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Disposal of Arsenic Filter Sludge in Soil and its Consequences

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Abstract: Incubation, macrocosm and field studies were carried out to observe any increase in the concentration of arsenic (As) in soil and its subsequent uptake by plants due to disposal of As-filter sludge into soil from two different arsenic removal media. One of the media was iron based and the other was activated alumina based. For the incubation study, sludge @ 1 T·ha^{-1} and 0.5 T·ha^{-1} from the two sources wer applied to soils and incubated for 180 days with five individual incubation periods viz., 15, 30, 60, 90 and 180 days. At the end of each incubation period the soils were extracted with 1M HCl. For the macrocosm study, a leafy vegetable-*Ipomoea aquatica* L. and rice (*Oryza sativa* L.) were grown in pots treated with sludge @ 1 T·ha^{-1} and 0.5 T·ha^{-1} soils. For the field study, two leafy vegetables viz., red amaranthus (*Amaranthus gangeticus* L.) and Kalmi (*Ipomoea aquatica* L.) were grown on soils treated with the sludge @ 1 T·ha^{-1} in plots of 1 m^2 sizes. Arsenic was found to have increased under upland and lowland conditions that contributed to an increased accumulation of the element in the plants. The increase of As was found to be relatively higher under upland condition than under submerged condition. Arsenic accumulation in plants was found to be the highest in the roots followed by straw and grain. Similar observation has been made under field condition too. Increased concentration of Fe an Al has also been observed which could be a new environmental hazard. The study reveals that the filters used for making As-safe drinking water cannot be safely disposed of to the soil, particularly to the agricultural soils.

Key words: Contamination, disposal, arsenic release, upland condition, lowland condition.

1. Introduction

Ingestion of arsenic contaminated groundwater is the major cause of arsenic poisoning in Bangladesh [1]. From the viewpoint of exploring arsenic remediation technique for drinking water, different types of adsorbents have been introduced and have been used in different filters [2-4]. The longevity of a filter is variable depending on the process of manufacture. The disposal of the sludge from these filters has become a great concern for the environmental, as well as plant and soil scientists. There has been much debate about this issue internationally. Soils are regarded as a natural sink for all unwanted materials. Once the unwanted materials are disposed of into the soil, it would decompose in soil at a certain time and there is a possibility of soil contamination with the toxic elements and it is likely that the element will subsequently end up in the growing plants. It has been shown recently that arsenic filter sludge, when disposed of in the soil do release the toxic element in soil and is accumulated in plants [5]. Since arsenic cannot be destroyed, all arsenic treatment technologies ultimately concentrate arsenic in sorption media, sludge, or liquid media. A variety of arsenic-rich solids and semisolids, such as arsenic-saturated hydrous ferric or aluminum oxides and other filter media are

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generated from arsenic removal processes. Regeneration of activated alumina and ion exchange resins results in various liquid wastes that may be acidic, caustic, saline, and too arsenic rich for simple disposal [6]. Hence, environmentally safe disposal of sludge, saturated media and liquid wastes rich in arsenic is a concern. Typically, sludge is disposed through either land filling, in municipal or industrial landfills, or through land application. The present work aimed at verifying the possible release of As and the matrix material (Fe or Al) in soil and its subsequent accumulation in plants from two different waste media used for treatment of As-contaminated water.

2. Material and Methods

The experiments were conducted in the BACER-DU research laboratory, a macrocosm study with plants in the net house of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh, and a field study in an arsenic affected area around Dhaka.

2.1 Sampling Sites

For the laboratory incubation study and the macrocosm study, soil samples were collected from a farmer's field adjacent to Dhaka, the geo-location of the sampling site being 23°54.749′ N 90°10.842′ E. The soil belonged to the Dhamrai soil series [7]. The soil is a Typic Haplaquept [8]. For the field experiment, an arsenic affected area in Keraniganj upazilla of Dhaka district was selected. The soil belonged to the Pagla soil series. The soil is a Typic Endoaquept [8].

2.2 Collection and Processing of Soil and Sludge Samples

The collected soil samples were processed as described elsewhere [7]. The two arsenic (As) filter sludge collected from the Department of Public Health & Engineering were: (a) Granular ferrichydroxide [Iron (Fe) based media] and (b) Activated alumina (Alcan) [Aluminum (Al) based media]. The collected sludge samples were dried in air for 3 days (at ~35 ℃) by spreading in a thin layer on a clean piece of paper after it was transported to the laboratory. After air-drying, a portion of the aggregates were broken by gently crushing them using a porcelain mortar. Ground samples were screened to pass through a 0.1 mm stainless still sieve. The sieved samples were then mixed thoroughly for making the composite sample. Sludge samples were preserved in plastic containers. These processed sludge is used for further experiment and various chemical and physicochemical analyses.

2.3 Experimental

In order to study the release of arsenic from arsenic filter sludge in soil and its subsequent accumulation in plants, the experiment was divided into three parts viz., (i) a laboratory incubation study, (ii) a macrocosm and (iii) a field study with plants.

2.4 Laboratory Incubation Study

In the incubation study, 100 mL sized plastic pots were used. 50 g of soil was placed in each of the pots and As-filter sludge was added to the soil. In the study, the two As-filter sludge: Granular ferrichydroxide (GR) and Activated alumina (AC) were used. The soil was spiked with each of the two sludge at two rates, viz., 1 $T \cdot ha^{-1}$ and 0.5 $T \cdot ha^{-1}$. Upland and lowland conditions of the soils were taken into consideration in this study. An upland soil having pH in the range of 4.0-5.0 was used. On the other hand, lowland condition of the soils was maintained throughout the study period by adding deionized distilled water into the pots. For the incubation study, the treatments were designed with the two As-sludge-GR and AC each with the two rates of application. Therefore, there were 10 treatments including the control. The study was continued for a total period of 180 days with five individual incubation periods viz., 15, 30, 60, 90 and 180 days. Each treatment was replicated thrice for each incubation period. Accordingly, there were 30 pots: 3 pots for each treatment; 15 pots for each of the two soil conditions. The treatment combinations were as follows:

- Control-Upland condition;
- Control-Lowland condition;
- Soil + GR 0.5 T·ha^{-1} — Upland condition;
- Soil + GR 0.5 T·ha^{-1} — Lowland condition;
- Soil + GR 1 T·ha^{-1} — Upland condition;
- Soil + GR 1T·ha^{-1} — Lowland condition;
- Soil + AC 0.5 T·ha^{-1} — Upland condition;
- Soil + AC 0.5 T·ha^{-1} — Lowland condition;
- Soil + AC 1 T·ha^{-1} — Upland condition;
- Soil + AC 1T·ha^{-1} — Lowland condition.

The soils under the incubation study at 15, 30, 60, 90 and 180 days were extracted with 1 M HCl in order to obtain the labile fractions of As, Fe and Al in the soils [9].

2.5 The Macrocosm Study

For the macrocosm experiment, an upland crop, a leafy-vegetable plant commonly known as Kalmi shak (Ipomoea aquatica L.) and a low land crop, Rice (Oryza sativa L.)-BRRI dhan-28 variety, were used. Seeds of kalmi (Ipomoea aquatica L.) were collected from local market and rice seedlings of BRRI Dhan-28 were collected from a farmer's field. The two As-filter sludge used in the incubation study were also used in the macrocosm study. The rates of sludge application were also similar i.e., 1 T·ha^{-1} and 0.5 T·ha^{-1}.

There were three replications for each treatment. A total of 30 pots were used in this pot experiment [(2 rates × 2 sludge × 3 replications + 3 control = 15 pots) × 2]. 5 L (for kalmi) and 7 L (for rice) sized earthen pots with no hole at the bottom were used. Air-dried 5 mm sieved soil samples amounting to 4 kg and 5 kg were taken in each of the earthen pots respectively for kalmi and rice. Ten seeds of kalmi were sown in each of the pots and allowed to germinate. After germination, 5 to 7 seedlings were kept in each pot and allowed to grow. For rice, proper puddling of the pot soil was done manually and then 9 seedlings of BRRI dhan-28 were sown in each of the pots randomly and allowed to grow. All the pots were arranged in a randomized way in the net-house.

Plants were watered twice daily, in the morning and in the afternoon because of warm weather. Tap water was used for this purpose. Intercultural operations were carried out whenever necessary. Weeds were removed manually. Positions of the pots were changed every alternate day to allow equal exposure of each of the pots to sunlight. Adequate plant protection measures were taken during the growing period. Different parameters like growth, appearance of any symptoms etc. were noted during the whole growing period.

The nutritional (N, P and K) requirement of the pot soil was calculated on the basis of "Soil Test Value Interpretation" as recommended by the Bangladesh Agriculture Research Council [10]. The requisite amounts of N, P and K were supplied from urea, TSP (Triple super phosphate) and MOP (Muriate of potash), respectively. The whole of TSP, MOP and one-third of the urea were applied at the time of soil preparation. The second one-third of urea was applied after 35 days of sowing the seeds and the final one-third was applied during the panicle initiation stage of the rice plants. For kalmi plants no fertilizer was applied to the soil.

At harvest, the plants and soils from every pot were collected individually and processed and prepared for chemical analysis.

Kalmi: Plants were allowed to grow for 45 days after emergence of the seedlings when the plants were sampled. The plants were sampled manually by uprooting them carefully from the pots. The roots of the sampled plants were washed first with tap water and then again with deionized distilled water three times to remove ions from the root free space as well as to dislodge any adhering particles on the root surface. Aerial parts of the plants were also washed. The wet samples were dried using paper towels. The plant samples were separated into two parts—root and edible parts (shoot and leaf). The samples were first air-dried and then oven-dried at 70 ± 5 ℃ for 48 hours and the dry weight of the plant samples were taken.

Rice: The plants were sampled 93 days after sowing of seedlings. The plants were sampled manually. The

upper portions of the plants were separated using a scissor and afterwards the roots were taken out from the soil. The grains were also collected at that time. Thus, the plant samples were separated into three parts—root, straw and grains. The plant samples were washed and processed in the same way as in the case of the kalmi plants. The dry weights and fresh weights as well as 1000-grain weights of the samples were recorded.

The dried samples of both the plants were then ground to pass a 0.2 mm sieve. The ground plant samples were mixed thoroughly to make it composite and stored in plastic containers for further chemical analyses. At the end of plant culture, the soil samples from each of the pots were collected and processed as before.

2.6 Field Study with Plants

For this experiment, two vegetable crops—Kalmi (*Ipomoea aquatica* L.) and Red Amaranthus (*Amaranthus gangeticus* L.) were grown in the field on plots of 1 m^2 sizes under upland condition with a mixture (1:1 ratio) of the As-filter sludge (GR & AC) @ 1 $T \cdot ha^{-1}$ soil to observe the effects of the application of the sludge under field condition. There were three replications for each treatment. The plots were selected for the crops in a completely randomized way. In the text the control and treated plots with kalmi and amaranthus are designated as ck, ca and tk, ta, respectively. Seeds of *Ipomoea aquatica* L. and *Amaranthus gangeticus* L. were collected from the local market. Seeds were sown in the plots 30 days after incorporation of the As-sludge into the soils. Before sowing of the seeds the sludge-mixed plot soils were collected for analysis.

2.7 Laboratory Analysis

Various physical and chemical properties of the soil samples and the sludge materials were analyzed in the laboratory, following the procedures described in Imamul Huq and Alam [11]. Arsenic in soil (pre- and post-experiment) and sludge was extracted with 1 M HCl and boiling aqua-regia, while aluminum and iron in the soil (pre- and post-experiment) and sludge was extracted only with boiling aqua-regia [12]. Arsenic, aluminum and iron in the plants were extracted with concentrated nitric acid (HNO_3) [12]. The background concentrations of N, P, K, S, As, Fe and Al were determined following the procedures described in Imamul Huq and Alam [11] and Imamul Huq et al. [7]. The Quality Control/Quality Assurance (QC/QA) of the analyses were as described in Imamul Huq et al. [7]. Statistical analyses (ANOVA and t-test) were carried out using the MINITAB 13.0 package.

3. Results and Discussion

The selected soil and the sludge were analyzed to assess the nutrient status of the soil as well as other elements present in them (Table 1).

3.1 As, Fe and Al in the Soils Treated with the Sludge

The concentration of As, as extracted by boiling aqua-regia, was found to be increased in the soils treated with the sludge (GR & AC) under both upland and lowland conditions in course of time. It indicates a gradual release of a fraction of the As present in the sludge. For the GR sludge, the concentration of As was found to be the maximum at 180 days of incubation at 0.5 $T \cdot ha^{-1}$ (Table 2) under both soil conditions. Arsenic in the soils with AC sludge was found to be higher for 1 $T \cdot ha^{-1}$ under both the soil conditions (Table 2). There has been a similar pattern for As concentration in the soils for the two sources of sludge at both the application rates (Table 2). The soil conditions have been found to have significant effect ($p \leq 0.01$) on the concentration of As in the sludge treated soils, whereas the effect of time on the concentration of As was found insignificant. Irrespective of the soil types, incubation periods and rates of sludge applied to the soils, the two sources of sludge showed no significant difference in the increased concentration of As in the soils as observed from t-test analysis. It indicated that whatever

Table 1 The physical, chemical and physico-chemical properties of the soils and the As-filter sludge.

Parameter	Soil		Arsenic Filter Sludge		
	Dhamrai Soil	Pagla Soil	Granular ferric hydroxide (GR)	Activated alumina (AC)	Mixed Sludge
% Sand	11.6	1.56			
% Silt	41.8	47.63			
% Clay	46.6	50.81			
Textural Class	Silty Clay	Silty Clay			
Available P ($mg \cdot kg^{-1}$)	4.67	4.41			
Available K ($mg \cdot kg^{-1}$)	33.43	31.16			
Total N (%)	0.17	0.27			
Total P (%)	0.07	0.09			
Total K (%)	0.18	0.13			
Total S (%)	0.03	0.12			
Organic C (%)	0.34	1.17			
Organic Matter (%)	0.59	2.02			
pH	7.26	5.02	6.80	7.38	7.46
Total As ($mg\ kg^{-1}$)	2.32	1.55	148.70	160.25	102.60
Total Fe (%)	3.26	3.35	31.20	19.64	30.44
Total Al (%)	1.27	1.89	10.94	28.98	20.36

Table 2 Boiling aqua-regia extractable As ($mg \cdot kg^{-1}$) in the control soil and in the soils treated with GR & AC sludge @ 0.5 $T \cdot ha^{-1}$ and 1 $T \cdot ha^{-1}$ at different periods of incubation under upland and lowland conditions.

Treatment	Soil Condition	Period of Incubation				
		15 Days	30 Days	60 Days	90 Days	180 Days
Control	Upland	0.54	0.75	0.37	0.77	1.08
	Lowland	0.17	0.28	0.16	0.20	0.30
GR 0.5 $T \cdot ha^{-1}$	Upland	0.56	0.88	0.44	0.84	1.34
	Lowland	0.18	0.31	0.17	0.25	0.40
GR 1 $T \cdot ha^{-1}$	Upland	0.55	0.98	0.44	0.86	1.12
	Lowland	0.20	0.30	0.18	0.30	0.38
AC 0.5 $T \cdot ha^{-1}$	Upland	0.55	0.95	0.40	0.87	1.12
	Lowland	0.19	0.40	0.17	0.23	0.34
AC 1 $T \cdot ha^{-1}$	Upland	0.62	0.98	0.42	0.87	1.31
	Lowland	0.22	0.42	0.20	0.26	0.32

be the source of As-sludge, the addition to soil is similar. The As contents in the two sludge were not widely different.

The soils under the incubation study at 15, 30, 60, 90 and 180 days when extracted with 1M HCl solution (soil to extractant ratio was 1:10) to assess the labile fraction of As in the soils [9, 13, 14], showed the maximum release after 30 days (Table 3) under both the soil conditions. The soil conditions have been found to have significant effects ($p < 0.01$ to $p \leq 0.05$) on the release, and thus the availability, of As in the sludge treated soils. The incubation time showed significant effect ($p \leq 0.05$) on the release of As in the soils for the GR sludge @ 0.5 $T \cdot ha^{-1}$ only, whereas for the other cases the effects were found insignificant.

The actual release of As in the soils from the As-filter sludge, at 15, 30, 60, 90 and 180 days of incubation has been calculated by deducting the amount of As in the control soil from that of the treated soil as obtained with 1M HCl extraction for both soil conditions. In most cases, the release of As was found to be higher @ 1 $T \cdot ha^{-1}$ for each of the sludge under both the soil conditions (Table 4) and the release was relatively higher under upland condition than that under

Table 3 1M HCl extractable As (mg·kg^{-1}) in the control soil and in the soils treated with GR & AC sludge @ 0.5 T·ha^{-1}and 1 T·ha^{-1} at different periods of incubation under upland and lowland conditions.

Treatment	Soil Condition	Period of Incubation				
		15 Days	30 Days	60 Days	90 Days	180 Days
Control	Upland	0.45	0.61	0.27	0.21	0.42
	Lowland	0.17	0.21	0.08	0.05	0.16
GR 0.5 T·ha^{-1}	Upland	0.43	0.77	0.32	0.30	0.61
	Lowland	0.16	0.30	0.11	0.03	0.18
GR 1 T·ha^{-1}	Upland	0.34	0.80	0.27	0.19	0.51
	Lowland	0.11	0.25	0.09	0.09	0.15
AC 0.5 T·ha^{-1}	Upland	0.52	1.12	0.29	0.15	0.63
	Lowland	0.18	0.35	0.08	0.06	0.16
AC 1 T·ha^{-1}	Upland	0.58	0.94	0.12	0.08	0.65
	Lowland	0.13	0.35	0.11	0.04	0.18

Table 4 Actual release of As (mg·kg^{-1}) from the sludge under upland (ULS) and lowland (LLS) soil conditions.

Treatment	Period of Incubation									
	15 Days		30 Days		60 Days		90 Days		180 Days	
	ULS	LLS	ULS	LLS	ULS	LLS	ULS	LLS	ULS	LLS
GR 0.5 T·ha^{-1}	NR	NR	0.16	0.09	0.05	0.03	0.09	NR	0.19	0.02
GR 1 T·ha^{-1}	NR	NR	0.19	0.04	0	0.01	NR	0.04	0.09	NR
AC 0.5 T·ha^{-1}	0.07	0.01	0.51	0.14	0.02	0	NR	0.01	0.21	0
AC 1 T·ha^{-1}	0.13	NR	0.33	0.14	NR	0.03	NR	NR	0.23	0.02

ULS = Upland soil; LLS = Lowland soil; NR = Not released.

lowland condition. The low release under lowland condition is important in respect to the low-land rice culture prevailing in the Bangladesh or elsewhere.

The incubation study also revealed that Fe was released into the soils from both the sludge (Table 5). The concentration of Fe in the soils was found to be higher for GR sludge than the AC sludge due to the composition of the GR sludge and the Fe in the soils from the AC sludge was perhaps due to the Fe (from the groundwater) adsorbed on the sludge. Compared to the control soil, the concentration of Fe in the treated soils was found to be increased up to 22% under upland soil condition and up to 33% under lowland soil condition. The concentration of Fe in the soils varied significantly ($p < 0.01$ for GR, $p < 0.05$ for AC) under upland and lowland conditions. Like As, the duration of incubation did not show any significant effect on the soil Fe concentrations. The t-test indicated that irrespective of the soil types, incubation periods and rates of sludge application, the two sources of sludge had no significant difference in the addition of Fe to the soils.

The concentration of Al in the control and treated soils was found to be almost similar at each corresponding day of incubation under both the soil conditions (Table 6). The addition of Al in the soils was observed to be increased with increasing incubation period. The concentration of Al was found to be increased up to 24% in the treated soils compared to the control soil under both the soil conditions. However, Al concentration was found higher in upland condition than in lowland condition. The soil conditions and the periods of time showed no significant effects on the concentration of Al in the soils. Like that for Fe, the t-test showed that irrespective of the soil types, incubation periods and rates of sludge applied to the soils, the two sources of sludge had no significant difference in the addition of Al to the soils.

Table 5 Concentration of Fe (%) in the control soil and in the soils amended by GR & AC sludge @ 0.5 T·ha^{-1} and 1 T·ha^{-1} at different periods of incubation under upland and lowland condition.

Treatment	Soil Condition	Period of Incubation				
		15 Days	30 Days	60 Days	90 Days	180 Days
Control	Upland	0.79	0.77	0.93	1.03	0.83
	Lowland	0.24	0.20	0.30	0.28	0.18
GR 0.5 T·ha^{-1}	Upland	0.87	0.94	1.06	1.09	0.78
	Lowland	0.24	0.14	0.34	0.34	0.19
GR 1 T·ha^{-1}	Upland	0.76	0.82	1.04	1.09	0.83
	Lowland	0.31	0.26	0.33	0.31	0.21
AC 0.5 T·ha^{-1}	Upland	0.81	0.87	0.70	1.24	0.24
	Lowland	0.21	0.24	0.23	0.35	0.24
AC 1 T·ha^{-1}	Upland	0.82	0.86	0.78	1.09	0.25
	Lowland	0.24	0.25	0.24	0.33	0.24

Table 6 Concentration of Al (%) in the control soil and in the soils amended by GR & AC sludge @ 0.5 T·ha^{-1} and 1 T·ha^{-1} at different periods of incubation under upland and lowland condition.

Treatment	Soil Condition	Period of Incubation				
		15 Days	30 Days	60 Days	90 Days	180 Days
Control	Upland	0.0376	0.0344	0.2819	0.4704	0.5390
	Lowland	0.0083	0.0122	0.1044	0.1490	0.1567
GR 0.5 T·ha^{-1}	Upland	0.0287	0.0344	0.2427	0.5857	0.5876
	Lowland	0.0103	0.0111	0.0940	0.1537	0.0970
GR 1 T·ha^{-1}	Upland	0.0263	0.0328	0.3050	0.4751	0.5827
	Lowland	0.0069	0.0108	0.0969	0.1525	0.1677
AC 0.5 T·ha^{-1}	Upland	0.0312	0.0299	0.3327	0.5395	0.5098
	Lowland	0.0073	0.0104	0.1044	0.1725	0.1755
AC 1 T·ha^{-1}	Upland	0.0326	0.0410	0.3096	0.5224	0.5584
	Lowland	0.0072	0.0120	0.0984	0.1490	0.1598

3.2 Growth and Yield Characteristics of Ipomoea Aquatica and Rice Plants in the Microcosm Study

Fresh and dry matter production as well as the growth of *Ipomoea aquatica* were observed to be higher for the plants grown on the soils spiked with GR and AC sludge than the plants grown on the control soil (Table 7). Dry matter production of *Ipomoea aquatica* was found to be higher for the plants grown on the soils spiked with the GR sludge than the plants grown on the soils spiked with the AC sludge. This could be due to the nutrients, particularly iron and other micronutrients, present in the sludge. On the other hand, the growth of rice plants in the control soil was observed to be superior to the soils spiked with the sludge. However, the 1000 grain wt (g) was higher for the sludge-mixed soils than the control soil (Table 7). The increased weight could be due to accumulation of increased amount of, among others, As, Fe and Al.

3.3 As, Fe and Al Contents in the Edible Parts of Ipomoea Aquatica and Rice

The edible parts of *Ipomoea aquatica* and rice accumulated the maximum amount of As at application rate of 1 T·ha^{-1} for both GR and AC sludge (Table 8). The contents of As in both the plants exceeded the permissible limits (1.5 mg·kg^{-1} [11] for *Ipomoea aquatica* and 1 mg·kg^{-1} [15] for rice grain) for the plant As content. The accumulation, however, increased with increasing rates of sludge application.

The mean Fe content in the edible parts of the plants varied from 52.85 to 223.22 mg·kg^{-1} and from 28.11 to 56.95 mg·kg^{-1} for *Ipomoea aquatica* and rice, respectively (Table 8). The edible parts of *Ipomoea*

Table 7 Fresh and dry weights of Ipomoea aquatica L. and Oryza sativa L.

Treatment	Ipomoea aquatica L.		Oryza sativa L.				
	Total fresh weight of Ipomoea (g/pot)	Total dry weight of Ipomoea (g/pot)	Dry weight of roots (g/pot)	Dry weight of straw (g/pot)	Dry weight of husk+unhusked grains (g/pot)	Total dry weight of rice plant (g/pot)	Weight of unhusked grains (1000 grain wt, g)
Control	10.45	1.90	4.76	31.19	26.52	62.47	18.03
GR 0.5 T·ha^{-1}	13.80	2.52	3.80	27.27	25.68	56.75	18.93
GR 1 T·ha^{-1}	14.95	2.67	4.24	29.62	22.98	56.84	18.20
AC 0.5 T·ha^{-1}	12.39	2.14	3.83	25.77	19.37	48.97	18.67
AC 1 T·ha^{-1}	14.33	2.44	3.75	28.01	22.16	53.92	18.67

Table 8 As, Fe and Al concentrations (mg·kg^{-1}) in the edible parts of *Ipomoea aquatica* and rice.

Treatment	As		Fe		Al	
	Ipomoea Shoot + Leaf	Rice Grain	Ipomoea Shoot + Leaf	Rice Grain	Ipomoea Shoot + Leaf	Rice Grain
Control	0.89	0.71	223.22	0.026	136.31	103.40
AC 0.5 T·ha^{-1}	0.61	0.80	102.88	0.024	141.02	117.92
AC 1 T·ha^{-1}	0.69	1.02	52.85	0.020	153.58	107.19
GR 0.5 T·ha^{-1}	0.83	0.78	163.88	0.013	131.60	105.30
GR 1 T·ha^{-1}	2.18	0.70	212.85	0.020	136.31	128.03

aquatica and rice were found to accumulate the maximum amount Fe under the control (223.22 mg·kg^{-1}) and the AC 0.5 T·ha^{-1} (56.95 mg·kg^{-1}), respectively.

The mean Al content in the edible parts of the plants varied from 136.31 to 153.58 mg·kg^{-1} and from 103.40 to 128.03 mg·kg^{-1} for *Ipomoea aquatica* and rice, respectively. The edible parts of *Ipomoea aquatica* and rice were found to accumulate the maximum amount Al under AC 1 T·ha^{-1} (153.58 mg·kg^{-1}) and GR 1 T·ha^{-1} (128.03 mg·kg^{-1}), respectively. However, the possibility of adverse effects due to excessive Fe and Al to plants was found to be lower under lowland condition than under upland soil condition.

3.4 Uptake of As, Fe and Al by Ipomoea and Rice

The uptake was calculated by multiplying the concentrations of As, Fe and Al in the dry matter and the total dry matter produced and the results are expressed as mg/pot.

Both the crops (*Ipomoea aquatica* and rice) showed an increased uptake of As when grown in the soils spiked with the two sources of sludge. The maximum uptake of As by roots and the edible parts of *Ipomoea aquatica* was observed for the GR sludge @ 1 T·ha^{-1} (Fig. 1), which was 62% and 38% of total plant uptake,

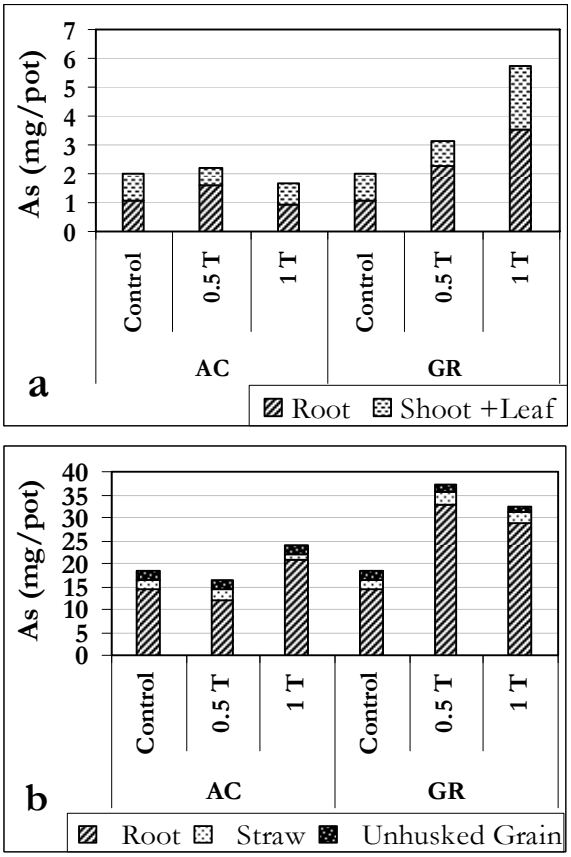

Fig. 1 Uptake of As by *Ipomoea aquatica* (a) and rice plant (b).

respectively for the two plant parts. Having a potential to accumulate high level of As, roots were noticed to take up higher amounts of As than the edible parts of *Ipomoea aquatica*. The roots of rice plants were also found to take up the highest amount of As (72.27 to 87.66% of total uptake) followed by stem + leaves (6 to 14%) and rice grains (4 to 14%). Similar observations have also been made by others [16-18]. The study also corroborated to earlier observation our [19] that the As that accumulates in the plants follows the order: root > straw > husk > grain. This uptake pattern, as it appeared, was irrespective of the sources of arsenic in the growth medium.

The study showed that Fe uptake was increased in the plant parts with the increase of As concentration in most of the cases and the maximum uptake was observed for the soils spiked with the GR sludge showing a synergy between As and Fe (Fig. 2).

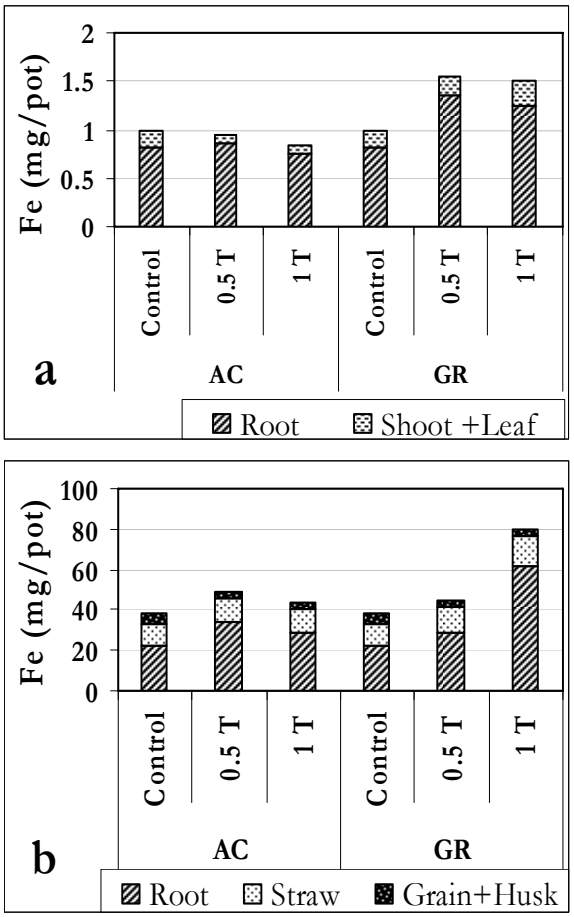

Fig. 2 Uptake of Fe by *Ipomoea aquatica* (a) and rice plant (b).

Fe uptake in the rice plants was found to be higher in roots followed by straw and unhusked grains (Fig. 2). The maximum uptake of Fe in the edible parts of *Ipomoea aquatica* was observed for GR 1 T·ha^{-1} (17.88% of total uptake) indicating 266% higher uptake of Fe than for AC 1 T·ha^{-1}. In the case of rice, the maximum uptake of Fe in roots was observed for GR 1 T·ha^{-1} (77.67% of total uptake) indicating 115% higher uptake of Fe compared to that for AC 1 T·ha^{-1}. Similar trends were found for straw also. The maximum uptake of Fe in unhusked grains was observed for GR 0.5 T·ha^{-1} (8.23% of total plant) indicating 18% higher uptake than for AC 0.5 T·ha^{-1}. Comparatively higher Fe uptake in the roots indicates the release as well as the availability of Fe in the soils.

The uptake of Al in roots was found to be higher under upland than under lowland soil condition (Fig. 3). Greater Al uptake in the control plants compared to the treated plants could be due to the fact that higher

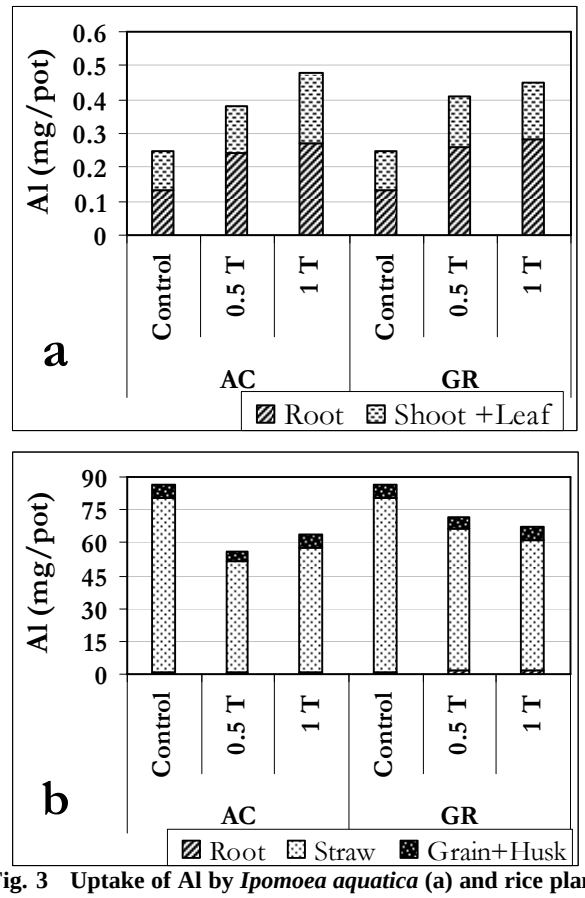

Fig. 3 Uptake of Al by *Ipomoea aquatica* (a) and rice plant (b).

accumulation of Fe has antagonized the Al accumulation in rice plants.

3.5 Accumulation of As, Fe and Al in Ipomoea Aquatica and Amaranthus Gangeticus under Field Condition

Concentration of As in the soils of all the treated plots was found to be increased after application of the mixture of the sludge compared to the background As concentration of the soil (Fig. 4). High amounts of As, Fe and Al were found to accumulate in both the crops (Figs. 5-7). Crops grown in the control plots

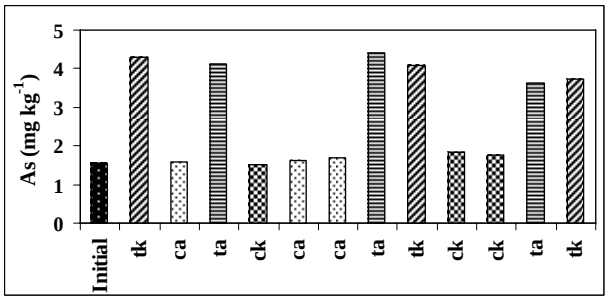

Fig. 4 As concentration in the soils of the treated and untreated plots.

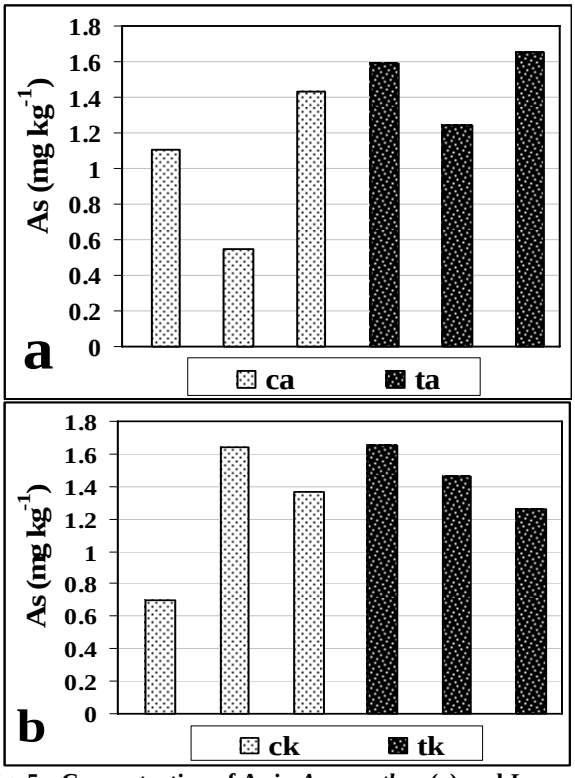

Fig. 5 Concentration of As in *Amaranthus* (a) and *Ipomoea* (b).

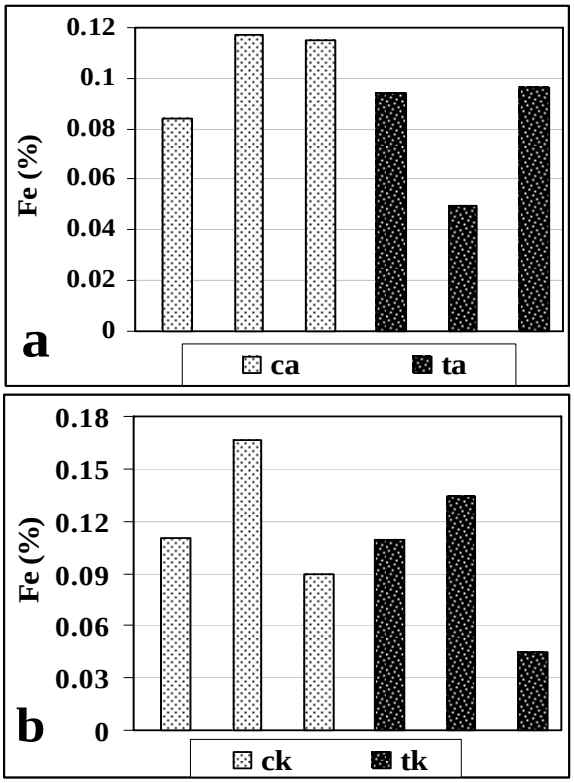

Fig. 6 Concentration of Fe in *Amaranthus* (a) and *Ipomoea* (b).

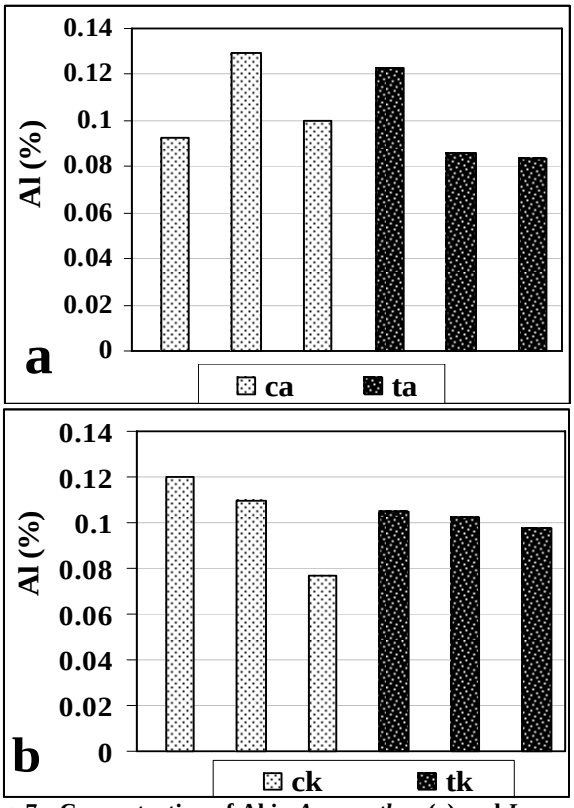

Fig. 7 Concentration of Al in *Amaranthus* (a) and *Ipomoea* (b).

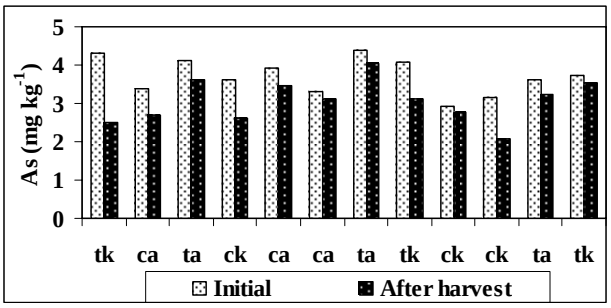

Fig. 8 Initial and after harvest As contents in the soils.

accumulated, in some cases, higher amount of the elements compared to the crops under the treated plots, the reason was perhaps due to the rhizosphere effect. The uptake of elements by plants sometimes increases as conditioned by the root exudates and composition of the root system [9, 20]. The concentrations of As, Fe and Al in the soils and their contents in the plants showed positive but insignificant correlation. However, As content in the plants, was found to be better correlated than the other two elements. After harvest of the crops, total As concentration in the soils was found to be decreased by 5.3% to 41.4% (Fig. 8). The decreases in the contents of the elements in the soils after plant culture indicate accumulation of the elements into the plants.

4. Conclusions

The results of the present study suggest that the concentration of As, Fe and Al in the soils and their contents in the plants is an indication of the release of the matrix elements from the arsenic removal water filter sludge. The materials that are being used for removing arsenic from drinking water are, therefore, not totally safe to be indiscriminately disposed of in the environment, particularly to the agricultural soils.

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