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EFFECT OF BALANCED FERTILIZATION ON ARSENIC AND OTHER HEAVY METALS UPTAKE IN RICE AND OTHER CROPS

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Abstract

Balanced fertilization of low land rice culture has not proven to be effective in avoiding arsenic accumulation. Accumulation of As has been found to be higher in BRRI-dhan 29 than in BRRI-dhan 28 grown under similar condition. The accumulation of a few heavy metals also indicated that balanced fertilization does not play any significant role in their accumulation. On the other hand, excess P over the required amount could help decrease accumulation of As in an upland crop of kangkong. When amaranthus was grown with balanced fertilizer, half that of balanced and one and a half times more than the balanced fertilizer, the balanced fertilizer could keep the accumulation of the heavy metals in the minimum. It seems that cropping system has a role to play in the accumulation of As and heavy metals when they are fertilized. The paper presents some findings in this regards.

Introduction

Balanced fertilization is the key to efficient fertilizer use for sustainable high yields. Long-term experiments demonstrate that utilization of nitrogen (N) alone, or N and phosphorus (P) created deficiencies of potassium (K) that can only be overcome by application of K fertilizers. Although dramatic increases in N, P and K fertilizer consumption in Bangladesh have taken place, the use of P and K fertilizers is low compared to N. Research on balanced fertilization remains a high research priority to achieve efficient plant nutrient utilization. In short-term experiments, N fertilizer alone had a good effect. However, with time this proved to be a poor practice. High and stable yields can only be achieved and maintained when N, P and K are combined rationally. Furthermore, applying organic manure along with NPK fertilizer has been found to be beneficial because it supplements P and K, adds some secondary and micronutrients, and improves the physical and biological characteristics of the soil (Sikder *et al.* 2007). Improving fertilizer use efficiency is essential and should be a common practice in farming. Bangladesh is beset with the problem of As contamination not only through drinking water but through food chain due to irrigation with As-laden water (Imamul Huq *et al.* 2006a).

Field crops receiving As through irrigation water might show yield differences and accumulation of the toxic element which could be avoided by proper nutrient balance in the growth medium. One of the quality criteria with which the consumer selects food at the market is whether the food is produced in environmentally acceptable ways. Maintaining a balanced nutrition requires judicious fertilization practice. The present paper attempts to highlight the necessity and effect of balanced fertilization on plant quality particularly as it concerns accumulation of arsenic and a few heavy metals.

Material and Methods

Sampling site

The area where groundwater As contamination has not been reported was sought. As such a farmer's field in Dhamrai Thana near Dhaka, Bangladesh was selected for soil sampling (Fig. 1). The georeference of the sampling site is 23°54.776′ N and 90°10.938′ E. The soil thus selected belongs to the Dhamrai soil series; general soil type is Non-Calcareous Grey Floodplain soil (GST No. 6); USDA soil taxonomy is Typic Andoaquept and FAO- UNESCO Legend is Chromi-Eutric Gley Sol.

Collection and preparation of soil sample

The bulk soil samples representing 0-15 cm depth from the surface were collected by composite soil sampling method as suggested by the soil survey staff of the United States Department of Agriculture (USDA 1951). The collected soil samples were air dried; visible roots and debris were removed from the soil samples and discarded. Then a portion of the larger and massive aggregates were broken by gently crushing them by a wooden hammer and were screened through a 0.5 mm stainless steel sieve. The sieved samples were then mixed thoroughly for making the composite sample. These soil samples were used for various laboratory analyses. The bulk soil samples were screened through a 2 mm sieve and used for pot experiment.

Experimental setup

Two different pot experiments were carried out in the net house of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh. In one experiment, arsenic at the rates of 0, 10, 20 and 40 mg/kg soil was mixed with the soils before one week from sowing of the rice seeds. Clay pots of 5L sizes were used. The pots were filled with 5 kg of soil. The pots were arranged randomly in the net house. Two different varieties (BRRI dhan-28 and BRRI dhan-29) of rice seeds were collected from Bangladesh Rice Research Institute (BRRI).

The other experiment was carried out with four imposed treatments of As at the rates of 0, 0.5, 1.0 and 2.0 mg As/L in irrigation water. In this experiment only BRRI dhan-28 was used. The soils used were sterilized in an autoclave (at 15 psi, 121^0C temperatures for 15 minutes) in batches of 5 kg. The pots were inoculated with a green and blue green algae cultivated in the laboratory (Imamul Huq *et al.* 2007). Treatments of arsenic were applied with irrigation water. Algal samples of 90 days aged were inoculated to each pot in equal amount (15 ml).

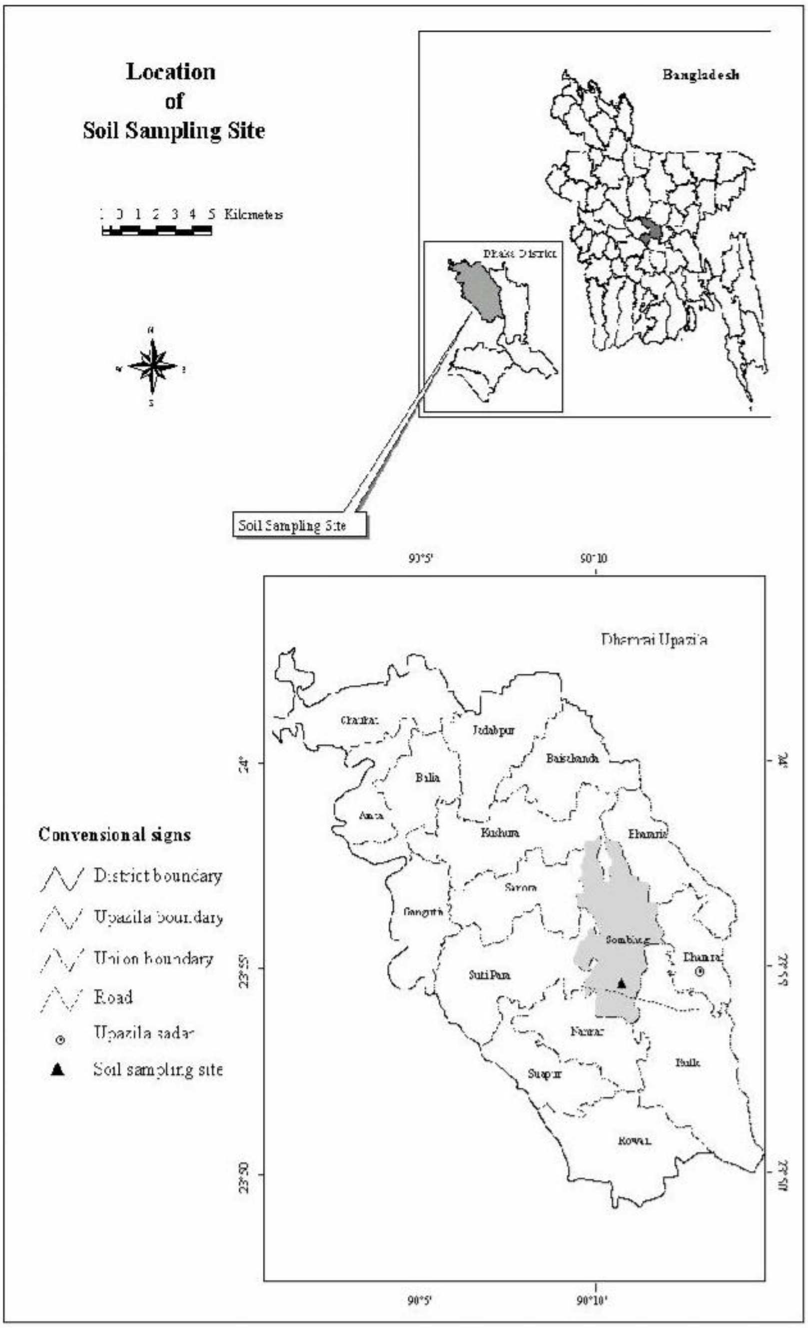

Fig. 1. Location map showing the geographic position of the sampling site.

Method of rice cultivation

The background level of As in soil was 1.6 mg/kg. This was taken as control. Sodium meta- arsenite was used as source of arsenic. All experiments were done in triplicates. The nutritional (N, P, K and S) requirement was calculated on the basis of "Soil Test Value Interpretation" as recommended by the Bangladesh Agriculture Research Council (BARC, 2005). This means that the soils were balanced fertilized. According to this recommendation the required amount of N, P, K and S for the given soil were met from the fertilizer sources urea, TSP, MOP and $ZnSO_4$ respectively. The whole of TSP, MOP, $ZnSO_4$, and 1/3 of the urea fertilizer were applied at time of soil preparation. Rice seeds were dipped in water and kept over night and then kept 2 to 3 days in dark condition for germination. The germinated seeds were sown directly in pots and were allowed to grow. The pots were thinned to 3 plants after seedling were established. Of the rest 2/3 urea fertilizer, 1/3 was applied after 35 days from seed sowing and the final 1/3 was applied during the panicle initiation stage of rice plant. Various cultural operations were made whenever necessary. Weeds were removed manually. Different agronomic characters of the plants were observed during the growth period.

Collection of plant samples

Rice plants of BR-28 and BR-29 were harvested after 120 days and 140 days from germination, respectively. The plants were harvested by uprooting them manually. The grains were collected two days before the harvest. The harvested roots were washed with tap water to dislodge the adhering soil, then with deionized distilled water several times to remove solutes from the ion free space. The aerial portions of the plants were also washed. The plant samples were separated into root, straw and grain. The collected plant samples were first air dried and then oven dried at $70°\pm5°C$ for 48 hours. The dried plant samples were then ground and were sifted through a 0.2 mm sieve. Algal samples from the pots were also collected at harvest. After harvest, soil samples from each pot were also collected from the rhizosphere and these soil samples were prepared following the procedures as described earlier.

Laboratory analysis

Various physical, chemical and physiochemical properties of the soils were determined following procedures described in Imamul Huq and Alam (2005). Soil, plant and algae were analyzed for total arsenic by hydride generation atomic absorption spectrometry (HG-AAS). Other heavy metals were analyzed by atomic absorption spectrometry (AAS). Arsenic of the plant and algae samples was extracted with HNO_3 and of the soil with aqua regia solution (Portman and Riley 1964). Certified reference materials were used through 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 and other heavy metals. 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 common statistical software MINITAB 13.0. The amount of uptake (mg/100 plants) by different plant parts and the plant as a whole were calculated. The uptake was calculated using the concentration in dry matter and dry weight of plant parts and the result is expressed as mg/100 plants:

Uptake = Concentration in dry matter × dry weight of plant part

Results and Discussion

Initial characteristics of the soil

The collected soil sample was analyzed in the laboratory before the set up of the experiment to see the nutrient status of the soil. Some important soil properties are presented in Table 1.

Table 1. Some properties of the soil sample

Properties	Values
pH (soil: water = 1:2.5)	6.36
Electrical conductivity	0.07 µS
Sand	7%
Silt	49%
Clay	44%
Texture	Silty clay
Organic matter	1.4%
Total nitrogen	0.15%
Total phosphorous	0.05%
Total potassium	0.32%
Total sulphur	0.21%
Arsenic	1.65 mg/kg
Zinc	0.4 mg/kg
Lead	18.10 mg/kg
Cadmium	0.5 mg/kg
Iron	2%
Manganese	1.6%

Agronomic parameters

Symptoms of any abnormality in the rice plants were noted during the experiment. Both the varieties showed severe symptoms of toxic effect at higher As concentration and the symptoms became pronounced with time of exposure of the plants to arsenic stress. The symptoms delayed seedling emergence, reduced plant growth, caused yellowing and wilting of leaves and finally reduced grain yield. Brown necrotic spots were also observed on old leaves of the plants growing at 20 and 40 mg/kg As treatment in both the varieties. At the initial stage of growth, plant height did not differ with the control plants. But at maturity, plant heights decreased with increasing arsenic treatment. Plants of both the rice varieties grown on 40 mg As/kg treated soil showed the minimum plant height. This decreasing trend of plant height with increasing As treatment was not statistically significant. It was also clear that arsenic did not readily cause plant height reduction but the progressive accumulation of arsenic in plants with the time of exposure caused the plant height reduction. A reduction in plant heights with increasing As concentration have also been reported in rice plants (Yamare 1989; Barrachina *et al.* 1995). Fresh as well as dry matter production of the two varieties decreased with increasing As treatment. Maximum weights were noted for the control plants whereas the minimum values were for plant growing at 40 mg/kg As treatment. No differences in either fresh weight or dry weights were observed due to varietal difference. The grain yield remarkably decreased as a result of higher As doses. A yield reduction of more than 40 and 60% for BR-28 and Iratom-24, respectively in As treated soil has also been reported (Hossain *et al.* 2005).

Arsenic accumulation

Arsenic concentrations in different parts (root, straw and grain) of rice plants of the two varieties are presented in Fig. 2. It is important to note that in the control plants of BR-29 there were some As accumulation and that could perhaps be due to the background As in the soil (1.6 mg/kg).

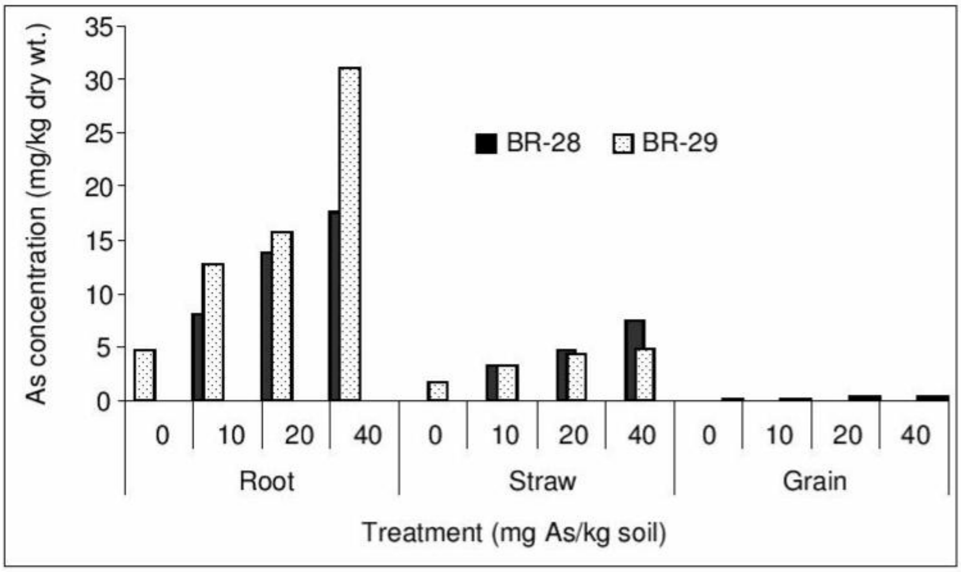

Fig. 2 Arsenic concentrations in different parts of BR-28 and BR-29.

Arsenic concentration in root of both the varieties increased with increasing As treatment. However, arsenic concentration in the roots of BR-28 was not significant. On the other hand, arsenic concentration in roots of BR-29 was significant ($p = 0.009$). In general, the roots accumulated higher As than the other parts. As concentration in roots of BR-29 was more than that of BR-28. Arsenic concentration in straw followed the same pattern as for roots.

The magnitude of the increasing trend varied considerably between the two varieties. Arsenic accumulations in rice grain were almost similar though there was a variation between the varieties. However, in none of the varieties the grain As concentration did exceed the maximum permissible limit of 1.0 mg of As/kg (NFA 1993). This Australian standard is taken as a reference as there has been no standard adopted yet in Bangladesh situation. Arsenic accumulation in rice grain was not significant for any of the variables.

Comparison among the plant parts

Maximum amount of As accumulation was observed in root followed by straw and grain. Similar observations have also been reported earlier (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 BR-29 accumulated more As than BR-28. This means that, in BR-29, As concentrated more in the roots and translocated less to the upper parts of the plant whereas in BR-28, As was translocated to the upper parts of the plants giving rise to a more risk of As ingestion. On the other hand, although As in straw was less translocated, yet grains of BR-29 accumulated more As than BR-28. Transfer factor values (greater than 0.1) indicated that rice plant has strong affinity to As accumulation (Farrago and Mehra 1992) for all treatments.

Comparison between the two varieties

Arsenic accumulation varied in different plant parts of the two varieties but there was no significant difference between the two varieties in As accumulation except in roots ($t = 3.27$, $p = 0.047$) for BR-29. Roots of rice variety BR-29 concentrated more As than BR-28 resulting less in straw whereas in grain As concentration was higher for BR-29 than BR-28.

Arsenic uptake

It was clear that in all parts of both the varieties As uptake was high. Arsenic uptake by the whole plants was significant only in plants ($p = 0.01$) for BR-28; it appears. Thus, that BR-28 is more susceptible to As accumulation than BR-29.

Iron uptake

The mean values of iron content in rice plants of BR-28 and BR-29 are presented in Table 2. Fe content in root, straw and grain of both the varieties increased with increasing As treatment, showing a synergistic relation between As and Fe. The highest amount of Fe accumulation was found in roots followed by straw and grain. Yamare (1989) showed that As levels of >2.5 mg/kg caused decrease in plant N, P, K, and Mg contents while Fe concentration in plants increased at the same level of As.

Table 2. Iron content (%) in rice plants of BR-28 and BR-29

Treatment (mg As/kg soil)	Iron content (%)					
	Root		Straw		Grain	
	BR-28	BR-29	BR-28	BR-29	BR-28	BR-29
0	0.65	0.50	0.03	0.02	0.05	0.04
10	0.56	0.56	0.09	0.05	0.05	0.03
20	0.66	0.45	0.08	0.10	0.07	0.05
40	1.20	1.00	0.09	0.09	0.10	0.06

Manganese uptake

The mean values of manganese concentration in different parts of the two rice varieties are presented in Table 3. Manganese concentration was found to be decreased with increasing As treatment in soil showing antagonistic relationship with As. In this experiment roots contained lower amount of Mn compared to straw and grain. Similar amount of Mn was accumulated by the two varieties.

Table 3. Manganese content (mg/kg dw) in rice plants of BR-28 and BR-29.

Treatment (mg As/kg soil)	Manganese content (mg/kg dw)					
	Root		Straw		Grain	
	BR-28	BR-29	BR-28	BR-29	BR-28	BR-29
0	165	195	415	395	323	450
10	145	210	308	412	240	425
20	100	115	267	285	251	500
40	170	167	325	274	174	239

For the 2nd experiment visual observations were also made and some agronomic parameters were recorded on the growth and yield of rice plant. No symptom of As toxicity was visible in the treated plants.

Effect of arsenic on plant growth and yield

Of the various growth and yield parameters, plant heights (cm), fresh weight of plants (g) and grain yield (t/ha) were considered. No marked differences were observed for the mean height of rice plants for As treatments. However, there had been a slight decrease in the fresh weights of rice. At 2.0 mg/L As treatment, rice showed a decrease of more than 16% from control. ANOVA test was done for fresh weight and the p value was 0.277 for treatment effect. The low p value confirms the significant effect of algae on fresh matter production of rice plants. The grain yield (t/ha) was not remarkably decreased as a result of higher As doses. At lower doses of As in irrigation water (0.5 and 1 mg/L) rice yield was slightly increased over the control treatment though the increase was not significant. The maximum yield of rice plants was observed at 0.5 mg/L treatment with the value being 7.07 t/ha. At high dose (2.0 mg/L) of As yield of rice decreased compared to lower doses of As.

Arsenic content in rice plants

From the result, it is evident that, arsenic accumulation increased with increasing arsenic concentration in irrigation water. Arsenic contents were higher in roots than shoots. The highest concentration of arsenic in roots was found to be 66.23 mg/kg (2.0 mg As/L dose) and the lowest was obtained for control (3.76 mg of As/kg). No detectable arsenic (the detectable level of As in the machine used – Varian Spectra 220 – is 0.0002 mg/kg) was found in grain. The mean values (for three replications) of arsenic concentration in root and shoot of rice are presented in Fig. 3. It is important to note that in control plants there were some As accumulation and perhaps that was due to the presence of water extractable As in soil.

Effect of balanced fertilization

ANOVA test was done for the root arsenic and it was found to be highly significant with the p value of 0.00. The statistical analyses revealed that presence of algae has been instrumental in reducing the entry of As into the rice roots. The highest concentration of As in straw was 6.62 mg/kg at 2.0 mg/L treatment.

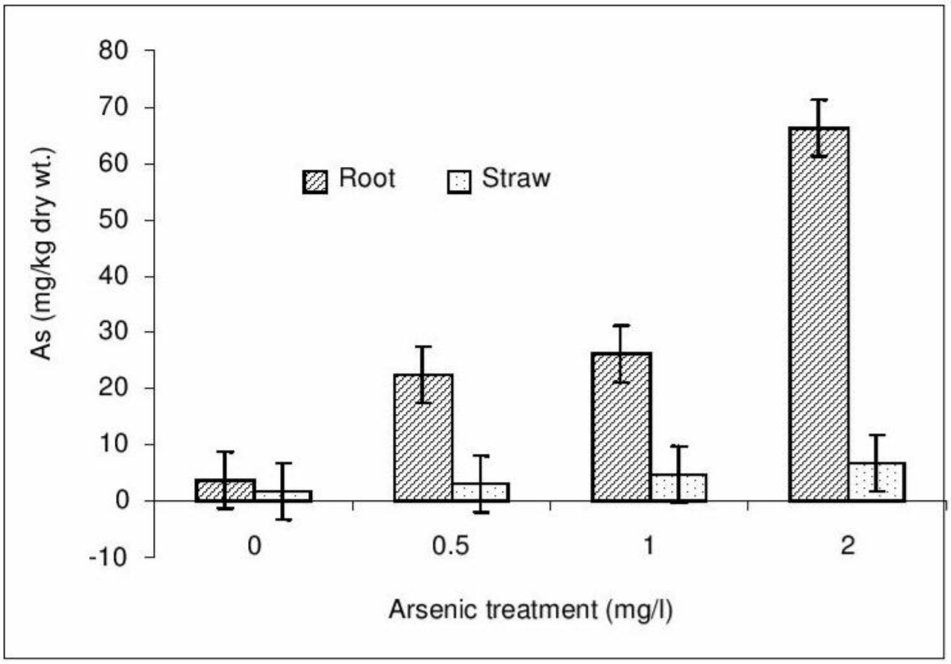

Fig. 3. Arsenic contents in root and straw of rice plant.

Uptake of Arsenic

The amount of As uptake by different plant parts (root and straw) and the whole plant are presented in Table 4. The total uptake of As by plant root at 2.0 mg of As/L in irrigation water was the maximum, the value being 162.93 mg/kg dry weight. The total uptake of As by plant straw at 2.0 mg of As/L was 24.43 mg/kg dry weight. When total plant uptake was considered it was observed that the total uptake of As by plant at 2.0 mg of As/L dose of treatment in irrigation water was the maximum, the values being 187.4 mg/kg dry weight.

Table 4. Arsenic (mg/kg) accumulations in root, straw and plant.

Treatment (mgAs/L)	As (mg/kg)		
	Root	Straw	Plant as a whole
0.0	10.94	7.52	18.50
0.5	63.56	12.69	76.30
1.0	66.89	18.62	85.50
2.0	162.93	24.43	187.40

Arsenic and other heavy metals accumulation in algae

Arsenic and other heavy metals content in algae after harvest were also analyzed and are presented in Table 5. When concentration of As in solution was increased, As concentration in algae also increased. The pot experiment showed that algae accumulated more than 85% of As from the growth media over the control treatment. The result indicates that algae could accumulate arsenic if it is present in solution. The higher the concentration of arsenic in solutions the greater will be the accumulation.

Table 5. Arsenic and other heavy metals in algae.

Treatment (mg As/L)	As	Pb	Cd	Zn
	(mg/kg)			
0.0	2.16	1.70	1.43	31.40
0.5	3.35	0.97	0.33	53.15
1.0	8.05	1.30	0.10	61.70
2.0	16.42	1.00	0.08	25.70

Besides arsenic, lead, cadmium and zinc concentration was higher at control than the treatment. Although there had been no lead, cadmium and zinc application yet it was found that there has been some lead, cadmium and zinc in algae in all the treatments. At 1 mg As/L of irrigation water an increase of about 26% in lead concentration was observed but at higher concentration of As treatment (2 mg As/L) there has been a decline of lead in algae. The accumulation of cadmium decreased gradually with increasing arsenic concentration in irrigation water. At 1 mg As/L of irrigation water an increase of about 50% in zinc concentration was observed over the control treatment but at higher concentration of As treatment (2 mg As/L) there had been a decline of zinc in algae. Similar observation was found by Imamul Huq *et al.* (2005). The result also indicated that the algae accumulate other heavy metals if present in the solution. In the present experiment it is possible that lead, cadmium and zinc were added to the solution as contaminants with the fertilizer materials as well as with the arsenic salt that was applied. It needs to be mentioned here that the cultured algae applied to rice plants contained some arsenic, lead, cadmium and zinc.

Arsenic and other heavy metals in soil after the harvest of rice plant

After the harvest of rice plant, the pot soils were analyzed and the results are shown in Table 6. The data indicated that algae could accumulate substantial amounts of arsenic applied to soil and thereby reduced the concentration of As in soil as well as the accumulation of arsenic in the growing rice.

Table 6. Arsenic and other heavy metals in soil after harvest.

Treatment (mg As/L)	As	Pb	Cd	Zn
	(mg/kg)			
0.0	1.01	0.74	0.17	6.20
0.5	2.14	0.74	0.13	5.10
1.0	3.76	0.79	0.20	6.70
2.0	6.47	0.81	0.25	6.80

Effect of balanced fertilization

In a separate experiment with a different soil BRRI-dhan 29 was grown on fertilized soil monoliths. One of the monoliths received As contaminated water as irrigation water at the rate of 0.5 mg/L while the other monoliths received irrigation through fresh water. Arsenic was not detected in any part of the BR-29 rice plants grown with fresh water (Table 7). It could be due to the fact that the water did not contain any As and the amount soluble was not large enough to cause any detectable accumulation in the growing rice. This gives an indication that fresh water irrigation can minimize As accumulation in plants even if the soil contains As. Similar observations were made by Imamul Huq (personal communication) with crops like arum, kangkong and amaranthus. Though there was no accumulation of As in any parts of the plants, Fe accumulated in a large amount in the roots while in other organs Fe was not detectable. Other elements like Zn and Mn accumulated in all parts of the plants, more in the roots and unfilled grains than either shoot or root. For the plants receiving As-contaminated water irrigation, As was found in the roots and shoots but no As was detected in the grains. Root accumulated as usual higher amount of As than shoot. 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.* 2006a; Imamul Huq *et al.* 2006b; Farid *et al.* 2003).

Table 7. Concentration of different elements in different parts of BR-29.

Plant parts	Fresh water irrigation				As-contaminated water irrigation			
	As (ppm)	Mn (%)	Zn (%)	Fe (ppm)	As (ppm)	Mn (%)	Zn (ppm)	Fe (ppm)
Root	0.00	0.91	0.066	1018.1	6.95	0.65	0.093	100.65
Shoot	0.00	0.31	0.026	0.00	0.12	0.56	0.032	145.00
Grain	0.00	0.24	0.041	0.00	0.00	0.28	0.038	0.00
Unfilled grain	0.00	0.45	0.056	0.00	0.00	0.31	0.071	0.00
Husk	0.00	0.38	0.056	0.00	0.00	0.40	0.046	108.70

In a different experiment with a leafy vegetable *Ipomea aquatica*, phosphorus was varied at different levels; *e.g.* no phosphorous, the required amount, 1.5 times of the required amount, 2.0 times the required amount and 2.5 times of the required amount. The soils were spiked with As at 10, 20 and 40 mg/kg soil. The objective of the experiment was to verify the possibility of using higher P rates to reduce As accumulation in plants. Two soils – one calcareous (Gopalpur series) and the other non-calcareous (Dhamrai series) were included in the study. The As spiking rates were similar in both the soils. However, the P application rate varies because of the soil requirements. Along with As accumulation, the accumulation of Fe, Mn and Zn were also assessed in the plant parts.

It was observed that the addition of P could alleviate As accumulation in both shoots and roots of *Ipomea aquatica* in both soils (Tables 8 and 9). The decrease in As accumulation was more in the non-calcareous than the calcareous soil. With increasing P application, uptake of the native soil As by roots showed a decreasing tendency. It became apparent from this experiment that increasing high amount of P in soil could reduce As uptake in plant by reducing its phytoavailability.

According to Kabata-Pendias and Pendias (1984), arsenic is less toxic when the plant is well supplied with phosphorus. The phytotoxicity of arsenic is reduced with high phosphorus availability. Arsenic is chemically similar to phosphorus (Barrachina *et al*. 1995) and roots take up arsenic and phosphorus by the same mechanism (Meharg and Macnair 1991). So, the chance of As – P interaction should always be expected. The results also tend to indicate that at high soil-As levels P fertilization will have positive effect on lowering the As accumulation in roots grown in both Dhamrai and Gopalpur soil.

Table 8. Arsenic uptake (mg/100 plants) by plant parts in Gopalpur soil (calcareous soil).

Phosphorus (mg/kg)	Arsenic (mg/kg)							
	As$_0$		As$_{10}$		As$_{20}$		As$_{40}$	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
P$_0$	3.70	0.25	24.06	15.28	96.36	24.26	177.22	26.63
P$_1$	3.18	0.39	30.50	12.39	60.62	28.13	132.80	32.98
P$_2$	2.25	0.35	28.68	17.25	61.25	24.22	129.45	34.46
P$_3$	2.84	0.07	30.15	12.39	82.90	23.06	143.45	20.62

Table 9. Arsenic uptake (mg/100 plants) by plant parts in Dhamrai soil (non-calcareous).

Phosphorus (mg/kg)	Arsenic (mg/kg)							
	As$_0$		As$_{10}$		As$_{20}$		As$_{40}$	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
P$_0$	0.54	0.20	19.69	1.65	24.48	2.93	25.31	3.55
P$_1$	0.19	0.16	13.98	2.39	17.17	4.68	20.41	5.25
P$_2$	0.17	0.27	4.84	2.80	17.17	4.14	19.95	4.56
P$_3$	0.01	0.19	5.92	1.35	14.21	1.88	18.20	2.35

The concentration of Fe in Gopalpur and Dhamrai soil as affected by increasing concentration of P are represented in Table 10. Iron is the only micronutrient element, which has been found to be synergistic with arsenic (Barrachina *et al*. 1995). The tendency of Fe accumulation in plant roots grown in Gopalpur (calcareous) and Dhamrai (non-calcareous) soil was found almost same. Yamare (1989) also found an increase in iron concentration in rice with the increase in As concentration. Gopalpur calcareous and Dhamrai non-calcareous soil didn't show any substantial difference in accumulation of Fe in plant shoots.

It was clearly observed that Mn was found to be increased with increasing As and P treatments showing synergistic relationship with both As and P (Table 10). Neither soil did show any significant difference in Mn release. The Mn accumulation in plant roots was found to be increased in all level of P. But the rate of accumulation in roots for both soils was found to be almost same. From the observation, it can be said that in almost all cases, a significant amount of Mn accumulated in roots and shoots. However, in the non-calcareous soil, Mn accumulated more in shots than in the roots.

Table 10. Accumulation of Fe and Mn in plant parts in Dhamrai and Gopalpur soil.

Soils	Phosphorus (mg/kg)	Fe (%)		Mn (mg/kg)	
		Root	Shoot	Root	Shoot
Non-calcareous (Dhamrai soil)	P_0	0.069	0.012	50.13	131.32
	P_1	0.048	0.002	45.87	125.26
	P_2	0.051	0.015	60.35	147.95
	P_3	0.059	0.010	56.27	168.52
Calcareous (Gopalpur soil)	P_0	0.012	0.038	71.60	30.43
	P_1	0.079	0.051	57.48	94.55
	P_2	0.115	0.039	65.60	101.25
	P_3	0.085	0.076	20.28	133.23

Yet, in another field experiment that was carried out with amaranthus and where balanced fertilization was practiced, the accumulation of heavy metals was studied. There were three different fertilizer rates, *viz.* ½ the required amount (F_1) of fertilizer (N, P, K and S); the required amount (F_2) and 1½ times the required amount (F_3) along with a control (F_0). It was observed that iron, zinc and manganese content in amaranthus was lower when it was grown with balanced fertilization than the control as well as when it was grown with both less and more amount of required fertilizer. Lead and cadmium content in amaranthus, however, increased with increasing rate of fertilizer application in soil (Table 11).

Table 11. Effect of different treatments of fertilizer on heavy metal content in amaranthus.

Treatment	Fe	Zn	Mn	Pb	Cd
	(%)			(mg/kg)	
F_0	0.21	0.028	0.015	<0.002	1.17
F_1	0.23	0.023	0.014	35.50	1.29
F_2	0.18	0.017	0.011	54.74	1.72
F_3	0.21	0.018	0.018	65.03	2.39

Conclusion

It is apparent from the above observations that balanced fertilization in low land rice culture, though is necessary to keep the yield levels at optimum, can not avoid the accumulation of As and other heavy metals in them. On the other hand, upland crops like kangkong and amaranthus behave differently to balanced fertilization. Balanced fertilization can improve the crop nutrient quality vis-à-vis As and other heavy metal accumulation in them. Further research is underlined to investigate in depth of these phenomena in fields.

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