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RETENTION OF IRRIGATION WATER ARSENIC IN DIFFERENT HORIZONS OF A SOIL PROFILE

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Abstract

A field-cum-laboratory experiment was carried out to find the fate of arsenic applied through irrigation in a soil profile. The main objective of the experiment was to see whether portion of As applied through irrigation water is moved down to the ground water. From the field observations, it is clear that the irrigation water As leached down the soil profile which was evidenced from the presence of more As in the lower horizons of soil profile at the end of irrigation (after crop harvest). In the laboratory, soil monoliths of the same soil profile were irrigated with simulated irrigation water. Similar trend of As movement in the monoliths was noticed as for the field. The leachates draining out of the soil profile contained a fraction of added arsenic indicating a probable recharge of groundwater with As from irrigation water.

Key words: Irrigation water; Arsenic retention and Soil profile

Introduction

Groundwater contamination with high arsenic (As) concentration has been found in most of the floodplain regions of Bangladesh particularly in the Gangetic Alluvium Floodplain which has become one of the world's most important natural calamities (Imamul Huq and Naidu 2005). According to the latest statistics, 270 upazilla covering 17 districts of the country have been identified to be affected with elevated level of arsenic in the groundwater of shallow depths (APSU 2005). This situation has posed a significant threat to the people living in those areas. A significant number of shallow tube-wells (STWs) is also used for irrigating crops, especially in the dry season (Imamul Huq and Naidu 2005). The use of groundwater irrigation has increased from 30 to 72 percent of total irrigated area during the period 1981 to 2002, and the area used STWs has increased from 12 to 58 percent during the same period (MoA 2004).

The use of As contaminated groundwater for irrigation in Bangladesh may lead to a substantial amount of As accumulation in the top soils and thus may create a situation of its entry into food chain (Imamul Huq *et al.* 2001, 2003, Imamul Huq and Naidu 2005). Again, arsenic accumulation and tolerance vary with plant species and varieties (Adriano 1986). A part of As addition from irrigation water is taken up by the standing crops, a portion is adsorbed onto soil surface, some As is lost through bio-methylation and volatilization and the rest is liable to be leached down to the ground water. However, different soil horizons varying in their individual properties (e.g. pH, Fe, clay and organic matter content) may also differ in their behavior towards As retention. Soil is regarded as a sink of arsenic (Ahmed 2003) and soils in floodplains develop some characteristic morphological features in their profiles due to seasonal flooding. The possible accumulation of arsenic in different soil horizons and subsequent leaching of arsenic through soil profiles resulting from the downward movement of As contaminated groundwater in the dry season when land is irrigated for Boro culture has, therefore, become critical issue (UNICEF 2001). To address the issue, the present experiment was conducted during the months of December 2005 to May 2006 to study As dynamics in soil profile of a Gangetic Alluvium Flood Plain Soil where As contaminated groundwater is being used as irrigation water.

Materials and Methods

A farmer's field at Doyarampur village under Gerda union (local administrative unit) of Faridpur Sadar Upazila (sub-district) was selected for sampling site. It is located in an area where As contaminated groundwater has been used for irrigation. Characteristically, the soil belongs to Grey Calcareous Floodplain Soil and the soil series is Ishuardi (SRDI 2005). It is taxonomically referred to as Aeric Endoaquept. Samples were collected from specific geographic location (23°33.289′ N; 89°54.638′ E). The soil is poorly drained, flooded up to 0.61-0.91 m for about 3 to 4 months, remains unsaturated for about 7-8 months in the dry season (SRDI 2005).

After opening up of the soil profile the individual horizons were delineated and soil samples from different horizons were collected periodically in three phases: irrigation (phase I), during irrigation (phase II) and the end of irrigation (phase III). Three undisturbed soil monoliths (representative soil profile) were also collected at the time of first sampling in rectangular shaped mild steel boxes (100 cm×25 cm×15 cm) and were carried to the laboratory to study the fate of As resulting from the movement of irrigation water As through the same profile. Soil and plant samples (BRRI dhan 29 rice) were collected at three phases. Shallow tube-well water (STW) that was used for irrigation was also collected three times. Procedures of sampling and preservation of samples were followed, as described by Imamul Huq and Alam (2005).

The experiment with soil monoliths was set up in the net house of the Department of Soil, Water and Environment, University of Dhaka, Dhaka. BRRI dhan 29 rice was transplanted to study the arsenic uptake by rice. For irrigation, normal tap water spiked with arsenic salt (sodium meta arsenite) at the rate of 0.5 mg AsL^{-1} was used. Plastic containers were put under the soil monoliths to collect the leachates. Leachates were collected from the day of plantation to the day of harvest. Rice plants were harvested after 105 days of transplantation. After crop harvest, soil samples were collected from the different horizons of the soil monoliths.

Sample preparation

The collected soil samples from field and net-house experiment were air dried, and visible roots and debris were removed. The soil aggregates were ground to pass through a 0.5 mm sieve. Plant roots were washed with deionized water The rice plant was separated into root and straw. These samples were oven dried at 70°±5°C for 48 hours and the dry weights were recorded. The dry plant samples were ground and sieved through a 0.2 mm sieve.

Laboratory analysis

Some routine analyses of the soils were done in the laboratory following the methods as described by Imamul Huq and Alam (2005). Soil arsenic was extracted by digestion with aqua-regia ($HCl : HNO_3$, 3:1) whereas the plant arsenic was extracted by digestion with concentrated nitric acid (HNO_3) (Portman and Riley 1964). All the extracted soil, plant and water samples as well as the leachates from the soil monoliths were analyzed for total arsenic by hydride generation atomic absorption spectrometry (HG-AAS). Certified reference materials were used through the digestion and analyzed as a part of the quality assurance/quality control protocol. Reagent blanks and internal standards were used where appropriate to ensure accuracy and precision of As analysis. Each batch of 10 samples was accompanied with reference standard samples to ensure strict QA/QC procedures. The experimental data were statistically analyzed by using the statistical software MINITAB 13.0.

Results and Discussion

Background concentration of As in the soil profile before irrigation in the field

The background level of As concentration in the soil profile was found to vary among the horizons with the highest As concentration in the Ap1 horizon (4.34 $mgkg^{-1}$ total As and 0.27 $mgkg^{-1}$ water extractable As). The water soluble As could subsequently be moved to the subsurface horizons (Bw1 and Bw2) and also to the substratum (C1 and C2). Relatively lesser amount of As was found in all horizons (i.e. Ap2, Bw1, Bw2, C1 and C2) compared to the surface horizon (Ap1) before irrigation (phase I). Arsenic concentration was observed to be decreased with increasing depth of the soil profile up to the Bw1 horizon, whereas a reverse trend of the As level was found in case of Bw2, C1 and C2 horizons. This could be related to the variation of the soil properties like texture, Fe, P, clay and organic matter contents (Joardar *et al.* 2005). Merry *et al.* (1983) also noted that the accumulation of As in subsoil did not account for all the As lost from the upper horizons. The water extractable As concentrations in all the horizons except in the Ap1 horizon were below the detection limit (<0.0002 mgkg-1). The background concentrations of As in different horizons of the soil profile are shown in Table 1.

Changes in As concentration in the soil profile during and at the end of irrigation in the field

The maximum amount of As was retained in the Ap1 horizon of soil profile during the period of irrigation and almost a similar trend of retention was found prior to irrigation. Analysis of soils collected

Table 1. Background levels of As in different horizons of the soil profile.

Horizons	As (mg/kg)	
	Total	Water extractable
Ap1	4.34	0.27
Ap2	1.70	bdl
Bw1	0.98	bdl
Bw2	1.38	bdl
C1	2.65	bdl
C2	3.41	bdl

bdl = below detection limit (<0.0002 mg/kg

during irrigation (phase II) revealed that As concentration decreased in the Ap1, C1 and C2 horizons and increased in the Ap2, Bw1 and Bw2 horizons after certain period of irrigation with As (0.066 mgL^{-1}) contaminated water. Some As has moved down the soil profile. At the end of irrigation (phase III) the surface horizon (Ap1) accumulated the maximum amount of As. The study clearly indicates that the irrigation water causes As loads in the surface soil. In an estimate, Imamul Huq and Naidu (2005) showed that for a boro crop requiring 1000 mm irrigation water with 0.55 mg/L As would accumulate 5.5 kg As/ha/yr. The surface soil As was higher than any other horizons in the soil profile in every phases. Arsenic concentration in Ap1 horizon at phase II was found reduced than at phase I and this could be due to temporary downward and lateral movement of As with the irrigation water. Comparing the data in Phase I, II and III it becomes clear that there is an indication of As build up in the individual horizons of the soil profile showing a recharge possibility of As in groundwater through the soil profile due to irrigation with As contaminated groundwater. Changes in soil pH values of the corresponding horizons of soil profile were found following the same trend as the trend of As retention in the individual horizon. The changes of As concentration are shown in Figure 1.

The changes of As in the soil profile through irrigation was highly significant ($p = 0.002$) between As concentrations of phase I and of phase III. The changes between phase II and phase III were also highly significant ($p = 0.004$) whereas the changes between As concentration at phase I and at phase II were not significant.

Changes of As concentration in the soil monolith profile at the end of irrigation

Noticeable increase of As concentration was observed in all the horizons of the soil monolith profile. There was a highly significant ($p=0.003$) change in As concentration in the soil profile before irrigation and after irrigation. Arsenic accumulation in the surface horizon at the end of irrigation and the trend of

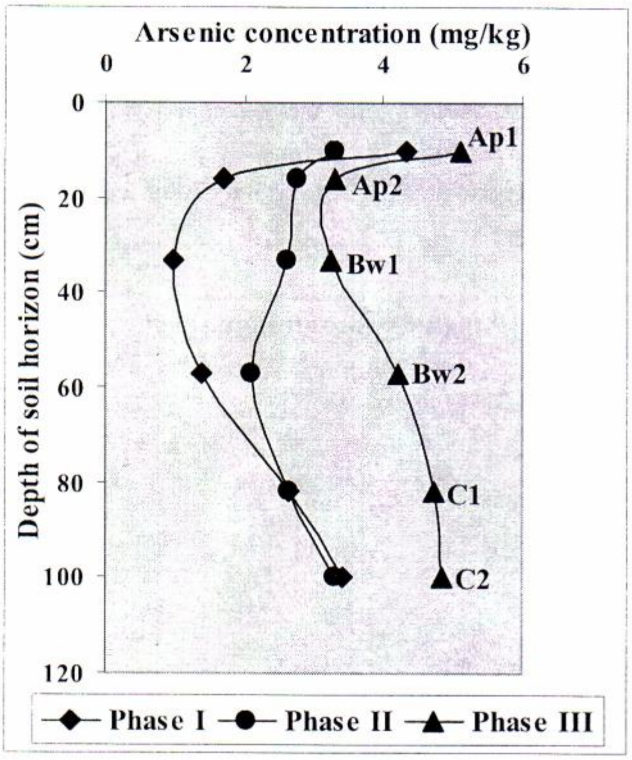

Figure 1. Changes of As in different horizons of soil profile under field condition.

As distribution in the soil profile followed a similar pattern as that observed for the in situ profile. The potential for As leaching has also been demonstrated in the laboratory studies using columns of disturbed soil (Isenbec-Schroter *et al.* 1994, Kuhlmeier 1997, Imamul Huq *et al.* 2006a). In a recent study on undisturbed soil column experiment it has been reported that the loss of As through leaching is the minimum (Khan 2007). However, the rate of As increase in the individual horizon of the monolith soil profile was much higher than that observed in the in situ profile. This might be due to the command area of irrigation. In the field, the movement of As contaminated irrigation water spread in a vast area encouraging a greater lateral and vertical movement causing lesser As retention by individual horizon of the in situ soil profile. Figure 2 shows the trend of changes in As concentration at the end of irrigation in the monolith soil profile.

Plant arsenic

At phase II, the field collected rice (BR 29) root and shoot contained 3.14 and 0.57 mgAskg^{-1} dry samples, respectively and at phase III rice root, shoot and grain contained 5.26, 3.60 and 0.004 mgAskg^{-1} dry samples, respectively. Under the net house condition where the same rice variety BR-29 was grown showed that only rice root and shoot contained 6.95 and 1.08 mgAskg^{-1} dry sample whereas no detectable amount of As was found in grain, unfilled grain and husk. Root accumulated higher amount of As as usual. This again confirms the observations that when irrigation water contains As, there will be an accumulation of the element in the crops receiving the irrigation (Imamul Huq *et al.* 2006b, Imamul Huq *et al.* 2006c, Farid *et al.* 2003). The translocation factor for As from root to shoot was 0.16.

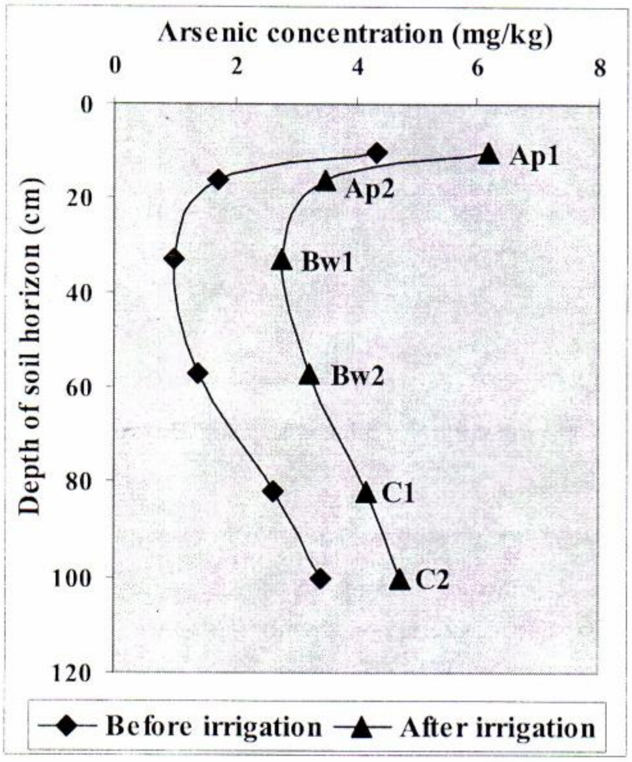

Figure 2. Changes of As in different horizons of the monolith soil profile.

Arsenic leaching

No detectable As was found in the leachates collected during the first 17 days of irrigation in the monolith. Irrigation was continued up to 86 day after transplantation and the leachate collection was also continued till that day. Arsenic concentration in the leachates of the specific days are presented in Figure 3. Leachate collection was not possible in some days since irrigation water was not leached out due to higher rate of volatilization for elevated temperature. It is apparent from the soil monolith experiment that a portion of irrigation water As could pass through the soil profile and may ultimately recharge the groundwater.

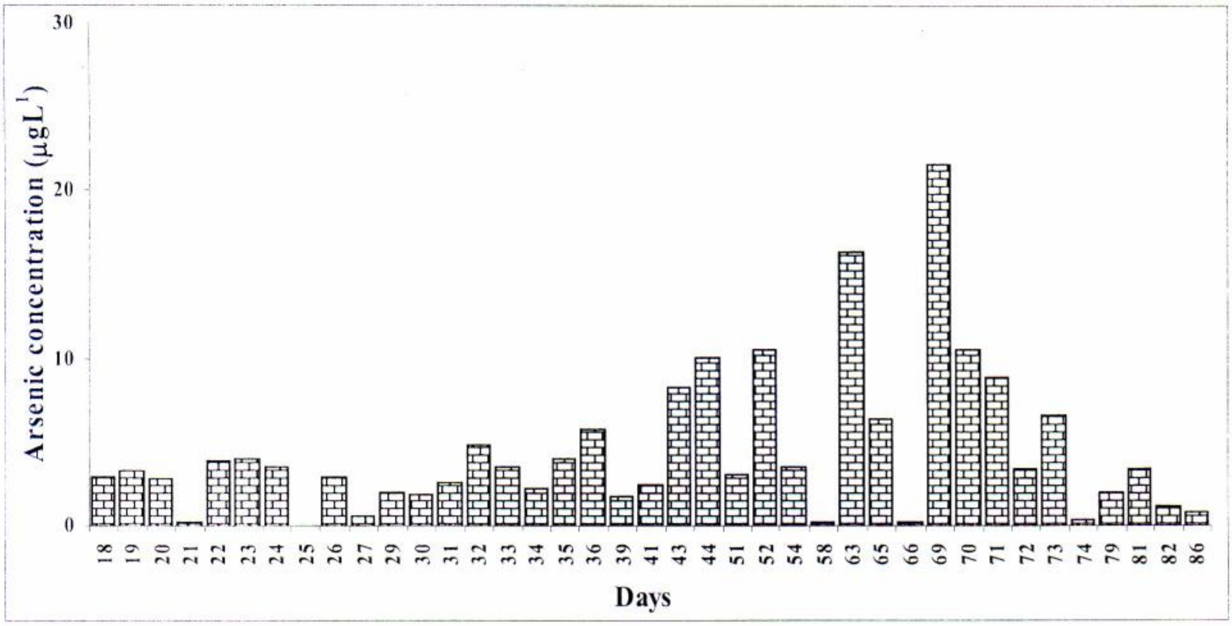

Figure 3. Arsenic concentrations in the leachates at different days.

A balance sheet of As in the soil profile was made to assess the fate of As of the irrigation water. The initial amount of arsenic in the topsoil was 36.46 mg and the amount of As added through irrigation was 29.48 mg. So, the total amount of As load in the top soil was 65.94 mg. At the end of irrigation and after harvest the topsoil contained 52.08 mg (52.99 % of the applied As) As, the amount of As accumulated by plants was 0.14 mg (0.47 % of the applied As) and 0.13 mg (0.44 % of the applied As) As was leached down through the profile. So, a total of 52.35 mg of the 65.94 mg As could be accounted. The rest 13.59 (46.10 % of the applied As) mg As was not accounted for. A small fraction of this As could be lost through volatilization and biomethylation processes while the rest of As was retained in the different horizons of the whole profile.

The above observation indicates clearly that the percolation of As through the soil profile may provide a substantial pathway for the temporary loss of As by various adsorption processes. Adsorption is totally irreversible and desorption of As back into solution is a distinct possibility. Indeed, desorption of As from the solid phase of the soil could probably be considered a prerequisite for the long-term loss of As from soils by leaching. However, As leaching is a complex process and the rates and amounts of As lost from soils by leaching depends on many factors. The potential for As leaching has been demonstrated in both field and laboratory studies. However, the issue relating to As build-up of soil through irrigation requires careful study.

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