) and murate of polash (M.O.P) at active tillering and before panicle initiation stage. Seeds of popular variety "*Khitish*" were dipped in water and kept, for 1–2 days in dark conditions for better germination. The germinated seeds were sown in seed bed with fertilizer dose of 40:20:20 kg/ha N, P_2O_5 and K_2O. The 35-day-old seedlings were transplanted in main plot size (5.0 × 6.0 m) and in the last week of January 2008 and 2009 with the spacing of 15 × 20 cm and crop was harvested in last week of May (2008 and 2009).

1.4 Plant sample analysis

Plants were harvested at panicle initiation by manual uprooting. The grains were collected before two days and harvested root were washed with tap water to dislodge the adhering soil, and then several times with deionized water to remove solute from ion free space. The aerial portions of the plant were also washed. The plant samples were separated into root, straw, husk and grain. The collected plant samples were first air dried and then oven dried at (70 ± 5)°C for 48 hr. The dried plant samples were grinded and were passed through a 0.2 mm sieve for digestion with three acid mixture (HNO_3:H_2SO_4:$HClO_4$, 10:1:4, *V*/*V*/*V*). The arsenic concentrations in the digested samples were measured by AAS.

1.5 Statistical analysis

The experimental data were statistically analyzed by using the statistical software INDOSTATE 7.5 and SPSS 17. The uptake and availability of arsenic and other nutrients were calculated and expressed in standard unit.

2 Results and discussion

2.1 Arsenic content at PI stage

The arsenic uptake by different plant parts were recorded at panicle initiation (PI) stage in Fig. 1. The arsenic uptake by root, shoot and leaf at PI stage was comparatively higher than at harvest. Intermittent ponding (2 DAD 5 ± 2 cm) from 15–35 DAT followed by CP decreased (23.33%, 13.84% and 19.84% in root, shoot and leaf respectively) the arsenic uptake in plant parts, which was at par ($p < 0.05$) with saturation (0–40 cm) from 15–35 DAT followed by CP (21.94%, 13.08% and 18.77% in root, shoot and leaf, respectively). In continuous ponding or farmer's practice (5 ± 2 cm), the maximum arsenic uptake was recorded as 8.66, 5.20 and 2.24 mg/kg in root, shoot and leaf, respectively. The given water management regimes, significantly reduced arsenic availability through alternate dry-wet process confirming the transformation

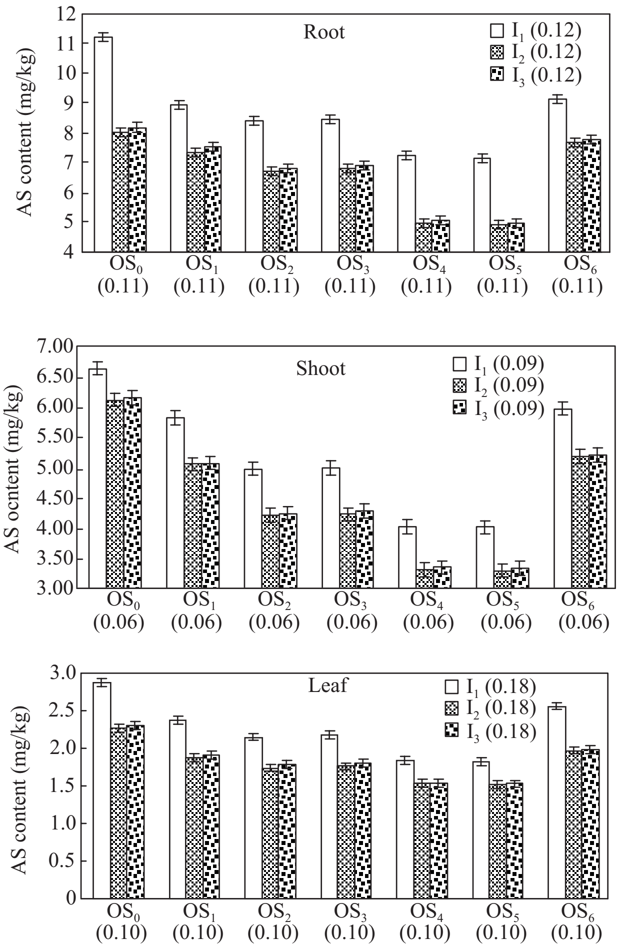

Fig. 1 Effect of water regimes and organic nutrients on root arsenic, shoot arsenic, and leaf arsenic at panicle initiation stage. Values in the parentheses indicate the corresponding critical difference (CD) value. I_1: continuous ponding; I_2: intermediate ponding; I_3: saturation; OS_0: control; OS_1: lathyrus; OS_2: vermicompost; OS_3: poultry manure; OS_4: chopped rice straw + lathyrus; OS_5: lathyrus + vermicompost + poultry manure; OS_6: inorganic fertilizers.

of inorganic to organic arsenic (Takamatsu et al., 1982), and its subsequent entry to the plant systems. Under continuous ponding of paddy field, the arsenic contaminated ground water is the primary source of irrigation in this area that could facilitate the conversion of arsenate to arsenite, more toxic and readily taken up by rice plant (Masscheleyn et al., 1991; Onken and Hossner, 1996). By using the contaminated groundwater as irrigation source to rice; the soil arsenic level can reach up to 58 mg/kg (Imamul Huq and Naidu, 2003) influencing the chemical properties of soil and water. Intermittent ponding of water or saturation of paddy field could save 40–50 cm of water instead of continuous ponding which could reduce 1.5–1.7 kg/ha arsenic load from groundwater. Water regimes also influenced the physio-chemical properties of the paddy soils through reduction-oxidation process, which could reduce the availability of arsenic to the soil solution through transformation of less toxic and available (arsenate) form (Takamatsu et al., 1982), and subsequent entry to plant systems. Intermittent or saturation of rice fields also facilitates the activity of soil microbes, which play a vital role for microbial degradation. This mechanism was proposed from a number of observations (Nickson et al., 2000). The experimental site is contaminated with arsenic in soil (10–15 mg/kg) in Table 1, reported by Pati and Mukhopadhyay (2009) while experimenting with rice elsewhere. Bhattacharya et al. (2009) also reported that the arsenic contamination in soil from 1.34 to 14.09 mg/kg and irrigation water from 0.318 to 0.643 mg/L in West Bengal (India), which is many folds higher than the recommended WHO permissible limit of 0.01 mg/L for drinking water, and FAO permissible limit for irrigation water (0.10 mg/L; FAO, 1985).

Application of lathyrus green manuring 5 tons/ha + vermicompost 2.5 tons/ha + poultry manure 2.5 tons/ha reduced uptake of arsenic (37.86%, 43.76% and 34.54% in root, shoot and leaf, respectively), and was at par ($p > 0.05$) with chopped rice straw 5 tons/ha + lathyrus green manuring 5 tons/ha (36.87%, 43.49% and 33.87% in root, shoot and leaf, respectively) in Fig. 1. Addition of organic matter in paddy field reduced the arsenic availability through formation of an insoluble arseno-organic complexes and their adsorption on to organic colloids of soil solutions (Das et al., 2008), however, its potentiality depends on the soil physiochemical properties of soil. The addition of organic amendments to soils reduce the heavy metal bioavailability by changing them from bioavailable forms to the fractions associated with organic matter or metal oxides or carbonates (Walker et al., 2004). Cao et al. (2003) reported that when biosolid was added to either acidic or neutral soil the adsorption of arsenic was increased and reduce the water soluble arsenic. Shiralipour et al. (1992) reported that the organic matter application to soil would increase soil cation and anion exchange capacity, which may increase arsenic adsorption by increasing the amount of positive charge on the oxide surface and/or forming a positively charged surface (Meng et al., 2000) and enhanced sorption capacity of the soil matrix. Single application of vermin-compost or poultry manure (5 tons/ha) had a little effect on arsenic reduction in plant, but was better than the individual application of inorganic fertilizer or lathyrus (10 tons/ha (fresh weight basis)).

2.2 Arsenic content at harvest stage

Water management and organic matter significantly influenced arsenic uptake by root, straw, whole grains, milled grains and husk (Fig. 2). Intermittent ponding (2 DAD 5 ± 2 cm) from 15–35 DAT followed by CP lower down the uptake of arsenic (1.07, 1.39, 1.72, 3.29 and 5.28 mg/kg in milled, whole grains, husk, straw and root, respectively), and was at par ($p > 0.05$) with saturation (0–40 cm) from 15–35 DAT followed by CP (1.12, 1.46, 1.74, 3.39 and 5.51 mg/kg, respectively). The arsenic levels in rice grain varied from 0.70–1.67 mg/kg, which did exceed the WHO recommended permissible limit in rice (1.0 mg/kg; Abedin et al., 2002). Islam et al. (2004) reported that grain accumulation of arsenic up to 2.0 mg/kg which is above the WHO recommended permissible limit in rice. The high background level of soil arsenic 10–15 mg/kg (Table 1), higher than the global average of 10.0 mg/kg (Das et al., 2002) and was below the maximum acceptable limit for agricultural soil of 20.0 mg/kg as recommended by the European Community (Rahman et al., 2007). Dahal et al. (2008) noticed that the uptake of arsenic by agricultural plants was far better correlated with the arsenic concentrations in irrigation water than soil arsenic contents. However, some reports clearly showed that the arsenic contents in the agricultural plants were correlated to the degree of arsenic contamination in irrigation water and soil (Roychowdhury et al., 2005). Growing of a crop, root is the entry point of the any elements supply from soil which subsequently passes through stem to sink (grain). The large accumulation of As by rice plants was observed, with comparable root and straw concentrations of up to 100 mg As/kg, when rice was irrigated with a solution containing 8 mg As/L as arsenate (Abedin et al., 2001). The arsenic content followed up the trend (root > straw > husk > whole grain > milled grain) as shown in Fig. 2, supported by Marin et al. (1992) and Abedin et al. (2002).

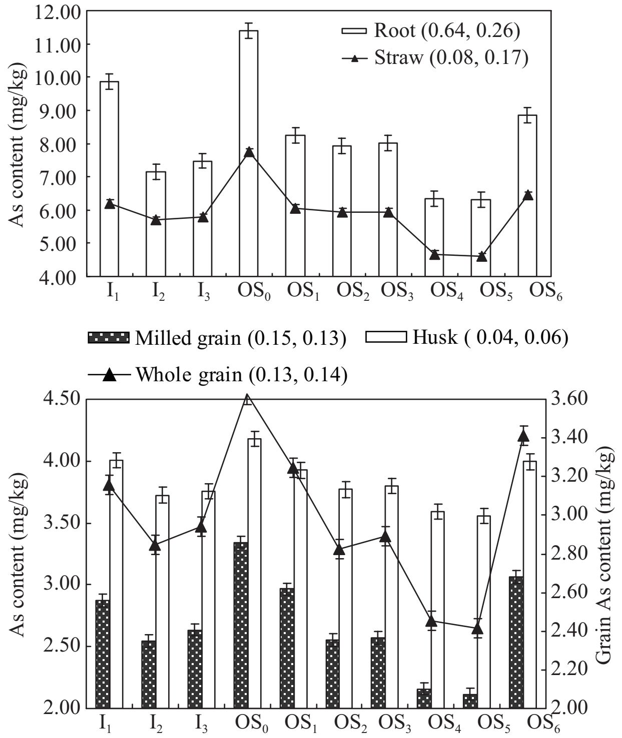

Fig. 2 Effect of water regimes and organic nutrients on root and shoot arsenic, milled grain, husk and whole grain arsenic at harvest. Numbers in parentheses is CD values for I_1, I_2, and I_3, and data for OS_0–OS_6, respectively.

The given organic amendment significantly influenced in reducing the arsenic content in root, straw, whole grains, milled grains and husk (Fig. 2). Combined application of lathyrus green manuring (5 tons/ha) + vermicompost (2.5 tons/ha) + poultry manure (2.5 tons/ha) reduced the arsenic content by 44.74%, 40.64%, 14.83%, 33.47% and 36.87% in root, straw, husk, whole grains and milled grain, respectively, followed by chopped rice straw (5 tons/ha) + lathyrus green manuring (5 tons/ha) by 44.43%, 39.68%, 14.11%, 32.37% and 35.52%, respectively. Single application of vermicompost reduced 23.73% of arsenic in milled grain, poultry manure (23.28%), lathyrus (11.49%) and inorganic fertilizer (8.51%) than control (Fig. 2). The vermicompost, poultry manure and lathyrus had little

Table 2 Different organic sources and its nutrients and arsenic content

Serial number	Arsenic content (mg/kg)	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Lathyrus	0.012–0.014	1.96–2.21	0.98–1.08	1.54–1.78
Vermicompost	0.021–0.032	1.79–2.28	0.89–1.20	1.47–1.59
Poultry manure	0.024–0.034	0.89–1.45	0.78–0.98	1.25–1.39
Chopped rice straw	2.51–3.17	0.54–0.67	0.21–0.23	0.34–0.41

Table 3 Correlation and regression equations between arsenic and N, P and K in different plant parts

	Root As	Straw As	Husk As	Whole grain As	Milled grain As
Grain N	$Y = 15.22–6.57X$ $R^2 = 0.396$**	$Y = 9.81–3.60X$ $R^2 = 0.456$**	$Y = 4.55–0.66X$ $R^2 = 0.281$**	$Y = 4.28–1.19$X $R^2 = 0.243$**	$Y = 4.00–1.21X$ $R^2 = 0.266$**
Straw N	$Y = 13.60–7.79X$ $R^2 = 0.397$**	$Y = 9.00–4.39X$ $R^2 = 0.483$**	$Y = 4.38–0.78X$ $R^2 = 0.275$**	$Y = 3.97–1.39X$ $R^2 = 0.236$**	$Y = 3.71–1.45X$ $R^2 = 0.270$**
Grain P	$Y = 15.03–17.27X$ $R^2 = 0.647$**	$Y = 9.66–9.36X$ $R^2 = 0.726$**	$Y = 4.67–2.08X$ $R^2 = 0.655$**	$Y = 4.57–3.94X$ $R^2 = 0.627$**	$Y = 4.29–3.99X$ $R^2 = 0.682$**
Straw P	$Y = 15.52–24.71X$ $R^2 = 0.557$**	$Y = 10.13–14.11X$ $R^2 = 0.694$**	$Y = 4.75–3.07X$ $R^2 = 0.598$**	$Y = 4.69–5.66X$ $R^2 = 0.544$**	$Y = 4.42–5.77X$ $R^2 = 0.599$**
Grain K	$Y = 15.40–10.08X$ $R^2 = 0.383$**	$Y = 9.74–5.29X$ $R^2 = 0.404$**	$Y = 4.53–0.97X$ $R^2 = 0.245$**	$Y = 4.25–1.74X$ $R^2 = 0.212$**	$Y = 3.98–1.78X$ $R^2 = 0.236$**
Straw K	$Y = 14.19–15.24X$ $R^2 = 0.248$**	$Y = 9.24–8.33X$ $R^2 = 0.284$**	$Y = 4.35–1.30X$ $R^2 = 0.125$**	$Y = 3.84–2.12X$ $R^2 = 0.089$*	$Y = 3.56–2.17X$ $R^2 = 0.099$*

Y is predicated arsenic content. ** $p < 0.01$; * $p < 0.05$.

amount of native arsenic Table 2. Application of these in combination had significant effect over the single in reducing the plant and residual soil arsenic content, due to the release of higher amount of organic acid (humic/falvic acid) (Mukhopadhyay and Sanyal, 2004), binding site of the arsenic in the soil rather than release of nutrients and changed the physiochemical properties of soil-water. Humic acid (HA) and fulvic acids (FA) are an inherently complex mixture of poly functional organic acids derived from organic matters, compete strongly with arsenic for active adsorption sites on mineral surfaces result in lowering the levels of As retention (Wang and Muligan, 2006), mobility and bioavailability of arsenic. The formation of HA/FA-metal complexes may strongly bind arsenate and arsenite anions through metal-bridging mechanism (Redman et al., 2002), which contributes to arsenic immobilization. HA/FA also form stable complexes with mineral surfaces effectively blocking arsenic from adsorption on iron oxides, alumina, quartz or kaolinite. The organic amendment also influenced the soil properties such as clay content, pH and redox conditions (Marin et al., 1993), ionic composition, type and amount of organic matter are considered to be the important variables for availability and phytotoxicity of plants to arsenic.

From the result, it may be concluded that the mobilization of arsenic decreased with the application of vermicompost, poultry manure and lathyrus; a greater decrease was observed for combined applications. Furthermore, interaction of intermediate ponding (2 DAD 5 ± 2 cm) from 15–35 DAT followed by CP or saturation (0–40 cm) from 15–35 DAT followed by CP with lathyrus green manuring (5 tons/ha) + vermicompost (2.5 tons/ha) + poultry manure (2.5 tons/ha) or chopped rice straw 5 tons/ha + lathyrus green manuring (5 tons/ha) showed effective combination for reducing arsenic load by rice parts.

2.3 Relationship between arsenic and N, P and K

Application of organic matter could not only reduce the arsenic load, but also influenced the uptake and use efficiency of phosphorus. Both arsenic and phosphorus belongs to group V (B) family in the periodic table and behaved similarly in many ways in the soil-plant system (Smedley and Kinniburgh, 2002). Nitrogen, P and K uptake were negatively correlated with arsenic uptakes in plant parts (Table 3). From the experimental data, a significant correlation between arsenic in plant parts and grain P ($R^2 = 0.627–0.726$ at $p > 0.01$), followed by straw P ($R^2 = 0.544–0.694$ at $p > 0.01$) and correlation between arsenic in parts and grain N ($R^2 = 0.243–0.456$ at $p > 0.01$) followed by straw N ($R^2 = 0.236–0.483$ at $p > 0.01$) were observed. In comparison to P and N, a relatively weak correlation was found between grain and straw K with arsenic ($R^2 = 0.089$ at $p < 0.05$) to 0.404 at $p < 0.01$. From Fig. 3, it was quite apparent that the exchangeable arsenic content in the soil solution was highly influenced by available soil major nutrients. The results showed that soil arsenic had a negative correlation with soil available phosphorus ($R^2 = 0.822$ at $p > 0.001$) followed by soil nitrogen ($R^2 = 0.762$ at $p > 0.01$) and soil potassium (R^2= 0.626 at $p > 0.01$).

3 Conclusions

Both the water regimes (intermittent and saturation) and organic amendment have merit when used individually, but their combined deployment produced the holistic picture for mitigating arsenic in rice by fixation of exchangeable arsenic with organic matters in soil solution. However, present study envisaged the need for further investigation on water regimes as well as different possible organic sources for sustainable mitigation of arsenic contamination in rice plants.

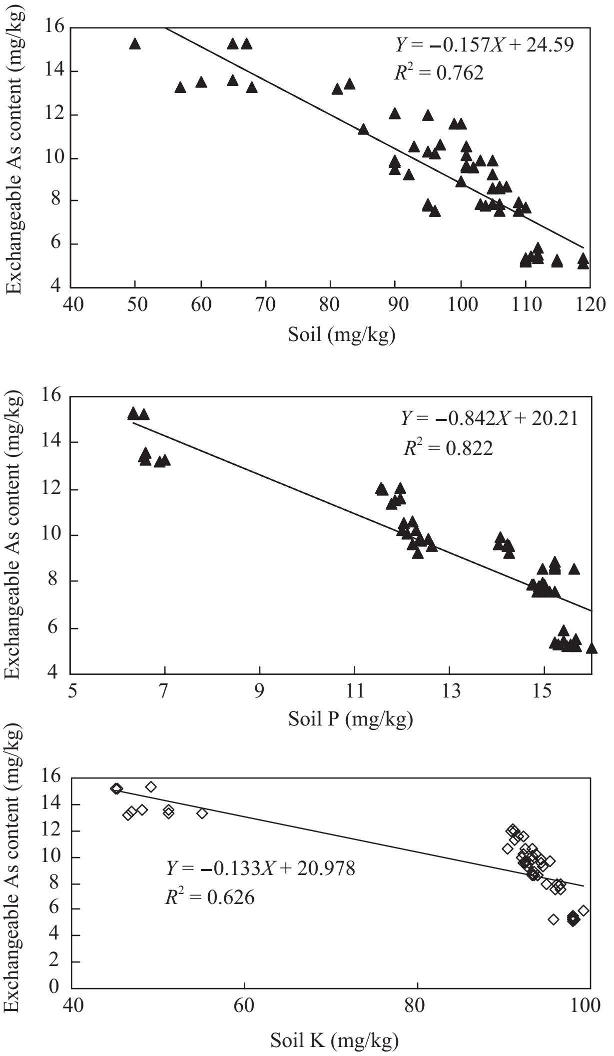

Fig. 3 Correlation between exchangeable soil arsenic and major available plant nutrients (N, P, and K).

Acknowledgments

This work was supported by the National Agricultural Innovation Project Component-IV (NAIP/C4/C1005/2006-07), Indian Council of Agricultural Research, Pusa, New Delhi, India. The first author would like to thank Mr. Amjad Ali (Farmer) Jalalpur, Manikchak, Malda, W. B for providing experimental field and co-operation.

References

Abedin M J, Cresser M S, Meharg A A, Feldmann J, Cotter-Howells J, 2002. Arsenic accumulation and metabolism in rice (*Oryza sativa* L.). *Environmental Science & Technology*, 36: 962–968.

Abedin M J, Feldman J, Meharg A A, 2001. Uptake kinetic of arsenic in rice (*Oryza sativa* L.). *Plant Physiology,* 128: 1120–1228.

Adhikary B, Bag M K, Tripathi R D, Rai U N, 2009. Screening and selection of low arsenic (As) accumulating rice germplasms under West Bengal Condition. *Journal of Crop and Weed,* 5(1): 254–257.

Bhattacharya P, Samal A C, Majumdar J, Santra S C, 2009. Accumulation of arsenic and its distribution in rice plant (*Oryza sativa* L.) in Gangetic West Bengal, India. *Paddy and Water Environment,* 8: 63–70.

Biswas B K, Dhar R K, Samanta G, Mandal B K, Chakraborti D, Faruk I et al., 1998. Detailed study report of Samta, one of the arsenic affected village of Jessore District, Bangladesh. *Current Science,* 74: 134–145.

Cao X, Ma L Q, Shiralipour A, 2003. Effects of compost and phosphate amendments on arsenic mobility in soils and arsenic uptake by the hyper accumulator, *Pteris vittata* L. *Environmental Pollution,* 126: 157–167.

Chakrabarty D, Sengupta M K, Rahman M M, Ahmed S, Chowdury U K, Hossain M A et al., 2004. Ground water arsenic contamination and its health effects in Ganga-Megna-Bramhaputra plain. *Journal of Environment Monitor,* 6: 74–83.

Chen S L, Yeh S J, Yang M H, Lin T H, 1995. Trace-element concentration and arsenic speciation in the well water of a Taiwan area with endemic black foot disease. *Biological Transform Element Research*, 48: 263–274.

Dahal B M, Fuerhacker M, Mentler A, Karki K B, Shrestha R R, Blum W E H, 2008. Arsenic contamination of soils and agricultural plants through irrigation water in Nepal. *Environmental Pollution*, 155: 157–163.

Das D K, Sur P, Das K, 2008. Mobilization of arsenic in soils and in rice (*Oryza sativa* L.) plant affected by organic matter and zinc application in irrigation water contaminated with arsenic. *Plant Soil Environment,* 54(1): 30–37.

Das D, Samanta G, Mandal B K, Chowdhury T R, Chanda C R, Chowdhury P P et al., 1996. Arsenic in ground water in six districts of West Bengal, India. *Environment Geochemistry Health*, 18: 5–15.

Das H K, Sengupta P K, Hossain A, Islam M, Islam F, 2002. Diversity of environmental arsenic pollution in Bangladesh. In: Bangladesh Environment (Ahmed M F, Tanveer S A, Badruzzaman A B M, eds.). Bangladesh Paribesh Andolon, Dhaka, Bangladesh. Vol. 1, 234–244.

Dhar R K, Biswas B K, Samanta G, Mandal B K, Chakraborti D, Roy S et al., 1997. Groundwater arsenic calamity in Bangladesh. *Current Science*, 73: 48–59.

Duxbury J M, Mayer A B, Lauren J G, Hassan N, 2003. Food chain aspects of arsenic contamination in Bangladesh: Effect on quality and productivity of rice. *Journal of Environmental Science Health,* 38(1): 61–69.

FAO (Food and Agriculture Organization), 1985. Water quality guidelines for maximum crop production. Food and Agricultural Organization/UN. www.fao.org/docrep/T0551E.2006/9/13.

Horswell J, Speir T, 2006. Arsenic phytotoxicity: Effect on crop yield and crop quality. In: Managing Arsenic in the Environment: From Soil to Human (CSIRO). Melbourne, Australia. 183–207.

Huang Y Z, Qian X C, Wang G Q, Gu Y L, Wang S Z, Cheng Z H et al., 1992. Syndrome of endemic arsenism and fluorosis: A clinical study. *Chinese Medical Journal,* 105: 586–590.

Imamul Huq S M, Naidu R, 2003. Arsenic in ground water of Bangladesh: contamination in the food chain. In: Arsenic Contamination: Bangladesh Perspective (Feroze A M, ed.). ITN-Bangladesh, Centre for Water Supply and Waste Management, BUET, Dhaka. 203–226.

Imamul Huq S M, Naidu R, 2005. Arsenic in ground water and contamination of the food chain: Bangladesh scenario.

In: Natural Arsenic in Groundwater: Occurrence, Remediation and Management (Bundschuh J, Bhattacharya P, Chandrasekharam D, eds.), Balkema, New York. 95–101.

Jahiruddin M, Harada H, Hatanaka T, Islam M R, 2000. Trace element status in agricultural soils and factors affecting their concentration. *Soil Science Plant Nutrition,* 46(4): 963–968.

Johnston R, Barnard W M, 1979. Comparative effectiveness of fourteen solutions for extracting arsenic from four Western New York soils. *Soil Science Society of American Journal,* 43: 304–308.

Madhavan N, Subramanian V, 2004. Fluoride and arsenic content in contaminated groundwater of Rajasthan and West Bengal In: National Seminar on Arsenic and Fluoride Contamination in Groundwater at Neriwalm, Tezpur, India. 268–274.

Mandal B K, Roy C T, Samanta G, Basu G K, Chowdhury P P, Chanda C R, 1996. Arsenic in groundwater in seven districts of West Bengal, India: the biggest arsenic calamity in the world. *Current Science,* 70: 976–986.

Marin A R, Masscheleya P H, Parrick J W H, 1992. The influence of chemicals forms and concentration of arsenic on rice growth and tissue arsenic concentration. *Plant and Soil*, 139: 175–183.

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

Masscheleyn P H, Dlaune R D, Patrick W H, 1991. Effect of redox potential and pH on arsenic speciation and solubility in a contaminated soil. *Environmental Science & Technology*, 25: 1414–1418.

Meharg A A, Rahman M M, 2003. Arsenic contamination of Bangladesh paddy field soils: Implication for rice contribution to arsenic consumption. *Environmental Science & Technology*, 37(2): 229–234.

Meng X G, Bang S, Korfiatis G P, 2000. Effects of silicate, sulfate, and carbonate on arsenic removal by ferric chlorite. *Water Research,* 34: 1255–1261.

Mukhopadhyay D, Sanyal S K, 2004. Complexation and release isotherm of arsenic in arsenic-humic/fulvic equilibrium study. *Australian Journal of Soil Research,* 42: 815–824.

Nickson R T, Mcarthur J M, Ravenscroft P, Burgess W G, Ahamed K M, 2000. Mechanism of arsenic release to groundwater, Bangladesh and West Bengal. *Applied Geochemistry*, 15: 403–413.

Nickson R, McArthur J, Burgess W, Ahmed K M, Ravenscroft P, Rahman M, 1998. Arsenic poisoning in Bangladesh groundwater. *Nature,* 395: 338–338.

Olsen S R, Cole C V, Watanable F S, Dean L A, 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United State Department of Agriculture Circulation. 939.

Onken B M, Hossner L R, 1996. Determination of arsenic species in soil solution under flooded conditions. *Soil Science Society of American Journal*, 60: 1385–1392.

Pati R, Mukhopadhyay D, 2009. Effects of organics influencing the arsenic transport in soil-plant systems. *Indian Journal of Agricultural Science,* 79(12): 996–999.

Rahman M A, Hasegawa H, Rahman M M, Rahman M A, Miah M A M, 2007. Accumulation of arsenic in tissues of rice plant (*Oryza sativa* L.) and its distribution infractions of rice grain. *Chemosphere*, 69: 942–948.

Redman A D, Macalady D, Ahmann D, 2002. Natural organic matter affects arsenic speciation and sorption onto hematite. *Environmental Science & Technology,* 36: 2889–2896.

Roychowdhury T, Tokunaga H, Uchino T, Ando M, 2005. Effect of arsenic-contaminated irrigation water on agricultural land, soil and plants in West Bengal, India. *Chemosphere,* 58: 799–810.

Shiralipour A, McConnel D B, Smith W H, 1992. Use and benefits of MSW compost: a review and assessment. *Biomass Bioenergy*, 3: 267–269.

Smedley P L, Kinniburgh D G, 2002. A review of the source, behavior and distribution of arsenic in natural waters. *Applied Geochemistry,* 17: 517–568.

Takamatsu T, Aoki H, Yoshida T, 1982. Determination of arsenate, arsenite, monomethylearsonate and diemethylarsonate in soil polluted with arsenic. *Soil Science,* 133: 239–246

Thakur A K, Chaudari S K, Singh R, Kumar R, 2009. Performance of rice varieties at different spacing grown by the system of rice intensification in eastern India. *Indian Journal of Agricultural Science,* 79(6): 443–447.

Walker D J, Clemente R, Bernal M P, 2004. Contrasting effects of manure and compost on soil pH, heavy metal availability and growth of *Chenopodium album* L. in a soil contaminated by pyritic mine waste. *Chemosphere,* 57: 215–224.

Wang S, Mulligan C N, 2006. Effect of natural organic matter on arsenic release from soils and sediments into groundwater. *Environment Geochemistry & Health*, 28: 197–214.