Journal of Civil Engineering (IEB), 33(2), 2005, 75-90

Estimation of arsenic accumulation in irrigated soil and paddy plant

Ganesh Chandra Saha[1] and M. Ashraf Ali[2]

[1]*Department of Civil Engineering*
Dhaka University of Engineering and Technology, Gazipur 1700, Bangladesh
[2]*Department of Civil Engineering*
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

Received on 20 April 2005

Abstract

From intensive monitoring of one sub-area of a paddy field during the boro season of 2004, it is estimated that about 90% arsenic added to the paddy field with irrigation water is accumulated in the top 0-450 mm of soil at the end of the irrigation season; about 71% of added arsenic accumulated in the top 0-75 mm soil segment. After the rainy season and before the beginning of the next irrigation season, the arsenic level in the top soil layers, however, decreased significantly and came back to levels comparable to those at the beginning of the irrigation season. The arsenic taken up by paddy plants accounted for about 4.4% of total arsenic that is added to the paddy field with irrigation water. Roots of paddy plants accumulated the maximum level of arsenic, followed by leaf and stem. Paddy grain and husk accumulated the least amount of arsenic. Arsenic content of top 0-75 mm soil segment was found to be strongly correlated with arsenic concentration in roots; poor correlation was observed with arsenic concentrations in other parts of paddy plants. Since paddy straw is used as cattle feed, this may pose a risk to cattle health in the arsenic-affected areas. Since rice is the staple food for the people of Bangladesh, it appears that intake of arsenic from rice could constitute an important part of overall arsenic intake for people living in the arsenic affected areas.

Keywords: Arsenic, groundwater, irrigation, soil, paddy

1. Introduction

In Bangladesh, presence of arsenic in shallow groundwater above acceptable level is a major public health concern. An estimated 270 upazilas (sub-districts) out of 465 in Bangladesh have been affected with significantly high concentrations of arsenic, with the greatest contamination in the south and south-east region of the country and least in the north-west and the uplifted areas in north central region (BGS and DPHE, 2001). In Bangladesh, groundwater extracted from shallow aquifers using hand-tubewells is the primary source of drinking and cooking water for most of its population of over 140 million. An estimated 10 million domestic tubewells constitute the backbone of rural water supply of the country. According to BGS and DPHE (2001), 35 million people of Bangladesh are exposed to an arsenic concentration in drinking water exceeding the national standard of 50 µg/l and 57 million are people exposed to a concentration exceeding the WHO guide line value of 10 µg/l.

Besides domestic use, groundwater is also widely used for irrigation during dry season (December to April), particularly for growing the dry-season paddy called boro, which requires about 1 m of irrigation. According to WRI (2000), about 86% of the total groundwater withdrawn is utilized in the agricultural sector. A total of 925,125 shallow tubewells (STW) and 24,718 deep tubewells (DTW) were used for irrigation during the 2004 dry season; STWs and DTWs covered about 60% and 15% of total irrigated area, respectively (BADC, 2005). Boro cultivation and irrigation increased together since 1970, and from 1980 up to present time, area under groundwater irrigation increased by almost an order of magnitude (Harvey et al., 2005). During 2003 dry season, about 87% of the total irrigated area of about 4 million hectare (about 28% of the total area of the country) was under boro cultivation and boro accounted for about 48.5% of the total paddy production (GoB, 2004). Thus, groundwater irrigation greatly increased agricultural production in Bangladesh and the country’s food security is heavily dependent on groundwater irrigation during the dry season.

Since groundwater from arsenic affected shallow aquifer is widely used for irrigation in many arsenic-affected areas, accumulation of arsenic in paddy field soil and its introduction into the food chain through uptake by paddy plants are major concerns. For example, irrigating a paddy field with groundwater having arsenic concentration of 100 g/l would add about 1 kg of arsenic per hectare of land. Based on available information on distribution of arsenic concentration in groundwater (BGS and DPHE, 2001) and area under shallow tubewell irrigation (BADC, 2005), Saha and Ali (2005) estimated that close to 1000 metric tons of arsenic is cycled each year with irrigation water. Due to its affinity for metal oxides/hydroxides in soil, higher accumulation of arsenic in irrigated surface soils is expected and a number of studies (e.g., Ullah, 1998; Jahiruddin et al., 2000; Huq et al., 2001; Meharg and Rahman, 2003; Huq et al., 2003; Ali et al., 2003; Panaullah et al., 2003; Ahmed, 2005; Farid et al., 2005; Islam et al., 2004, 2005; Jahiruddin et al., 2005) have reported relatively higher levels of arsenic in paddy field soils irrigated with arsenic bearing groundwater. In a study conducted in five upazilas (Senbagh, Brahmanbaria, Paba, Tala and Faridpur) of the country, Islam et al. (2005) found wide variation in total arsenic concentrations in soil samples. The arsenic level at these locations varied from 0.3 to 48.8 mg/kg, with a mean of 12.3 mg/kg. Jahiruddin et al. (2005) reported arsenic concentration in paddy fields in Chapai Nawabganj Sadar upazila to vary from 5.8 to 17.7 mg/kg. Based on analysis of soil samples (top 15 cm) collected from 161 sites, Shah et al. (2004) reported that 65% of soil had arsenic concentration exceeding 10 mg/kg. On the other hand, lower soil arsenic levels were reported by Huq et al. (2003) for a study covering 24 upazilas of the country.

Based on the monitoring of soil samples throughout the irrigation season, Saha and Ali (2004, 2005) reported that arsenic concentration in paddy field soil irrigated with arsenic bearing irrigation water increases significantly at the end of the irrigation season. However, the extent of increase in soil arsenic content has been found to vary significantly within a paddy field. In a typical paddy field, irrigation water is carried to different sub areas within the field by narrow irrigation canals (see Fig.1). In general, higher increase in soil arsenic concentration has been found for sampling points that are located close to the irrigation water inlets. Dittmar et al. (2005) found that in a paddy field in Munshiganj, soil arsenic concentrations near the water inlet were about twice as high as that at the opposite side of the field. This occurs because arsenic present in irrigation water is quickly adsorbed or co-precipitated (with iron) onto soil as irrigation water travels through a paddy field.

Saha and Ali (2004, 2005) also reported that arsenic concentrations in the paddy field soils could be quite dynamic. For paddy fields irrigated with arsenic bearing irrigation water in four different arsenic affected areas of the country, Saha and Ali (2004, 2005) reported that arsenic concentration in top 0-150 mm soil increased significantly at the end of the irrigation season, but after the rainy season (which immediately follow the boro season) soil arsenic concentrations decreased significantly and came down to levels comparable to those found at the beginning of the boro season. Hence, it is evident that in order to estimate accumulation of arsenic over a paddy field, the sampling points and sampling times need to be chosen carefully, keeping in mind the spatial and temporal variation of arsenic accumulation within a paddy field.

Available data suggest that higher arsenic in irrigation water results in higher accumulation of arsenic in different parts of paddy plants. Most studies conducted to date focused on arsenic content of paddy grains; some studies (e.g., Islam et al., 2004b, Jahiruddin et al., 2004, 2005; Farid et al. 2005) reported arsenic contents of paddy grain and straw. In a study conducted in five upazilas - Senbagh, Brahmanbaria, Paba, Tala and Faridpur - of the country, Islam et al. (2005) found mean arsenic concentration in boro rice grains to be 0.42, 0.48, 0.07, 0.44 and 0.33 mg/kg, respectively. Farid et al., (2005) reported that in Brahmanbaria area, arsenic concentrations in straw of boro paddy plants varied from 0.33 to 4.02 mg/kg (mean 2.0 mg/kg), and in grain it varied from 0.16 to 1.20 mg/kg (mean 0.43 mg/kg). In a study conducted in Chapai Nawabganj Sadar upazila, Jahiruddin et al. (2005) found grain arsenic concentration of boro paddy to range from 0.24 to 1.30 mg/kg and straw arsenic concentration to range from 1.48 to 17.6 mg/kg. Only a few studies (e.g., Masud, 2003; Ali et al., 2003) reported arsenic concentration in all different parts of paddy plants. Ali et al. (2003) reported that roots of paddy plants accumulate the highest level of arsenic followed by leaves and stem; grains and husk accumulate the least amount of arsenic. However, none of these studies provide quantitative estimates of the total amount of arsenic that is taken up by the paddy plants in an irrigated rice field. It is also not clear whether accumulation of arsenic in paddy plants also varies along with the variation of arsenic accumulation of arsenic in paddy field soil.

Major objective of this study was to develop estimates of the amount of arsenic that is added to the paddy field with irrigation water, the amount that is retained by the top soil and the amount taken up by paddy plants. On the basis of intensive monitoring of a piece of boro paddy field located in Sreenagar, Munshiganj during 2004, this paper presents estimates of arsenic that is added to the paddy field with irrigation water, the amount of arsenic retained by different top soil layers, and amount of arsenic taken up by the paddy plants. Besides, possible correlations between the concentrations of arsenic in top-soil and in paddy plants have also been investigated.

2. Methodology

2.1 Site selection

The field site of the present study is located in the arsenic-affected Bejgaon *union* of Sreenagar *upzilla* of Munshigonj district. The selected boro paddy field, shown in Fig. 1, measures about 3.17 hectares. The entire paddy field was divided into 18 sub-areas. One sub-area of the paddy field, measuring about 3255 sq.m., identified by ‘R’ in Fig. 1, was selected for intensive monitoring of arsenic in irrigation water, in top soil, and in the paddy plants during the 2004 boro season.

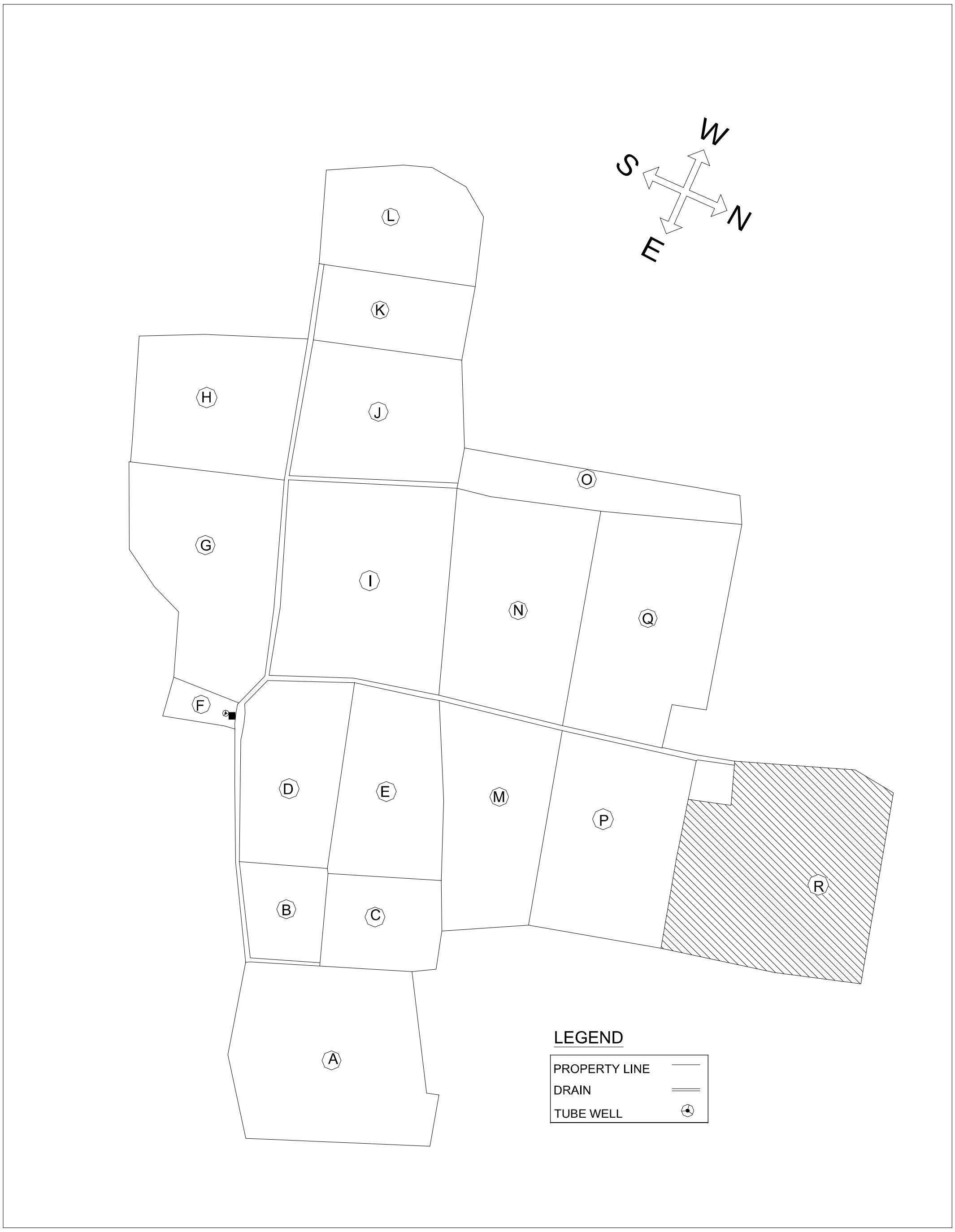

Fig. 1. Survey map showing sampling areas

2.2 Sample collection

Collection of water samples: Water samples from the irrigation well were collected once in every two weeks, during the period from January 2004 to April 2004. Water samples were collected in two pre-washed 500 ml plastic bottles, after running the well for at least 15 minutes. Water sample in one bottle was acidified with 1 ml concentrated hydrochloric acid, which was later analyzed for dissolved arsenic and iron.

Estimation of irrigation water quantity: In order to estimate the volume of water added to the paddy field, the owner of irrigation well (Mr. Ripon) was employed to record the schedule of pumping over the entire irrigation period (24 December 2003 to 22 April 2004). Rate of pumping from the irrigation well was estimated by recording the time required to fill an 80-L bucket at each sampling time.

Collection of soil samples: Soil core samples were collected from the sub area 'R' at four different times, just before the commencement of irrigation season (December 2003, 1st Sampling), at the end of irrigation season (May 2004, 2nd Sampling), during the rainy/flood season (June 2004, 3rd Sampling), and after the rainy season (November 2004, 4th Sampling). During each sampling, a total of 7 soil core samples were collected from the sub area 'R' of the field.

Reported root zone depth of paddy plants varies from about 400 mm to 600 mm (Rashid, 1997), and the depth of soil core samples was selected to cover this depth. Soil core samples were collected by inserting into the soil, a 37.5 mm diameter PVC pipe sampler, about 750 mm in height. A 3-pound hammer was used to insert the pipe sampler to a depth of about 500 mm. After withdrawing the sampler along with the soil core, both its ends were sealed with tapes to reduce contact with air and transported to the laboratory. Each sampling point in the sub-area 'R' was identified by measuring distances from one edge and one side of the sub-area.

Collection of paddy plant samples: Boro paddy of BR-29 variety was cultivated in the sub area 'R'. Paddy samples were collected just before harvest time. Entire paddy plants, including the roots, were collected. A total of 7 paddy plants were collected from the sub area 'R', from the locations from where soil core samples were collected during the first sampling.

Collection and analysis of fertilizer samples: Samples of four different types of fertilizers used in paddy cultivation were collected from local vendors. These were TSP (Triple Super Phosphate), Urea, Zinc, and Potash. Chemical characterization (including determination of arsenic content) of the fertilizer samples were carried out at EAWAG (Swiss Federal Institute of Aquatic Science and Technology), Switzerland.

2.3 *Laboratory analysis of water, soil and paddy plant samples*

Analysis of water samples: Water from acidified sampling bottles was analyzed for arsenic and iron. Water from the non-acidified bottles was analyzed for a wide range of water quality parameters, including pH, conductivity, ammonia, nitrate and phosphate. Arsenic was measured with an AAS (Shimadzu, Japan, AA6800) attached with a graphite furnace. Iron concentration was measured with flame emission atomic absorption spectrophotometry, using an AAS (Shimadzu, Japan, AA6800). Detection limits of arsenic and iron were 1 μg/l and 0.02 mg/l, respectively. pH was measured using a pH meter (HACH Co., USA), and conductivity with a conductivity meter. Ammonia, nitrate, and phosphate concentrations were determined with a spectrophotometer (HACH Co. USA, DR4000U). Ammonia was measured using the Nessler method, nitrate by the Cadmium Reduction method and phosphate by the Molybdenum Blue method. Detection limits of ammonia, nitrate and phosphate were 0.06 mg/l, 0.001 mg/l, and 0.01 mg/l, respectively.

Analysis of soil samples

Division of soil core sample: Before analysis, each soil core sample was divided into four segments; the first segment consisting of the top 75 mm of soil, the second segment consisting of the next 75 mm, the third segment consisting of the next 150 mm, the fourth segment consisting of the rest of the core. Each segment of soil was analyzed for total (aqua-regia extractable) arsenic.

Digestion and analysis of soil sample: For determination of aqua-regia extractable arsenic, the soil samples were taken in an aluminum bowl and kept in an oven at 110^0 C for 24 hours. After drying for 24 hours, the samples were grinded in a grinder. The grinded soil samples were digested with aqua-regia for extraction of metal ions. For digestion, 2.5 ml concentrated nitric acid and 7.5 ml concentrated hydrochloric acid were added to 5 gm grinded oven dried soil sample taken in a 500 ml volumetric flask. The sample was kept overnight in the flask and then it was heated to boiling for two hours. Afterwards deionized water was added up to the 500 ml graduation mark. The contents of the flask were stirred for 5 minutes, then cooled and finally filtered using a filter paper (0.45 micron). The filtrate was stored in a plastic bottle for analysis of arsenic using an AAS attached with a graphite furnace (Shimadzu, Japan AA6800). The detection limit of arsenic in this system was 1 μg/l.

Analysis of paddy plant samples

Division of plant sample: Before analysis, the paddy plant samples were divided into five parts: (i) root, (ii) stem, (iii) leaf, (iv) grain, and (v) husk.

Digestion and analysis of plant sample: For analysis of total arsenic, the different parts of the paddy plant samples were digested. The procedure reported in Shimadzu AAS Cookbook was used in this study.

Briefly the digestion procedure consists of the following steps: (i) wash plant samples with deionized water, (ii) divide the plant sample into parts (as described above), (iii) take weight of each part of the sample, (iv) oven-dry the sample at 65^oC for 24 hours and take weight of the oven-dried sample, (v) take approximately 2 grams of oven-dried sample in a volumetric flask and make it moist by adding a few milliliters of deionized water, then add 25 ml nitric acid to the flask and keep it overnight, (vi) heat the flask for two hours to boiling, then after cooling add 10 ml of perchloric acid to the flask and heat again (to boiling) for one hour, (vii) if color of the sample turns yellow, digestion is assumed to be complete, (viii) if color of the sample turns dark, add 2 to 3 ml of nitric acid to the flask and apply heat; repeat the process until the color turns yellow. Arsenic analysis of plant samples were carried out with hydride generation atomic absorption spectrophotometry (HVG-AAS) using an AAS (Shimadzu, Japan AA6800). The detection limit of arsenic in this system was 0.1 μg/l.

Chemicals and reagents used

All chemicals used in this study were of analytical grade. Deionized water from a Barnstead Fistreem III Glass Still distiller was used throughout. Stock solutions of arsenic (1000±10 mg/l as As^{3+}, prepared from As_2O_3; HACH Co., USA) and iron (100±0.5 mg/l as Fe; HACH Co., USA) were used for preparation of standard solutions for AAS. Arsenic standard solutions of 10, 20, 30, and 40 μg/l were prepared for GF-AAS analysis; and standard solutions of 1, 2, 3, and 4 μg/l were prepared for HVG-AAS analysis. Iron standard solutions of 1, 2, 3, and 4 mg/l were prepared for Flame-AAS analysis. Standard solutions were prepared daily and the calibrations curves for arsenic and iron were also prepared daily using the standard solutions. Stock solutions of ammonia (100 mg/l as NH_3-N; HACH Co., USA), nitrate (1000±10 mg/l as N; HACH Co., USA), and phosphate (100±1.0 mg/l as PO_4) were used for preparation of standard solutions for measurement of these parameters using a spectrophotometer (HACH Co., USA).

All acids used in this study were of analytical grade. Hydrochloric acid (fuming 37%, extra pure, Merck, Germany), nitric acid (65%, extra pure, Merck, Germany), sulphuric acid (95-98%, extra pure, Merck, Germany), and perchloric acid (70%, extra pure, Merck, Germany) were used throughout.

3. Results and discussion

3.1 Estimation of arsenic accumulation in paddy field soil

Irrigation water quality: A total of 8 water samples were colleted from the irrigation well of the paddy field during the period from January 2004 to April 2004. Concentrations of selected chemical constituents of water samples are shown in Table 1. Arsenic concentration in irrigation water samples varied from 328 μg/l to about 411 μg/l. Mean total arsenic concentration in the well water was 366 μg/l. As shown in Table 1, the irrigation water also contained high concentrations of iron, ammonia and phosphate. It may be noted that high arsenic concentrations in groundwater have often been found to be associated with high iron, phosphate and ammonia concentrations (e.g., BGS and DPHE, 2001; Harvey et al., 2002).

Estimation of arsenic added to paddy field: Estimate of the amount of arsenic added to the paddy field during the irrigation season was made from the estimated quantity of irrigation water added to paddy field and mean arsenic concentration in the irrigation water.

The volume of water added to the paddy field was estimated from records of pumping schedule and flow rate of water from the irrigation well. According to the pumping records, the paddy field was irrigated for about 655 hours over the entire boro season.

Table 1: Concentration of selected chemical constituents of irrigation water samples

Sampling	pH	Conductivity (μS/cm)	As (μg/l)	Fe (mg/l)	NH_3-N (mg/l)	PO_4 (mg/l)	NO_3-N (mg/l)
Sampling-1	6.98	596	328.25	7.80	6.35	2.68	0.85
Sampling-2	7.00	498	341.66	6.87	7.30	4.82	< 0.01
Sampling-3	6.88	637	359.72	9.90	6.61	3.84	2.56
Sampling-4	7.07	662	411.29	8.16	8.50	3.89	< 0.01
Sampling-5	7.27	536	408.31	8.92	7.58	4.65	1.27
Sampling-6	6.68	512	375.47	7.26	9.14	6.23	0.69
Sampling-7	7.09	698	380.15	5.84	6.37	4.68	2.67
Sampling-8	6.78	540	329.24	6.37	6.72	3.68	1.05

Rate of pumping from the irrigation well was estimated to be around 13 liters per second. Figure 2 shows calculated volumes of water added to the paddy field during the period from 24 December 2003 to 22 April 2004. Thus, on an average, the paddy field was irrigated with a total of about 0.96 m of water over the entire season, a number consistent with values (~1m) reported for boro paddy irrigation (e.g., Hossain et al., 2003). Considering mean arsenic concentration in irrigation water to be 366 μg/l, this corresponds to an arsenic loading of about 3.51 kg/ha; in other words, about 1.14 kg of arsenic was added to the sub-area 'R' of the paddy field with irrigation water during the boro season.

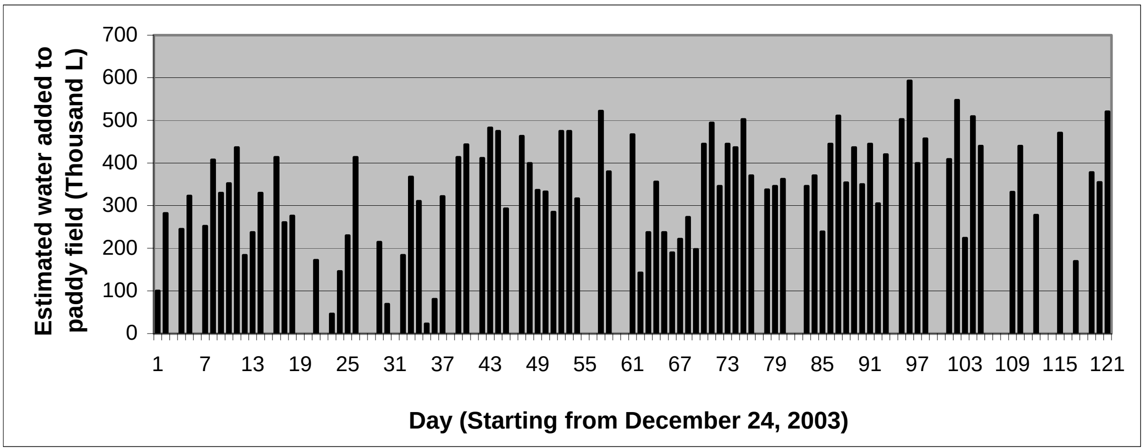

Fig. 2. Estimated volumes of water added to the paddy field site during the period from 24 December 2003 to 22 April 2004

In making the above estimate, it was assumed that the arsenic concentration in irrigation water does not change significantly as it travels through the irrigation channels to different sub-areas of the paddy field. Results from a recent and related study (Roberts et al., 2005) show that this is a reasonable assumption. Roberts et al. (2005) showed that along the irrigation channels of this paddy field in Munshiganj, total arsenic concentration remained virtually unchanged, though dissolved arsenic decreased and colloid-bound arsenic concentration increased with increasing distance from the irrigation well. Based on this study, Roberts et al. (2005) concluded that the arsenic input to a single paddy field through irrigation does not depend on its distance from the irrigation well along the irrigation canal.

Arsenic content of TSP, urea, zinc and potash fertilizers were found to be 3.8 mg/kg, 0.6 mg/kg, 0.7 mg/kg, and < 1 mg/kg, respectively. These four fertilizers are added to paddy fields approximately at the rate of 88 kg/ha, 141 kg/ha, 44 kg/ha and 70 kg/ha, respectively during the irrigation season. However, according to the local farmers, only TSP and urea are regularly used in the paddy fields, while potash and zinc are rarely used. Considering application of all fertilizers, an estimated 1.6×10^{-4} kg of arsenic was added to the sub-area 'R' of the paddy field with fertilizers during the boro season. This amount is negligible compared to the arsenic input from irrigation water. Hence arsenic input from fertilizers to the paddy field was considered negligible and was neglected in estimating arsenic input to paddy field soil.

Arsenic enrichment in paddy field soil

Spatial variation of arsenic in paddy field soil: Arsenic concentrations in different layers of the soil core samples collected at different times from the paddy field show that arsenic concentration varies significantly over a paddy field. Figure 3 shows arsenic concentrations of the top 0-75 mm segment of soil for the core samples collected at the beginning (December 2003) and at the end (May 2004) of the irrigation season. It shows that arsenic concentration in soil varies significantly over the paddy field, both at the beginning and at the end of the irrigation season. Similar variation was also observed for the other soil layers and also for samples collected at other sampling times (i.e., third and fourth samplings).

Arsenic concentrations in the top 0-75 mm of the soil segment varied from 6.45 to 19.21 mg/kg (with a mean of 13.70 mg/kg) at the end of the irrigation season (May 2004), compared to 6.40 to 15.95 mg/kg (with a mean of 11.60 mg/kg) at the beginning of the irrigation season. A closer look at Fig. 3 reveals that the increase in arsenic concentration at the end of the irrigation season differed significantly among the sampling points. In fact, such variation in increase of arsenic concentration is expected because arsenic present in irrigation water is quickly adsorbed or co-precipitated (with iron) onto soil as arsenic bearing irrigation water travels through the paddy field. The sub-area 'R' had a gentle slope toward the south, which induced a flow toward this direction; depth of standing water was higher on the southern side of this field. This appears to have resulted in higher increase in arsenic concentration for sampling points located close to the southern side of the sub-area.

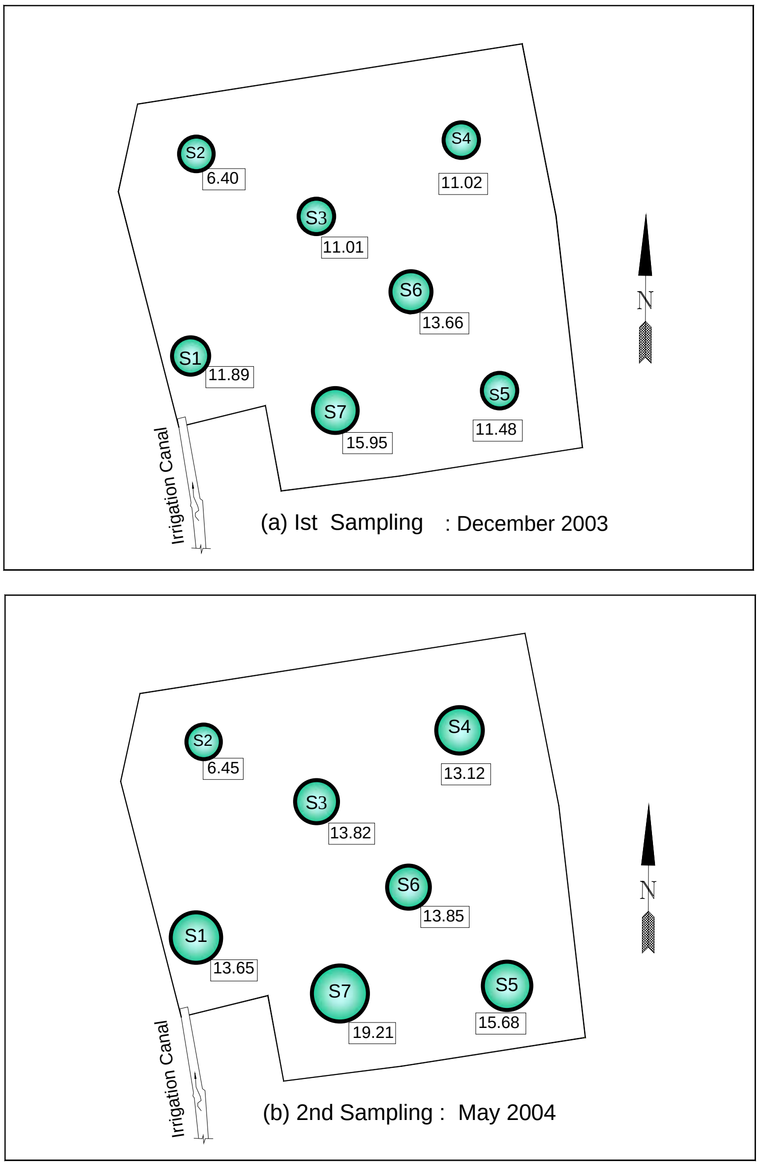

Fig. 3. Schematic representation of sub-area "R" of the paddy field along approximate sampling locations and arsenic concentration in top 0-75 mm segment of soil

Variation of arsenic concentration of paddy field soil with depth: Figure 4 shows the variations of arsenic concentration of three soil core samples at different sampling times as a function of depth. Each data point in the figure represents the average concentration of arsenic for a particular segment of the soil core and has been plotted at a depth representing the mid-depth of the segment. It shows that arsenic concentration in the paddy field soil varies significantly with depth as well as with time of sampling. In general, arsenic concentrations in the top soil layers are relatively higher than those in the bottom layers. Arsenic concentration in the top soil layers (up to about 150 mm) increased significantly at the end of the irrigation season in May 2004. For example, for soil core S-5, arsenic concentration in the top 0-75 mm segment of soil increased from 11.48 mg/kg in December 2003 to 15.68 mg/kg at the end of the irrigation season in May 2004. Saha and Ali (2004, 2005) also reported similar increase in arsenic concentration for the top 0-75 mm soil layer for paddy fields in four arsenic affected areas, including Munshiganj.

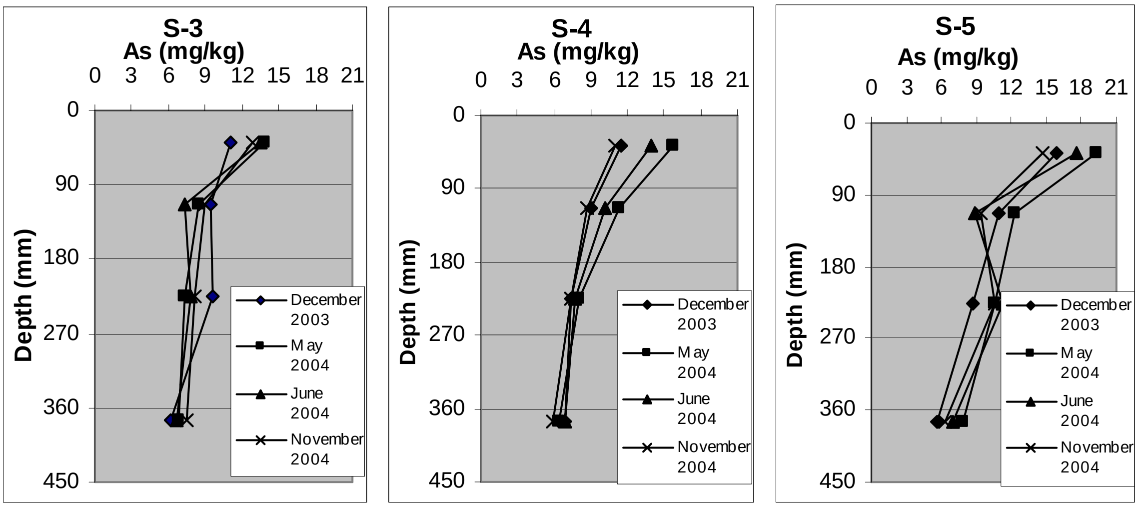

Fig. 4. Arsenic profiles of soil cores collected from the sub-area "R" of the paddy field.
(S# = sampling point identification number)

Arsenic accumulation in top soil at the end of irrigation season: In estimating arsenic accumulation in the top soil at the end of the irrigation season, it was assumed that the seven soil core samples distributed over the paddy field represent the average condition over the entire paddy field. Average arsenic concentrations of the 7 soil core samples collected at the beginning and at the end of the irrigation season were used to estimate arsenic accumulation in the different soil layers/segments during the irrigation season. Table 2 shows range, mean and standard deviation of arsenic contents in different segments of the soil cores collected at the beginning and at the end of the irrigation season. Using average arsenic concentrations of each segment and a measured dry unit weight of 1.62 gm/cc for the soil, it is estimated that about 0.81 kg of arsenic was retained in the top 0-75 mm segment of soil up to the end of the irrigation season. Similarly, the amount of arsenic retained in the next three segments i.e., 75-150 mm, 150-300 mm and 300-450 mm were 0.12, 0.03 and 0.07 kg, respectively. These values correspond to arsenic accumulation of 2.49, 0.37, 0.09, and 0.22 kg/ha for the top 0-75mm, 75-150 mm, 150-300 mm and 300-450 mm of soil, respectively. Thus, significant amount of arsenic is accumulated in the top 0-75 mm segment of soil, which accounted for about 71% of estimated total arsenic that is added to the paddy field with irrigation water. Accumulation in next three segments of soil accounted for about 10.5, 2.6 and 6.1%, respectively of the estimated total arsenic added to the field. Thus, arsenic accumulated in the top 0-450 mm of soil accounts for about 90% of total arsenic that is added to the paddy field with irrigation water.

Depletion of arsenic in soil after rainy season Similar to the trends reported by Ali et al. (2003) and Saha and Ali (2004, 2005), arsenic concentrations in the top soil layers were found to decrease significantly after the rainy season, during which the paddy field remained inundated with rain/flood water for a period of about three months. Figure 4 shows that arsenic concentrations of soil cores collected in November 2004 are comparable to those collected at the beginning of the irrigation season in December 2003. Saha and Ali (2004, 2005) noted that since the majority of the arsenic in the top soil layer is associated with iron oxyhydroxides, this is most likely due to partitioning of arsenic from soil into the aqueous phase during inundation by reductive dissolution of iron oxyhydroxides and desorption. Thus, results from this study confirms earlier observation by Saha and Ali (2004, 2005) that long-term arsenic accumulation in agricultural soil appears to be counteracted by biogeochemical pathways leading to arsenic removal from soil during rainy season.

Table 2
Range, mean and standard deviation (SD) of arsenic contents in the different segments of the seven soil core samples collected at the beginning and at the end of the irrigation season

Segment and Depth	Parameter	1st Sampling (December 2003) (mg/kg)	2nd Sampling (May 2004) (mg/kg)
Segment-1 (0-75 mm)	Range	6.40-15.95	6.45-19.21
	Mean ± SD	11.60 ± 2.83	13.70 ± 3.81
Segment-2 (75-150 mm)	Range	5.03-10.97	4.54-12.27
	Mean ± SD	8.42 ± 1.82	8.73 ± 2.38
Segment-3 (150 -300mm)	Range	3.25-9.66	3.76-10.57
	Mean ± SD	6.99 ± 1.96	6.95 ± 1.92
Segment-4 (300-450 mm)	Range	4.05-6.87	3.91-7.85
	Mean ± SD	5.92 ± 0.87	6.09 ± 1.23

3.2 Uptake of arsenic by paddy plants

Arsenic contents of different parts of paddy plants: Figure 5 shows arsenic concentrations in different parts of paddy plants collected from the field site. It shows that the roots of paddy plants accumulated the maximum level of arsenic, followed by leaf and stem. Paddy grain and husk accumulated the least amount of arsenic. These trends are in agreement with those reported by Abedin et al. (2002) and Ali et al. (2003).

Average arsenic concentrations in root, leaf, stem, husk and grain have been found to be 14.2, 6.83, 5.04, 1.01 and 0.66 mg/kg, respectively. Arsenic concentration in the paddy grains varied from 0.28 mg/kg to 1.32 mg/kg; arsenic concentrations in grains of two out seven paddy plants exceeded the Australian food hygiene limit of 1.0 mg/kg. These results are similar to those of arsenic concentrations in paddy grains and straw reported by Farid et al. (2005), Islam et al. (2004a, 2005) and Jahiruddin et al. (2004, 2005).

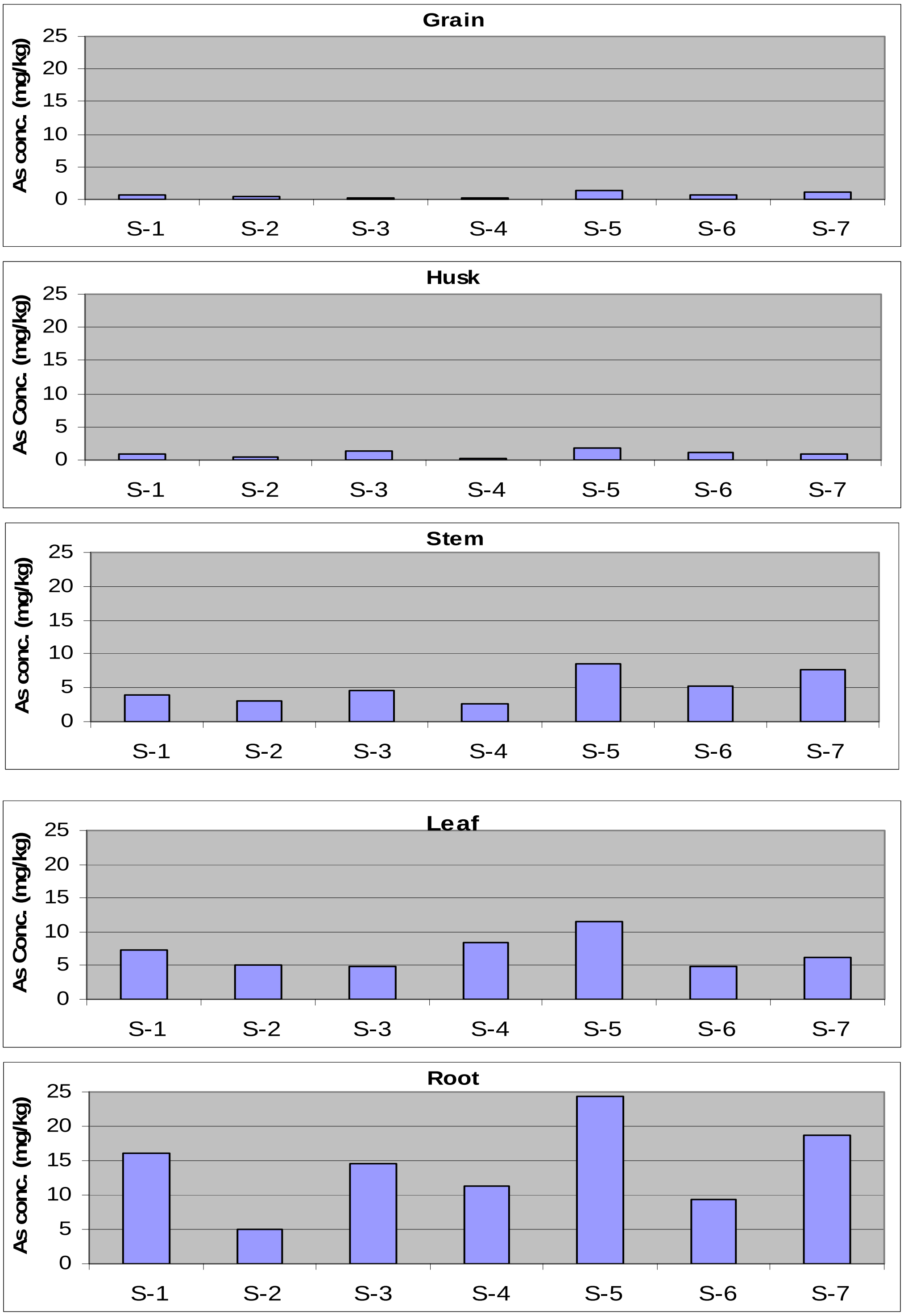

Fig. 5. Arsenic concentrations in grain, husk, stem, leaf and root of paddy plants (S# = sample identification number)

Estimation of arsenic accumulation in paddy plant: In order to estimate the total mass of paddy plant, the number of plants per sq.m. area of the paddy field was counted at different locations of the field and oven dried mass of different parts of paddy plants were determined (Table 3). It was found that there were about 45 paddy plants per sq.m. area.

Using average arsenic concentrations and measured dry weight of different parts of paddy plants, it was estimated that about 0.05 kg of arsenic was taken up by the paddy plants of sub-area "R" of the paddy field under investigation. This accounts for about 4.4% of arsenic added to the paddy field with irrigation water. Figure 6 shows arsenic uptake by different parts of paddy plants. Of the total uptake by paddy plants, root accounted for about 47%, stem 29%, leaf 17%, husk 3%, and grain 4%.

Table 3
Average (n=7) oven dried (65° C) mass of different parts of a paddy plant sample

Root (gm)	Leaf (gm)	Stem (gm)	Husk (gm)	Grain (gm)	Total (gm)
11	8	19	9	19	66

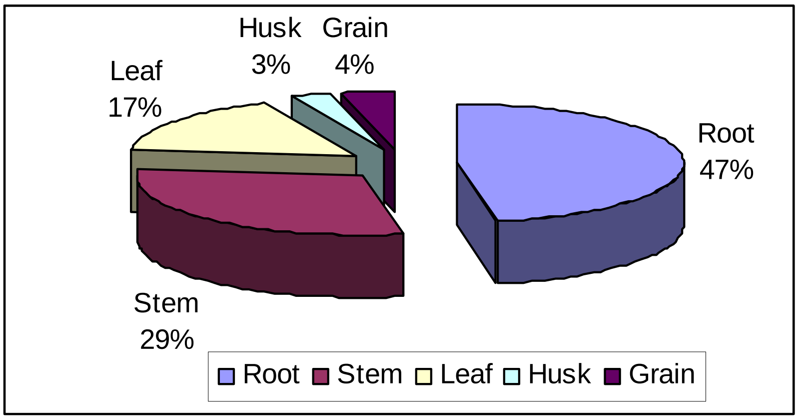

Fig. 6. Arsenic uptake by different parts of paddy plants in terms of % of total uptake

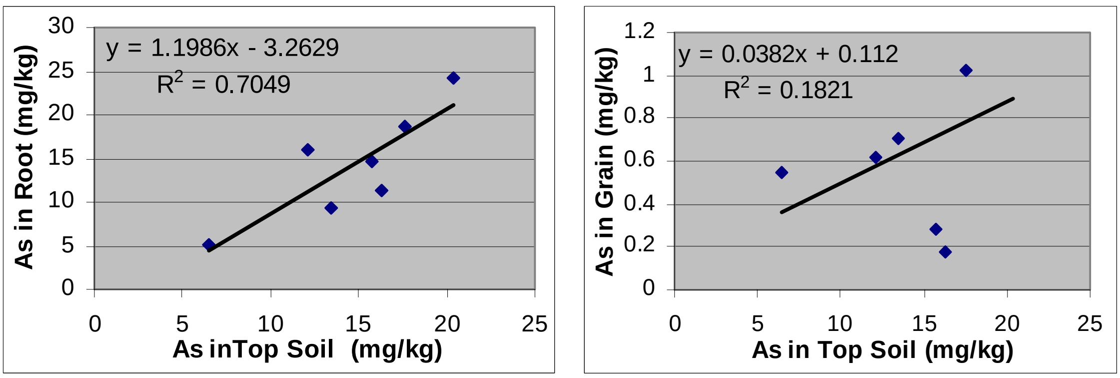

Fig. 7. Correlations between the arsenic content in top 0-75 mm soil layer with arsenic contents of root and grain of paddy plants

Correlation between arsenic in soil and arsenic in paddy plant: Figure 7 shows correlation between arsenic in top 0-75 mm soil and arsenic in roots and grains of the seven paddy plant samples. It shows that arsenic content in the topsoil is strongly correlated with arsenic concentration in root (R^2=0.70). However, arsenic in topsoil poorly correlates with arsenic in paddy grains (R^2=0.18). Similar poor correlation was also observed between soil arsenic content and arsenic contents of straw, leaf and husk. Based on a study carried out in Chapai Nawabganj Sadar upazila, Jahiruddin et al. (2005) also reported poor correlation between grain arsenic concentration and arsenic concentration in both irrigation water and soil.

4. Conclusions

Arsenic concentration in the top (~ 450 mm) soil layers of a piece of paddy field located in the arsenic-affected Munshiganj district was monitored during 2004 boro (dry season rice) season. The average arsenic concentration of the irrigation water for this paddy field was 366 μg/l. For the top 0-75 mm segment of soil layer, arsenic concentration increased significantly at the end of the irrigation season (May 2004). However, after the rainy season and before the beginning of the next irrigation season, the arsenic level in the top soil layer decreased significantly, and came back to levels comparable to those at the beginning of the irrigation season. It is estimated that about 90% arsenic added to the paddy field with irrigation water is accumulated in the top 0-450 mm of soil layer at the end of the irrigation season. The top 0-75 mm soil layer accumulated about 71% added arsenic. Determination of arsenic concentrations in paddy plant samples collected just before harvest time showed that the roots of plants accumulated the maximum level of arsenic, followed by leaf and stem. Paddy grain and husk accumulated the least amount of arsenic. Arsenic content in 0-75 mm soil layer correlated strongly with arsenic concentration in root; however, poor correlation was found between arsenic concentration in soil and paddy grains. The arsenic taken up by paddy plants accounted for about 4.4 % of total arsenic that is added to the paddy field with irrigation water. Of the total uptake by paddy plants, root accumulated 47%, stem 29%, leaf 17%, husk 3%, and grain 4%. Since paddy straw is used as cattle feed, high concentration of arsenic in straw poses a risk to cattle health in the arsenic-affected areas. Rice is the staple food for the people of Bangladesh, with an average consumption of about 450 gm/person/day. Thus it appears that intake of arsenic from rice could constitute an important part of overall arsenic intake for people living in the arsenic affected areas.

References

Abedin, M. J., Cresser, M. S., Meharg, A. A., Feldmann, J. and Cotter-Howells, J. (2002). Arsenic Accumulation and Metabolism in Paddy, *Env. Sci. Technol.*, 36(5), 962-968.

Ahmed, Z. U. (2005). Water-Soil-Crop Arsenic Interrelationships. In: Proceedings of Symposium on Behavior of Arsenic in Aquifers, Soil and Plants: Implication for Management, Organized by CIMMYT, CU, TAMU, USGS, and GSB, Dhaka, Bangladesh, January 2005.

Ali M. A., Badruzzaman A. B. M., Jalil M. A., Hossain M. D., Ahmed M. F. et al. (2003). Arsenic in plant soil environment in Bangladesh. In: M. F. Ahmed, M. A. Ali and Z. Adeel, editors. Proceedings of the BUET-UNU International Symposium on Fate of Arsenic in the Environment, Dhaka, Bangladesh, February 2003, 85-112.

BADC (2005). Survey Report on Irrigation Equipment and Irrigated Area in Boro/2004 Season, Bangladesh Agricultural Development Corporation.

BGS and DPHE (2001), Arsenic Contamination of Groundwater in Bangladesh, Department of Public Health Engineering, DFID, British Geological Survey.

Dittmar, J., Voegelin , A., Kretzschmar , R., Roberts, L. C., Hug , S. J., Saha , G. C., Ali , M. A. and Badruzzaman , A. B. M. (2005). Biogeochemical cycling of As in a paddy soil – rice plant system in Bangladesh, Abstract submitted at World Congress of Soil Science.

Farid, A.T.M., Sen, R., Haque, M. A., Hossain, K. M., Panaullah, G. M. and Meisner, C. (2005). A. Arsenic status of water, soil, paddy grain and straw of individual shallow tube well command area of Brahmanbaria. In: Proceedings of Symposium on Behavior of Arsenic in Aquifers, Soil and Plants: Implication for Management, Organized by CIMMYT, CU, TAMU, USGS, and GSB, Dhaka, Bangladesh, January 2005.

GoB (2004). Bangladesh Economic Review, Publication from Ministry of Finance, Government of Bangladesh, 72-73

Harvey, C. F., Swartz, C. H, Badruzzaman, A. B. M., Keon-Blute, N., Yu, W., Ali, M. A., Jay, J., Beckie, R., Niedan, V., Brabander, D., Oates, P., Ashfaque, K. N., Islam, S., Hemond, H. F., and Ahmed, M. F. (2002). Arsenic Mobility and Groundwater Extraction in Bangladesh. *Science*, 298, Issue 5598, 1602 - 1606.

Harvey, C. F., Swartz, C. H, Badruzzaman, A. B. M., Keon-Blute, N., Yu, W., Ali, M. A., Jay, J., Beckie, R., Niedan, V., Brabander, D., Oates, P., Ashfaque, K. N., Islam, S., Hemond, H. F., and Ahmed, M. F. (2005). Groundwater arsenic contamination on the Ganges delta: biogeochemistry, hydrology, human perturbations, and human suffering on a large scale. *C. R. Geoscience*, 337, 285-296.

Hossain, M., Lewis, D., Bose, M., and Chowdhury, A. (2003). Paddy research: Technological progress and impacts on the poor: The Bangladesh case (Summary Report), International Food Policy Research Institute (IFPRI).

Huq S. M. I., Ahmed K. M., Suktana N. and Naido R. (2001). Extensive Arsenic Contamination of Groundwater and Soils of Bangladesh, In: Proceeding of Arsenic in The Asia Pacific Region Workshop, Adelaide, Managing Arsenic for the Future, 94-96.

Huq, S. M. I, Rahman, A., Sultana, S. and Naidu, R. (2003). Extent and severity of arsenic contamination in soils of Bangladesh. Proc.: Fate of Arsenic in the Environment, BUET-UNU International Symposium, Dhaka, F. Ahmed, M. A. Ali, Z. Adeal (eds.), pp. 69-84.

Islam, M. R., Jahiruddin, M. and Islam, S. (2004). Assessment of arsenic in the water-soil-plant systems in Gangetic floodplains of Bangladesh. *Asian J. Plant Sci*. 3(4):489-493.

Islam, M. R., Islam, S., Jahiruddin, M. and Islam, M. A. (2004a). Effects of irrigation water arsenic in the rice-rice cropping system. J. Biol. Sci. 4 (4): 542-546.

Islam, M. R., Jahiruddin, M., Rahman, G. K. M. M., Miah, M. A. M., Farid, A.T.M., Panaullah, G. M., Loeppert, R. H., Duxbury, J. M. and Meisner, C. A. (2005). Arsenic in paddy soils of Bangladesh: levels, distribution and contribution of irrigation and sediments. In: Proceedings of Symposium on Behavior of Arsenic in Aquifers, Soil and Plants: Implication for Management, Organized by CIMMYT, CU, TAMU, USGS, and GSB, Dhaka, Bangladesh, January 2005.

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

Jahiruddin, M., M. R. Islam, A. L. Shah, S. Islam and M. A. Ghani (2004). Effects of arsenic contamination on yield and arsenic accumulation in crops. In: M. A. L Shah et al., editors. Proceedings of Workshop on Arsenic in the Water-Soil-Crop Systems, 22 July 2004, Publication no. 147, pp 39-52, BRRI, Gazipur.

Jahiruddin, M., Islam, M. R., Shah, M. A. L., Rashid, M. A., Rashid, M. H., and Ghani, M. A. (2005). Arsenic in the Water-Soil-Crop Systems: PETRRA-BRRI-BAU-AAS Study", In: Proceedings of Symposium on Behavior of Arsenic in Aquifers, Soil and Plants: Implication for Management, Organized by CIMMYT, CU, TAMU, USGS, and GSB, Dhaka, Bangladesh, January 2005

Masud, M. A. A. (2003). A study on Arsenic in irrigation water and plant-soil environment in Bangladesh, M. Sc. Engg., Thesis report, Department of Civil Engg., BUET, Dhaka, June, 43.

Meharg, A. A. and Rahman, M. M. (2003). Arsenic contamination of Bangladesh paddy field soils: implications for paddy contribution to arsenic consumption. *Environ Sci Technol*., 37, 229 –34.

Panaullah, G. M, Ahmed, Z. U., Rahman, G. K. M. M., Jahiruddin, M., Miah. M. A. M., Farid, T. M., Biswas, B. K., Lauren, J. G., Loeppert, R. H., Duxbury, J. M. and Meisner, C. A. (2003). The arsenic hazard in the irrigation water-soil-plant system in Bangladesh: A preliminary assessment. Proc. 7th International Conference on the Biogeochemistry of Trace Elements, Ed. Gobran, G. R. and Lepp N., vol. 2, pp. 104-105.

Rashid, M. H. (1997). "Manual on Irrigation and Soil Water Engg." By Md. Harun-ur-Rashid, Principal Scientific Officer, Irrigation and Water management division, Bangladesh Agricultural Research Institute, Gazipur. June, 1997.

Roberts, L. C., Dittmar, J., Saha , G. C., Hug , S. J., Voegelin , A., Kretzschmar , R., Ali , M. A. and Badruzzaman , A. B. M. (2006). Spatial heterogeneity of Arsenic input to paddy soil through irrigation water in Bangladesh, Paper submitted for the International Symposium on Environmental Sustainability (ISES), held in Dhaka, Bangladesh during 7-9 February, 2006.

Saha, G. C. and Ali, M. A. (2004). Accumulation of Arsenic in Agricultural Soil from Irrigation Water in Different Regions of Bangladesh, Proceedings of the Second International Symposium on Southeast Asian Water Environment, December 1-3, 2004, Hanoi, Vietnam, 63-70.

Saha, G. C. and Ali, M. A. (2005). Dynamics of arsenic concentration in agricultural soil irrigated with arsenic bearing irrigation water in Bangladesh, Manuscript submitted to the *Science of Total Environment* for possible publication.

Shah, A.L., Jahiruddin, M., Rahman, M.S., Rashid, M.A., Rashid M.H. and Gani. M.A. (2004), Arsenic accumulation in rice and vegetables grown under arsenic contaminated soil and water, In M. Abdul Latif Shah et al. (ed.) Proc., Workshop on Arsenic in the Food Chain: Assessment of Arsenic in the Water-Soil-Crop Systems, Dhaka, Bangladesh. 22 July 2004. Bangladesh Rice Research Institute, Gazipur, Bangladesh. 23-37.

Ullah, S. M. (1998). Arsenic Contamination of Groundwater and Irrigated Soils in Bangladesh, In: Proceedings of International Conference on Arsenic Pollution of Groundwater in Bangladesh: Causes, Effects and Remedy, Dhaka, 133.

WRI (2000). Peoples and Ecosystem: The Fraying Web of Life. World Resources Institute, Washington D.C.