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Experiments on Alleviating Arsenic Accumulation in Rice Through Irrigation Management

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1. Introduction

Arsenic (As) in groundwater is a major health concern in Bangladesh and the risks of As ingestion using shallow tubewells (STWs) for drinking-water was identified in the deltaic region, particularly in the Gangetic alluvium of Bengal including Bangladesh and West Bengal of India during the early nineties. It has been termed the world's biggest natural calamity in known human history. Ground water is the primary source of drinking water for approximately 90% of the total 147 million people (WHO 2001). More than 35 million people of Bangladesh are exposed to an As contamination in drinking water exceeding the national standard of 50 $\mu\text{g L}^{-1}$ while an estimated 57 million people are at the risk of exposure to As contamination exceeding the WHO guideline of 10 $\mu\text{g L}^{-1}$ (BGS/DPHE 2001). Extensive contamination in Bangladesh was confirmed in 1995, when additional survey showed contamination of mostly shallow tube-wells (STWs) across much of southern and central Bangladesh (Imamul Huq et al. 2006a). However, a few instances of deep tube-wells (DTWs) contamination are also in report. Approximately 27% of STWs and 1% of DTWs in 270 upazillas (sub-districts) of the country are contaminated with As at Bangladesh standard whereas about 46% of STWs are contaminated at WHO standard. So far 38,000 persons have been diagnosed with an additional of 30 million people at risk of As exposure (APSU 2005). Concentrations of arsenic exceeding 1,000 $\mu\text{g L}^{-1}$ in shallow tube-wells were reported from 17 districts in Bangladesh (Ahmed et al. 2006). Efforts are being directed towards ensuring safe drinking water either through mitigation technique or through finding alternative sources. Even if an As-safe drinking water supply could be ensured, the same groundwater will continue to be used for irrigation purpose, leaving a risk of soil accumulation of this toxic element and eventual exposure to the food-chain through plant uptake and animal consumption (Imamul Huq 2008). Given the studies on As uptake by crops (Imamul Huq et al. 2001; Abedin et al. 2002; Ali et al. 2003; Islam et al. 2005) there is much potential for the transfer of As present in groundwater to crops. The use of groundwater for irrigation has increased abruptly over the last couple of decades. About 86% of the total groundwater withdrawn is utilized in the agricultural sector

(Imamul Huq et al. 2005). There has been a gradual increase in the use of ground water for irrigation over the last two decades. The increase from 1999–2000 to 2006–2007 has been more than 22 per cent. In the *Boro* (dry) season of 2004, 75% of the irrigation water was from ground water (BADC 2005), which was 41% of the total in 1982–83. About 40% of total arable land of Bangladesh is now under irrigation facilities and more than 60% of this irrigation need are met from groundwater extracted by deep tube-well (DTW), shallow tube-well (STW) or hand tube-well. Of the total area of 4 million ha under irrigation, 2.4 million ha is covered via STWs and 0.6 million ha is covered via 23,000 DTWs. In the dry season, 3.5 million ha is used for *Boro* rice (FAO 2006).

It has been estimated that water extraction from the shallow aquifer for irrigation adds 1 million kg of As per year to the arable soil in Bangladesh, mainly in the paddy fields. The background level of As in soils is 4 to 8 mg kg⁻¹. In areas irrigated with As contaminated water, the soil level can reach up to 58 mg kg⁻¹ (Imamul Huq and Naidu 2003).

It is of concern that a number of studies from Bangladesh have reported increased As concentrations in soils and crops because of irrigation with As-contaminated groundwater. The increase in soil concentrations may finally result in a reduction of soil quality and crop yields. Recent data on total and inorganic As in rice and vegetables from Bangladesh (Williams et al. 2006; Williams et al. 2005) indicate that rice contributes significantly to the daily intake. A positive correlation between As in groundwater resources, soil and rice has been reported, indicating that food chain contamination takes place because of prolonged irrigation with contaminated water (Correll et al. 2006). The risks of land degradation are likely to increase with the accumulation of As in the soil.

Management options should, therefore, focus on preventing and minimizing As input to soils. Farmers often use more irrigation water than needed. Optimizing water input would be a sound option to reduce As input while saving water. Furthermore, aerobic growth conditions in paddy fields may reduce bioavailability and uptake of As in rice. Other possible options include breeding crops tolerant to As and/or low accumulation of As in grains, and shifting from rice in the dry season to crops that demand less water, where feasible.

This paper aims at devising remedial measures through water management to minimize As toxicity in rice by making more oxidized rice rhizosphere (oxidizing arsenite) as well as to reduce the entry of arsenic into food chain.

2. Materials and methods

Sampling site

Soil where groundwater contamination by Arsenic has not been reported was sought. As such, a field from Block no-9, research station of Bangladesh Jute Research Institution (BJRI), Jagir, Manikganj was selected for sampling. The whole sampling site was divided into two sampling spots. The soil thus selected belongs to the Sonatola soil series under the AEZ-8 (Young Brahmaputra and Jamuna Floodplains) and land type was Medium Highland. The geolocation of the sampling spot is 23° 53.034' North and 90° 02.265' East.

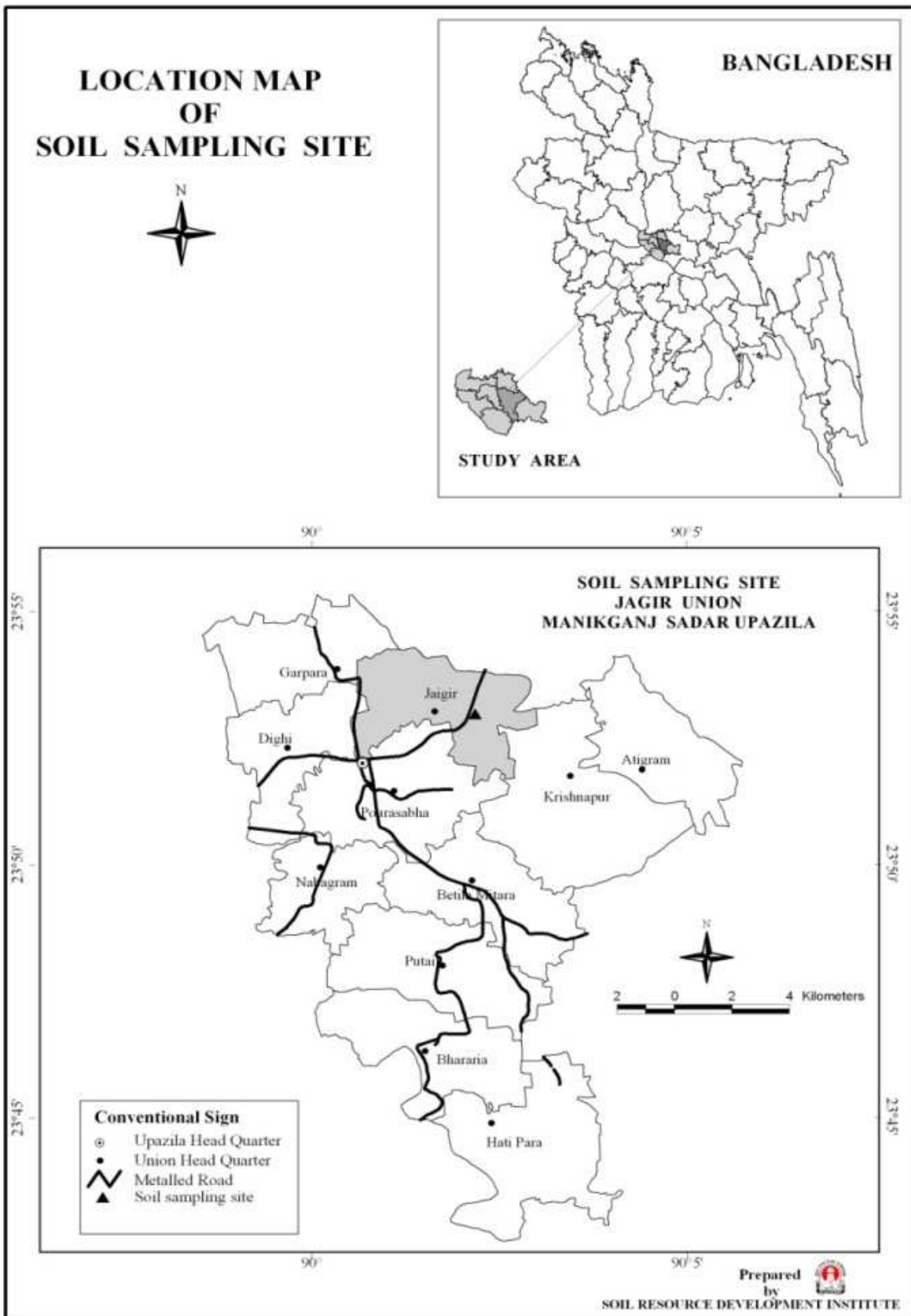


Fig. 1. Location map showing the geographic position of the sampling site from where soils were collected for the experiment

Collection and preparation of soil samples

The bulk of soil samples representing 0-15 cm depth from the surface were collected by composite soil sampling method as suggested by soil survey staff of the United States Department of Agriculture (USDA 1951). For laboratory analyses, the samples were collected from top to bottom with the help of an auger and mixed thoroughly. Samples were collected from the two sampling sites and put in polythene bags, tagged with rubber band and labeled. For the bulk portion, samples were collected with spade into jute made large bags and carried to the net house. The collected soil samples were dried in air for 3 days (40° C) by spreading in a thin layer on a clean piece of paper. Visible roots and debris were removed from the soil sample and discarded. For hastening the drying process, the soil samples were exposed to sunlight. After air drying, a portion of the larger and massive aggregates were broken by gently crushing them with a wooden hammer. Ground samples were screened to pass through a 2 mm stainless steel sieve. The sieved samples were then mixed thoroughly for making the composite sample. Soil samples were preserved in plastic containers and labeled properly showing the soil number, sample number, date of collection. These soil samples were used for various physical analyses. Another portion of soil samples (2 mm sieved) was further ground and screened to pass through a 0.5 mm sieve. The sieved sample were mixed thoroughly to make composite samples and persevered in the same way as above. These soils were used for chemical and physicochemical analyses. The bulk soil sample collected for pot experiments were air dried, cleared off the debris and crushed to make the bigger clods smaller. The crushed soil samples were screened through a 5 mm sieve.

Experimental set-up

A pot experiment was carried out in the net house of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh. In the experiment, three water regimes and two sources of As salts were chosen. The water regimes maintained were 100%, 75% and 50% of field capacity. The FC value has been predetermined in the fields and the value was used in the pot experiments. For maintaining the required water regime, the pots were measured every alternate days and the required amount of water was added to the pots. The two sources of arsenic used were As^{III} and As^V. The salts used were sodium meta arsenite (NaAsO₂) as a source of As^{III} and hydrated sodium meta arsenate (Na₂HAsO₄·7H₂O) as a source of As^V. The application rates were 0 (control) and 30 mg As/kg soil from both the sources. All experiments were done in triplicates. The pots were arranged in the net house in three blocks with randomization in each block. The three blocks belonged to the three moisture regimes. Two varieties of rice seeds *viz.*, BRRI dhan-28 and BRRI dhan-29 were collected from the Bangladesh Rice Research Institute (BRRI). The background level of As in soil was 1.62 mg/kg which was taken as control. There were a total of 36 pots for each variety 3 (2×2×3) i.e. 3 replication, 2 sources of arsenic salt, 2 doses of arsenic and 3 moisture regimes. Thus, a total of 72 pots were used for the experiment. Earthen pots of 5 L volume were taken having no holes on the bottom and marked in accordance with water regime, arsenic dose, sources of salt and variety of rice plants. Each pot was filled with 4.5 kg soil. Fertilizer requirement for the rice plants were calculated on the basis of soil test values as described in Fertilizer Recommendation Guide 2005 (BARC 2005). The whole amount of required P (TSP) and K (MP) and 1/3 of the N (Urea) doses as estimated for the soil of each pot were mixed with the

soil thoroughly before the transplantation of seedlings into the pots. Arsenic was applied to the soil as solution before transplantation of the seedlings.

Method of rice cultivation

Seeds of BRRI dhan-28 and BRRI dhan-29 were at first taken into two separate pots, dipped in water and kept overnight. Then seeds of the two varieties were spread on two separate seedbeds made of the same soil used for the pot experiment. It took 2 to 3 days for germination while the seedbeds were kept under dark by covering with wet jute bag. After the germination of the seeds, the seedbeds were taken into the net house and kept under natural condition. After one month, the seedlings were transplanted into the pots. The pots were thinned to 5(five) plants after seedling were established. Second 1/3 dose of N (Urea) was applied 35 days after transplantation and the final 1/3 was applied during panicle initiation stage of rice plants. Weeds were removed manually. Agronomic characters like plant height, tiller numbers, panicle numbers, leaf colors etc. were observed during the growth period.

Collection of plant samples

Plants of BRRI Dhan-28 and BRRI Dhan-29 were harvested at the age of 130 and 140 days of the transplants respectively. The plants were harvested by uprooting. The unfilled grain samples of the two varieties were collected before two days of harvesting. The harvested roots were washed with deionized water several times to remove ion from the ion free space as well as to dislodge any adhering particles on the root surface. The upper parts of the plants were also washed. The height of the plant samples were measured from the top leaf blade to bottom of the plant from where root starts. Then the plant samples are wrapped with tissue paper to remove the extra water and dried in air for half an hour. Then fresh weight of whole plants was taken. The plant samples were separated replaced into two parts, root and straw. The plant samples were then air dried before putting to oven drying at $75\pm 5^{\circ}\text{C}$ for 48 hours and the dry weight of plant samples were noted. The dried plant samples were then ground and were sifted through a 0.2 mm sieve. The ground plant samples of two varieties were preserved in small plastic bottles separately. After harvesting, soil samples in each pot were collected from the rhizosphere. The samples were air dried and homogenized and was screened to pass through a 0.5 mm sieve for chemical analysis. The soil samples were preserved in plastic bags and labeled.

Laboratory analysis

Various physical, chemical and physiochemical properties of the soils were determined following procedures described in Imamul Huq and Alam (2005). Both plants and soil were analyzed for total arsenic by hydride generation atomic absorption spectrometry (HG-AAS) with the help of 5% potassium iodide (KI) and 10% urea in acid medium. The hydride was generated using 6N HCl and 1.2% NaBH_4 and 1% NaOH in deionized water. The arsenic from the plant samples was extracted with HNO_3 , and from the soil with aqua regia solution (Portman and Riley 1964). 0.5 g of plant sample was weighed separately into 100 ml Pyrex glass beaker. 15 ml of nitric acid (HNO_3) was added and the beaker left for half an hour. Then the sample beakers were placed on the hotplate. At first the beakers were heated at low temperature ($50\text{--}75^{\circ}\text{C}$) before increasing the temperature to 140°C for the final dissolution of organic material. After dissolution was complete; samples were

diluted to 25 ml into volumetric flask, shaken and filtered into plastic bottles. This extract was also used for the determination of total As, Fe, P and K content of plant samples. Certified reference materials were used throughout the digestion and analyzed as part of the quality assurance/quality control protocol. Reagent blanks and internal standards were used where appropriate, to ensure accuracy and precision in the analysis of arsenic. Each batch of ten samples was accompanied by reference standard samples to ensure strict QA/QC procedures. The amount of As uptake (mg/100 plants) by different plant parts and the plant as a whole were calculated. The uptake was calculated using the As concentration in the dry matter and the dry weight of plant parts, and the result was expressed as mg/100 plants.

Uptake (As) = Concentration (As) in dry matter × dry weight of plant part for 100 plants

The Transfer Co-efficient in root, straw and husk of plants was determined using the following formula:

$$T.F = \frac{(mg \text{ of the elements} / kg \text{ dry weight of plants})}{(mg \text{ of the elements} / kg \text{ dry weight of soil})}$$

3. Results and discussion

The collected soil sample was analyzed in the laboratory before setup of the experiment to see the nutrient status of the soil. Background level of As (arsenic) was also determined in the soil sample. Some important physical, physicochemical and chemical properties of the experimental soil sample are listed in the table 1.

Soil properties	Value
Particle size analysis	
Sand	17.456 %
Silt	62.246 %
Clay	20.298 %
Textural class	Silt loam
pH	7.2
Organic carbon	0.65 %
Organic matter	1.11 %
Field capacity	35.89 %
Moisture content	8.25 %
Total nitrogen	0.0567 %
Total phosphorous	768.50 mg/kg
Available phosphorous	30 mg/kg
Total potassium	2121.93 mg/kg
Available potassium	63.33 mg/kg
Arsenic	1.62 mg/kg
Iron	21289.06 mg/kg

Table 1. Some physical, physicochemical and chemical properties of the soil sample used for the experiment

Agronomic parameters

Symptoms of any abnormality in the rice plants were noted during the experiment in order to assess the phytotoxicity of As. Both varieties showed some symptoms of toxic effects at As treated soil (30 mg/kg As concentrations) and the symptoms became more pronounced with time of exposure of the plants to arsenic. The symptoms were: reduced plant growth; yellowing and wilting of leaves. Brown necrotic spots were also observed on old leaves of the plants of both the varieties growing on As treated soil. Red brown necrotic spots on old leaves, tips and margins of rice, due to arsenic toxicity, have also been reported (Aller et al. 1990; Marin et al. 1992). Plant heights were measured from time to time and finally at maturity. At the initial stage of growth, plant height did not differ from the control plants but at maturity, plant heights decreased in arsenic treated pots with decreasing moisture level. Plants of both the rice varieties grown on 30 mg As/kg-treated soil under 50% moisture regimes showed the shortest plant height. The decreasing trend of plant height with decreasing moisture regime was not statistically significant except for BRRI dhan-29 growing under arsenate (As^{V}) treated soil. It was clear that arsenic did not readily cause plant height reduction, but the progressive accumulation of arsenic in plants with time of exposure might have caused the plant height reduction. A reduction in plant height with increasing As concentration has also been reported in rice plants (Yamare 1989; Barrachina et al. 1995; Islam 1999). Fresh as well as dry matter production of the two varieties did not show any appreciable difference for arsenite or arsenate treatments under the three moisture regimes. Maximum weights were noted for the control plants of 100% moisture level, whereas the minimum values were for plants growing at 75% moisture level. At 50% moisture regime higher value in both fresh and dry weights was found than that of 75% moisture regime in both arsenite and arsenate treated soils. Significant difference in fresh and dry weight was observed between the moisture regimes only in case of BRRI dhan-28 under 30 mg As/kg arsenate (As^{V}) treated soil. The value showed that, both fresh and dry matter production was higher in 50% FC in some cases than 75% FC but lower than 100% FC for BRRI dhan-28 grown under 30 mg As/kg arsenate (As^{V}) treated soil.

Arsenic accumulation

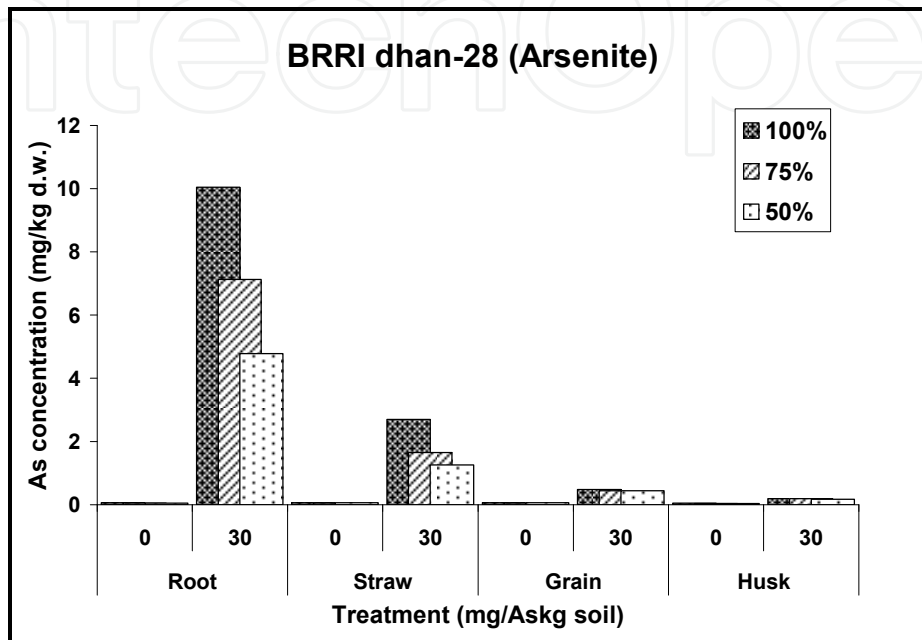
Arsenic concentrations in different parts (root, straw and husk) of the rice plants at different moisture levels (100%, 75% and 50% FC) of the two varieties are presented in Figure 2 (a & b) and Figure 3 (a & b). It is important to note that in the control plants of both varieties there were some As accumulation which could be due to the presence of the background As (1.62 mg/kg) in soil.

BRRI dhan-28

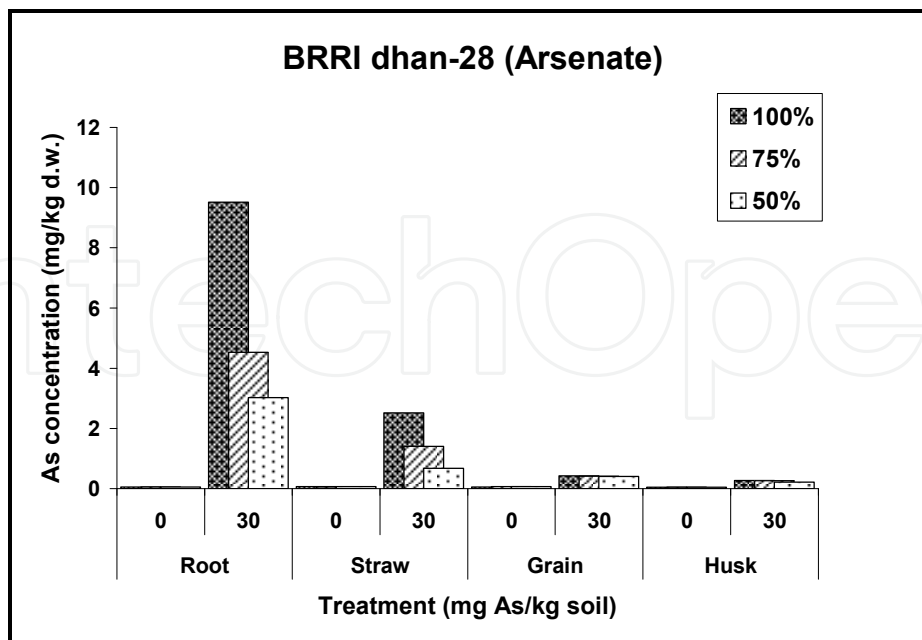
Root

Arsenic concentration in roots of both arsenite (As^{III}) and arsenate (As^{V}) treated soil increased with increasing moisture level. Arsenite (As^{III}) salt contributed more towards As accumulation at 100%, 75% and 50% FC moisture level than arsenate (As^{V}). This possibly could be due to high mobility of As^{III} than the As^{V} into the soil through pore spaces. For 30mgAs/kg arsenic treated soil, the concentration of As was 10.04 mg/kg d.w. for As^{III} treatment, while the value was 9.51 mg/kg d.w. for As^{V} treatment in the roots of BRRI dhan-28 at 100% FC moisture level but at 50% FC As concentrations were 4.78 mg/kg d.w. 3.02 mg/kg d.w. for arsenite and arsenate treatment respectively (Figure 2 a & b). However, the maximum values were found to be 10.04 mg/kg d.w. and 9.51 mg/kg d.w. in roots of BRRI dhan-28 from As^{III} and As^{V} sources

respectively (Figure 2 a & b). Both at 75% and 50% FC As concentration in the roots of BRR1 dhan-28 was lower than in those of 100% FC for both As sources. These values clearly show that with the reduction of moisture level As accumulation in roots reduced. However, arsenic concentration in the roots of BRR1 dhan-28 at different moisture level, either from As^{III} or As^V , was not statistically significant. In general, the roots accumulated higher As than the other plant parts. Indeed, the As concentration in the roots of BRR1 dhan-28 was higher at 100% FC than 75% and 50% FC for both As sources.



(a)



(b)

Fig. 2. Arsenic concentration in different parts of BRR1 dhan-28 under the three moisture regimes as affected by (a) arsenite (As^{III}); (b) arsenate (As^V)

Straw

Arsenic concentration in straw of BRRI dhan-28 followed the same pattern as for roots in both arsenite and arsenate treated soil. The magnitude of the increasing trend varied considerably between the moisture levels. The maximum As concentration (2.70 mg/kg d.w.) was found in straw of BRRI dhan-28 treated with 30 mg As/kg soil from As^{III} at 100% FC, while for 50% FC it was 1.25 mg/kg d.w. (Figure 2a). The arsenic concentration for As^V treated soil in straw of BRRI dhan-28 was 2.52 mg/kg d.w. at 100% FC and 0.66 mg/kg d.w. at 50% FC (Figure 2b). The accumulation did not differ significantly for the two sources in this variety. As accumulation in straw was higher for As^{III} treated soil at all the moisture regimes.

Grain

The arsenic concentrations in grain were almost similar, irrespective of the moisture regime and source of arsenic. The maximum value was found 0.48 mg/kg d.w. for arsenite treated soil while for arsenate treated soil it was 0.42 mg/kg d.w. at 100% FC. However, from none of the arsenic sources did the grain As concentration exceed the maximum permissible limit of 1.0 mg of As/kg in the grain of rice (National Food Authority 1993). This Australian standard is taken as a reference, as no standard has yet been adopted in Bangladesh. Arsenic accumulation in grain was not significant for any of the variables. In a previous work with two moisture regimes, it has been observed that arsenic accumulates more under 100% FC than under 75% of FC (Imamul Huq et al. 2006b).

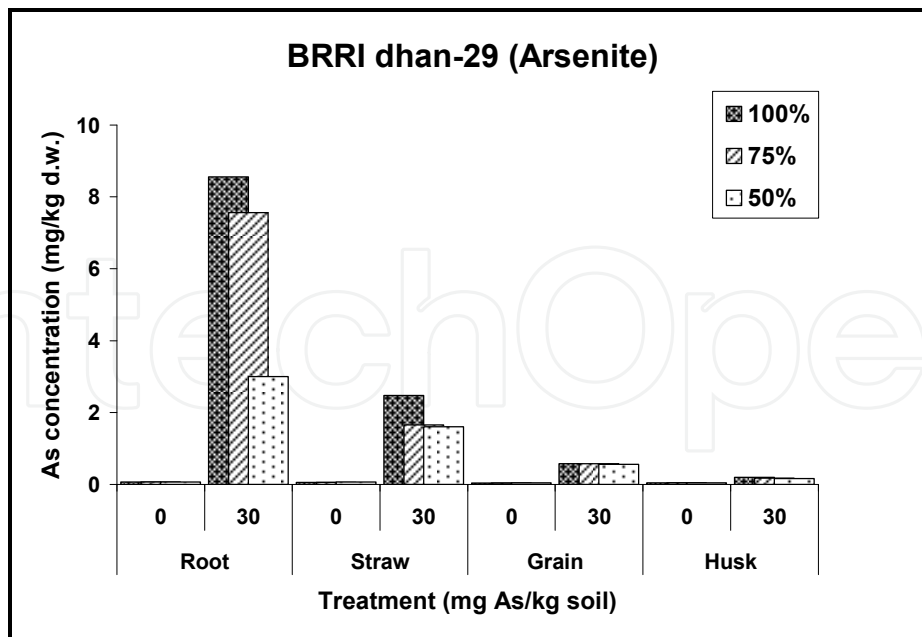
Husk

Arsenic accumulations in rice husk were almost similar for the two sources of arsenic, though there was a variation between the moisture regimes. The maximum value was found 0.27 mg/kg d.w. in husk of BRRI dhan-28 treated with 30 mg As/kg soil from As^V at 100% FC, and the concentration decreased very slightly with decreasing moisture level. The husk As concentration did not exceed the maximum permissible limit of 1.0 mg of As/kg- similar to what was observed for the moisture regime at 75% and 50% FC.

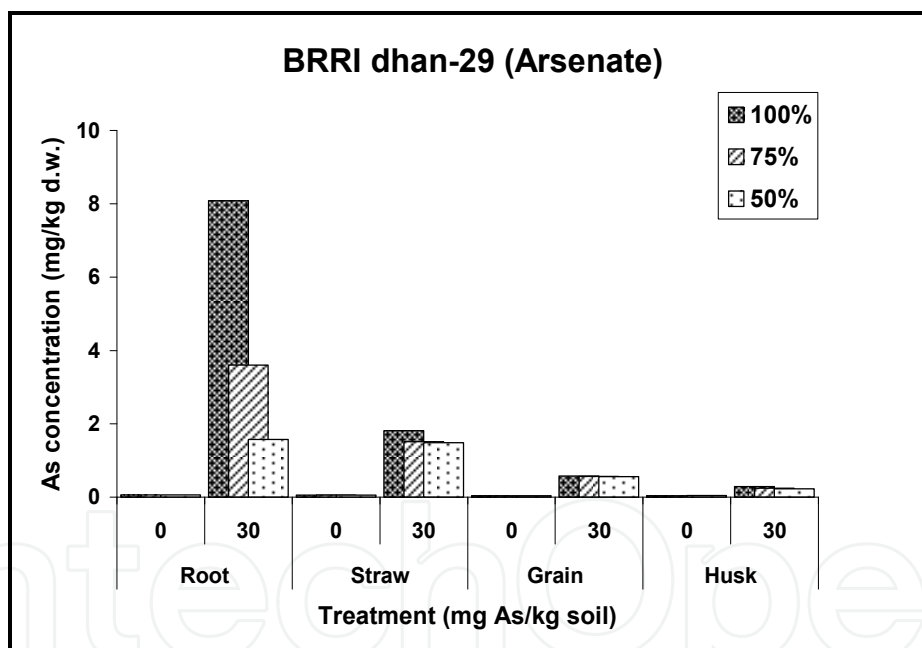
BRRI dhan-29

Root

In this variety too, arsenic concentration in the roots from both the sources (As^{III} and As^V) increased with increasing moisture level. However, the values were relatively lower than what was observed for BRRI dhan-28. The maximum As concentration in roots of BRRI dhan-29 was 8.55 mg/kg d.w. for As^{III}, and 8.08 mg/kg d.w. for As^V treated soil at 100% FC (Figure 3 a & b) whereas at 50% FC the values were 2.99 mg/kg d.w. and 1.57 mg/kg d.w. for arsenite and arsenate treatment respectively. Of the three moisture regimes, at 100% FC arsenic accumulation was more in roots from both As^{III} and As^V sources than 75% and 50% FC. These values clearly show that with the reduction of moisture level As accumulation in roots reduced. However, arsenic concentration in the roots of BRRI dhan-29 at different moisture level, either from As^{III} or As^V, was not statistically different. Arsenic concentration in roots of both arsenite (As^{III}) and arsenate (As^V) treated soil increased with increasing moisture level. In general, with the 100%, 75% and 50% moisture regime, the roots of BRRI dhan-29 from As^V treated soil accumulated lesser amounts of As than As^{III} treated soil.



(a)



(b)

Fig. 3. Arsenic concentration in different parts of BRRi dhan-29 under the three moisture regimes as affected by (a) arsenite (As^{III}); (b) arsenate (As^{V})

Straw

The As concentration in straw of BRRi dhan-29 increased with increasing moisture regime in the growth medium. The magnitude of the increasing trend varied considerably between the sources of arsenic. The maximum As concentration (2.47 mg/kg d.w.) was found in BRRi dhan-29 treated with As^{III} at 100% FC, while the value was 1.81 mg/kg d.w. for As^{V} at 100% FC (Figure 3 a & b). A similar trend was also observed for BRRi dhan-28 (Figure 2 a &

b for BRRi dhan-28). Under 50% FC the As^{III} treated plants accumulated 1.60 mg As/kg d.w., while for As^V treated plants it was 1.48 mg/kg d.w. Of the three moisture regimes, straw of BRRi dhan-29 accumulated more As from As^{III}, than from As^V.

Grain

The arsenic concentrations in grain were almost similar, irrespective of the moisture regime and source of arsenic. In BRRi dhan-29 the maximum value was found to be 0.58 mg/kg d.w. for arsenite treated soil while for arsenate treated soil it was 0.57 mg/kg d.w. at 100% FC. The concentration decreased very slightly with decreasing moisture level (Figure 3 a & b). However, from none of the arsenic sources did the grain As concentration exceed the maximum permissible limit of 1.0 mg of As/kg in the grain of rice (National Food Authority 1993). Arsenic accumulation in grain was not significant for any of the variables.

Husk

Arsenic accumulations in rice husk were almost similar for the two sources of arsenic, though there was a variation between the moisture regimes. The maximum value was found to be 0.28 mg/kg d.w. in the husk treated with 30 mg As/kg soil from As^V at 100% FC, and the concentration decreased very slightly with decreasing moisture level. The husk As concentration did not exceed the maximum permissible limit of 1.0 mg of As/kg- similar to what was observed for the moisture regime at 75% and 50% FC.

Comparison among the three moisture regimes

In both varieties, As accumulation was found to be reduced at 75% of field capacity and more reduced at 50% of field capacity than the 100% FC. In our previous experiment with two water regimes, similar observations have been made (Imamul Huq et al, 2006b). Reducing moisture up to 50% did not cause any significant yield difference in terms of biomass production while it reduced the uptake and accumulation of arsenic in all the plant parts of rice.

Comparison among the plant parts

Maximum As accumulation was observed in roots, followed by straw and husk. Similar observations have been reported earlier (Imamul Huq and Naidu, 2005, Imamul Huq et al. 2006a, Imamul Huq et al. 2007, Marin et al. 1992, Xie and Huang 1998). Abedin et al. (2002) showed the rice tissue As concentration in the order: root > straw > husk > grain. Roots of BRRi dhan-28 accumulated more As than BRRi dhan-29 under the three moisture regimes, and more from As^{III} than As^V. In both BRRi dhan-28 and BRRi dhan-29 As concentrated more in the roots and was transferred to the upper parts of the plant. Although As in straw was comparatively less than the roots, there are high possibilities to accumulate As in grains in both the varieties. Transfer factor values (Farrago and Mehra 1992) greater than 0.1 indicated that the rice plant has a strong affinity to As accumulation for all treatments. Transfer factor values also showed greater affinity for As^{III} than for As^V, irrespective of the variety.

Comparison between two arsenic sources

Arsenic accumulation in all parts of both the varieties was little bit higher for As^{III} than for As^V under three moisture regime (100%, 75% and 50% of field capacity). Similar

observations have also been noted earlier (Imamul Huq et al. 2006b). However, there was no significant difference in arsenic accumulation between the two arsenic sources.

Comparison between the two varieties

Arsenic accumulation varied between the different plant parts of the two varieties, but there was no significant difference in As accumulation between the two varieties. Roots of the rice variety BRRI dhan-28 concentrated more As than BRRI dhan-29, resulting in higher accumulation in the straw of BRRI dhan-28 under three moisture regimes, irrespective of the source of the arsenic.

Arsenic uptake

It was observed that As uptake decreased with decreasing moisture regime in both the As (As^{III} and As^{V}) treated plants irrespective of variety. However, As uptake was higher in the As^{III} -treated plants than in As^{V} . It was clear that in all parts of both varieties, As uptake was higher at 100% field capacity. It has been found that BRRI dhan-29 is more susceptible to As accumulation than BRRI dhan-28.

4. Conclusions

From this experiment it was observed that growing rice at reduced moisture level could alleviate As toxicity without significant biomass yield reduction. Reduction in moisture level or irrigation water could reduce As uptake in rice plant by reducing its phytoavailability, thereby helping to reduce its entry into the food chain to some extent.

5. Acknowledgements

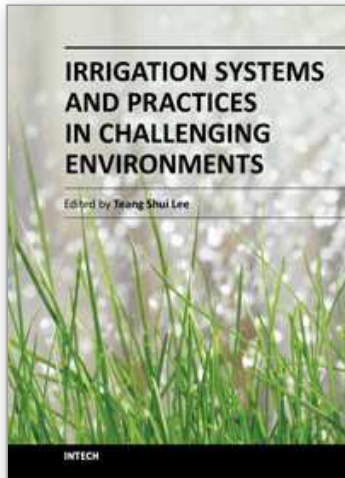
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The book *Irrigation Systems and Practices in Challenging Environments* is divided into two interesting sections, with the first section titled *Agricultural Water Productivity in Stressed Environments*, which consists of nine chapters technically crafted by experts in their own right in their fields of expertise. Topics range from effects of irrigation on the physiology of plants, deficit irrigation practices and the genetic manipulation, to creating drought tolerant variety and a host of interesting topics to cater for the those interested in the plant water soil atmosphere relationships and agronomic practices relevant in many challenging environments, more so with the onslaught of global warming, climate change and the accompanying agro-meteorological impacts. The second section, with eight chapters, deals with systems of irrigation practices around the world, covering different climate zones apart from showing casing practices for sustainable irrigation practices and more efficient ways of conveying irrigation waters - the life blood of agriculture, undoubtedly the most important sector in the world.

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