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Interaction of arsenic with other elements in arsenic hyperaccumulating weeds

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Abstract

A phytoremediation study was carried out with eight weed species commonly grown in Bangladesh to develop an appropriate phytoremediation technology for the farmers of arsenic affected areas of Bangladesh. The soil was collected from the previous step of phytoremediation study. Initially the soil was treated with seven As levels *viz.* 0, 10, 20, 30, 50, 70 and 100 mg kg^{-1} arsenic as sodium arsenite ($NaAsO_2$). The residual soils after a series of phytoremediation study were used for the present study. In all weeds, the concentration of arsenic increased with increasing soil arsenic levels. While considering the interaction effect of As with other elements it was found that, with the increase of As concentration, the concentrations of the phosphorus and sulphur also increase both in root and shoot of the weeds. On the other hand, As reduces the uptake of calcium by the weeds.

Keywords: Phytoremediation, Arsenic, Hyperaccumulating weeds, Phosphorus, Sulphur. Calcium

Introduction

In recent years, the global levels of the metalloid arsenic have dramatically increased predominantly from anthropogenic activities. Consequently, remediation of these contaminated sites through a concerted effort by researchers has become a top priority. Arsenic-contaminated soil is one of the major sources of arsenic in drinking water (Hingston et al., 2001). The concentration of arsenic in cereals, vegetables and fruit is directly related to the level of arsenic in contaminated soil. Although the remediation of arsenic-contaminated soil is an important and timely issue but cost-effective remediation techniques are not currently available. Phytoremediation, an emerging, plant-based technology for the removal of toxic contaminants from soil and water is a potentially attractive approach (USEPA 2000). This technique has received much attention lately as a cost-effective alternative to the established treatment methods used at hazardous waste sites. The technique is ecologically friendly and will be economically feasible in Bangladesh context. In some phytoremediation studies, research works are available with the effect of phosphorous on As accumulation by the plants. Here in our phytoremediation experiments we studied the effect of As on the uptake of phosphorus, sulphur and Ca by the weeds. The objective of the study was to asses the interaction of As with other elements in order to develop an appropriate phytoremediation technology. Considering this, a phytoremediation study was conducted in the net house of Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Materials and Methods

The experiment was conducted in the net-house of the Department of Agricultural Chemistry, BAU, Mymensingh from March to August 2004. The initial soil was collected from Vabokhali union, Sadar Upazila, Mymensingh at 0-15 cm depth. The soil contained 2.56 mg/kg arsenic. The post harvest soils of these pots after a series of phytoremediation study were used for this study. The experiment was carried out in Completely Randomized Design with three replications.

Treatments

In the initial phytoremediation study there were seven treatments of arsenic *viz,* 0, 10, 20, 30, 50, 70 and 100 mg kg^{-1} Arsenic (Soil basis) from Na-Arsenate ($NaAsO_2$). Initially, urea, TSP, MP and gypsum were added at the rates of 135, 100, 70 and 60 kg ha^{-1} respectively in each pot. In the present study, there was no fertilizer application and the residual soil arsenic contents were considered as treatments. The As contents of the soil (treatments) have been given in Table 1.

Table 1. Arsenic content (mg/kg) in residual soil

Treatment (Residual As)	Barnyard grass	Yellow nut sedge	*Joina*	Water cress	*Malancha*	*Chesra*	*Topapana*	Water taro
T_o	0.60	1.44	0.88	0.63	1.06	1.31	0.88	0.88
T_1	1.19	1.69	1.94	1.44	2.00	2.13	1.88	2.75
T_2	2.00	2.63	2.69	2.06	2.69	3.94	2.25	3.63
T_3	3.69	3.00	3.25	2.87	4.31	3.88	3.25	4.38
T_4	2.63	3.44	6.50	4.19	5.57	4.13	4.75	4.50
T_5	5.56	5.38	6.75	5.63	5.44	5.04	5.88	7.81
T_6	6.88	8.50	8.19	5.00	10.56	7.19	7.44	9.56

In the phytoremediation study eight weed species were used. The weeds included barnyard grass (*Echinochloa crusgalli*), yellow nut sedge (*Cyperus rotundas*), *joina* (*Fimbristylis miliacea*), chesra (*Scirpus juncoids*), *topapana* (*Pistia stratiotes*), water taro (*Monochoria hastata*), water cress (*Enhydra fluctuants*), *malancha* (*Alternanthera philoxeroides*). The weed seedlings were collected from Agronomy farm area of BAU, Mymensingh and other places of this district which are known as arsenic free areas.The weed seedlings were transplanted in the experimental pots on 4th March, 2004. Three seedlings were transplanted in each pot.

The plants were harvested at 45 days of transplanting. The weeds were harvested carefully so that all the roots were collected. The weeds were washed repeatedly with water to remove all the soil particles. Then, the samples were air-dried followed by oven drying at 60^0C for 24 hours. The weeds were weighed separately for root and shoot. Plant extracts were prepared separately for root and shoot samples. Digestion was completed using 0.5g plant and 1g soil sample with HNO_3 followed by H_2O_2 at 120 ^0C temperature.

Chemical analysis:

Total arsenic content of soil was determined from the digest by flow injection hydride generator atomic absorption spectrophotometer (Unicam 969 with a hydride generator assembly) using matrix-matched standards (Welsch *et al.*, 1990). Analysis of phosphorus was done by stannous chloride method with the help of a spectrophotometer at 660 nm wavelength as mentioned by Jackson (1973). The concentration of S in the root and shoot extract was determined turbidimetrically using $BaSO_4$ with the help of a spectrophotometer at 420 nm wavelength as described by Page *et al.* (1982). Calcium was determined by atomic absorption spectrophotometric method (Issac and Kerber, 1971).

Results and Discussion

Accumulation of arsenic in different weeds

Arsenic concentration was significantly increased with increasing levels of soil As. In all 8 weed species, the highest amount of As accumulation was found in T_6 treatment. The concentrations of As and their relative distribution of in shoot and root have been presented in Table 2. It was found that root accumulated higher amount of As than shoot The highest As concentration in shoot was found in case of barnyard grass (8.77 mg kg^{-1}) followed by *topapana* (8.10 mg kg^{-1}) at T_6 treatment while the lowest As level was found in case of yellow nut sedge (0.43 mg kg^{-1}) followed by *cheshra* (0.77 mg kg^{-1}).The highest As concentration in root was found in case of barnyard grass (53.10 mg kg^{-1}) and the lowest in case of watercress (18.77 mg kg^{-1}). Ma *et al.* (2004) conducted an experiment on phytoremediation with Brake fern (*Pteris vittata*) and found similar trend of result that As content in fern increased with increasing As concentration up to 500 mg kg^{-1}. Islam (2001) reported that with the increasing accumulation of As in soil, As uptake by plants also increases. The present results were at par with those findings.

Effect of arsenic on phosphorus uptake by the weeds

Increasing rate of As significantly increased the uptake of phosphorus by the weeds both in shoot and root (Table 3). The highest P accumulation was found in the shoot of yellow nut sedge at T_6 treatment (0.5%) while the lowest in the root of same weed at T_0 treatment (0.051%).

Considering the shoot samples, the P concentrations ranged from 0.085-0.5%, 0.139-0.245%, 0.102-0.283%, 0.108 to 0.326%, 0.087 - 0.26%, 0.208-0.387%, 0.219-0.394%, 0.117-0.266% for Yellow nut sedge, barnyard grass, *joina,* cheshra, *malancha*, water cress, water taro and *topapana* respectively. In root samples, the highest P concentration was found in the root of water taro (0.382%) followed by yellow nut sedge (0.370%), *chesra* (0266%), watercress (0.318%), *joina* (0.268%), *malancha* (0.215%), barnyard grass (0.258%) and *topapana* (0.220%). Ma *et al.* (2004) and Mitra (2004) also reported similar results, where increased As concentration increased the P concentration in the phytoremediator body. The possible reason for increasing P level with the increase of As might be that As has synergistic relationship with P and thus increase in phosphorus uptake.

Effect of arsenic on sulphur uptake by the weeds

Like phosphorus, increasing level of As also increased the S content in the phytoremediator body; both in shoot and root. Table 4 represents that in most cases S concentration increased with the increased As level. The weeds give significant response for S accumulation with increased As level at 1% level of probability. The concentrations of S ranged from 0.033-0.50%. In case of shoot sample, the highest S was found in water taro (0.501%) followed by yellow nut sedge (0.486%), water cress (0.419%), *chesra* (0.410%), *joina* (0.415%), barnyard grass (0.371%), *malancha* (0.342%) and *topapana* (0.376%).

Effect of arsenic on the uptake of Ca by the weeds

A significant negative relationship was observed between As level and Ca concentration in weed hyperaccumulators. In both root and shoot, the concentration of Ca decreased in most cases with increasing soil As levels (Table 5). Accumulation of Ca ranged from 0.11-1.03. The highest Ca content was found in the shoot of water taro at T_0 treatment (1.03%) and the lowest in the root of barnyard grass, *chesra* and *topapana* at T_6 treatment (0.11%). In most cases, the Ca accumulation was higher in shoot than in root and the highest Ca content was found in T_0 treatment.

In case of shoot samples, the concentration of Ca ranged from 0.27-0.57%, 0.16-0.44%, 0.30-0.67%, 0.27-0.84%, 0.30-0.70%, 0.35-0.80%, 0.53-1.03%, 0.13-0.62% for yellow nut sedge, barnyard grass, *joina*, cheshra, *malancha*, water cress, water taro and *topapana*, respectively. While in case of root, the Ca content ranged from 0.13-0.52%, 0.11-0.35%, 0.22-0.54%, 0.11-0.38%, 0.18-0.46%, 0.41-0.89%, 0.11-0.43% for yellow nut sedge, barnyard grass, *joina, chesra, malancha,* water cress, water taro and *topapana*, respectively. The decreasing trend of Ca with increasing arsenic level might be that arsenic inhibit the accumulation or uptake of calcium as it reduce growth of the weeds.

A correlation matrix was done in order to examine the relationship among soil As and P, S and Ca uptake by different weeds. In all the nutrients only the shoot results are considered here. The values of correlation coefficient 'r' and their level of significance revealed that a strong positive relationship existed among P and S uptake with increased soil As levels.

The correlation results of Ca revealed that a strong negative relationship existed among soil As levels and Ca concentrations. In barnyard grass, *chesra, malancha,* water cress and *topapana* the 'r' values ranges between -0.8* to -0.98** indicating a strong negative relationship. In water taro a negative but weak relationship existed among Ca concentration in shoot and soil As levels, as the 'r' values is -0.445^{NS}. The result showed that higher As concentrations in soil reduced the Ca uptake by the studied phytoremediators.

Finally it can be said that, arsenic has definite interaction with phosphorus, sulphur and calcium which can play significant role on its effect on crop. These interactions should be considered carefully for developing an appropriate phytoremediation technology.

Table 2. Concentration of arsenic (mg kg^{-1}) in different weeds

Treatment	Concentration of As (mg kg^{-1})															
	Barnyard grass		Yellow nut sedge		Joina		Chesra		Water cress		Malancha		Water taro		Topapana	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
T_0	1.10d	4.77f	0.43f	3.67g	1.10d	2.10f	0.77e	4.10e	1.03c	2.40g	0.77f	4.77g	1.10c	3.40f	1.10e	5.43f
T_1	2.10c	5.43ef	1.10ef	6.43f	1.08d	3.87e	1.43de	4.10e	1.03c	4.13f	1.43e	9.43f	1.40c	5.78e	1.10e	6.77ef
T_2	2.10c	6.43e	1.77de	10.10e	1.43d	4.73e	2.10d	10.77d	1.77bc	6.43e	1.77d	17.43e	1.77bc	5.77e	2.10d	7.77e
T_3	2.43c	17.77d	2.43d	11.10d	3.10c	6.77d	1.77de	11.10d	2.10b	8.76d	1.77d	21.43d	1.77bc	7.77d	2.77cd	11.60d
T_4	2.17c	25.43c	3.43c	14.10c	4.50b	18.10c	3.43c	12.43c	2.40b	10.43c	2.43c	22.77c	2.10b	9.10c	3.43c	13.10c
T_5	5.43b	39.10b	6.10b	18.43b	5.10b	22.10b	6.39b	18.13b	3.53a	14.43b	3.77b	26.10b	4.10a	14.10b	4.43b	22.40b
T_6	8.77a	53.10a	8.10a	23.10a	7.43a	35.10a	7.90a	29.10a	4.43a	28.77a	4.10a	35.43a	4.43a	24.10a	8.10a	25.43a
SE	0.21	0.35	0.19	0.15	0.16	0.32	0.28	0.21	0.23	0.18	0.25	0.27	0.15	0.22	0.19	0.34

Table 3. Concentration of phosphorus (%) in different weeds

Treatment	*Concentration of phosphorus (%)*															
	Barnyard grass		*Yellow nut sedge*		*Joina*		*Chesra*		*Water cress*		*Malancha*		*Water taro*		*Topapana*	
	Shoot	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*
T_0	0.139c	0.109d	0.085d	0.051c	0.102c	0.074b	0.108d	0.103f	0.208b	0.163b	0.087c	0.076c	0.219g	0.213f	0.117c	0.087c
T_1	0.150c	0.120cd	0.148cd	0.055c	0.117c	0.104b	0.170cd	0.150e	0.218b	0.166b	0.103c	0.093c	0.254f	0.237e	0.123c	0.123bc
T_2	0.181b	0.138bcd	0.163cd	0.058c	0.167bc	0.124b	0.219bc	0.193d	0.236b	0.199ab	0.126bc	0.129bc	0.312e	0.291d	0.146bc	0.133bc
T_3	0.186b	0.158abc	0.199bc	0.145b	0.246ab	0.136b	0.300abc	0.216c	0.289a	0.227ab	0.128bc	0.132bc	0.322d	0.312c	0.159bc	0.163abc
T_4	0.189b	0.194bcd	0.227bc	0.153b	0.254ab	0.114b	0.288ab	0.256bc	0.324a	0.233ab	0.159abc	0.138bc	0.317c	0.313c	0.177bc	0.206ab
T_5	0.230a	0.218ab	0.271b	0.174b	0.250ab	0.181ab	0.268ab	0.282b	0.325a	0.253ab	0.194ab	0.188ab	0.325b	0.334b	0.227ab	0.176ab
T_6	0.245a	0.258a	0500a	0.370a	0.283a	0.268a	0.326a	0.266a	0.387a	0.318a	0.260a	0.215a	0.394a	0.382a	0.266a	0.220a
SE	0.02	0.01	0.02	0.02	0.03	0.03	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Table 4. Concentration of sulphur (%) in different weeds

Treatment	Concentration of sulphur (%)															
	Barnyard grass		Yellow nut sedge		*Joina*		*Chesra*		Water cress		*Malancha*		Water taro		*Topapana*	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
T_0	0.122c	0.033d	0.102c	0.115c	0.140c	0.101d	0.128c	0.081d	0.133c	0.128d	0.114d	0.117c	0.166f	0.126g	0.141c	0.092c
T_1	0.214bc	0.136cd	0.156c	0.124c	0.175c	0.158cd	0172c	0.164c	0.175c	0.233cdd	0.217c	0.148bc	0.210e	0.159f	0.174c	0.198b
T_2	0.258ab	0.201bc	0.210bc	0.122c	0.179c	0.156cd	0.188c	0.170c	0.249bc	0.264bcd	0.238bc	0.165bc	0.291d	0.264e	0.228bc	0.202b
T_3	0.229bc	0.223abc	0.172bc	0.139c	0.256bc	0.255bc	0.170c	0.189bc	0.336ab	0.351abc	0.268abc	0.224ab	0.319c	0.328c	0.238bc	0.291a
T_4	0.283ab	0.282abc	0.197bc	0.140c	0.268bc	0.256bc	0.206c	0.221bc	0.274bc	0.391ab	0.310ab	0.275a	0.291d	0.304d	0.294b	0.298a
T_5	0.284ab	0.302ab	0.277b	0.325b	0.339ab	0.368ab	0.296b	0.254b	0.417a	0.437a	0.334a	0.253a	0.413b	0.409b	0.309b	0.308a
T_6	0.371a	0.322a	0.486a	0.302a	0.415a	0.406a	0.410a	0.448a	0.419a	0.466a	0.342a	0.295a	0.501a	0.425a	0..376a	0294a
SE	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02

Table 5. Concentration of calcium (%) in different weeds

Treatment	Concentration of calcium (%)															
	Barnyard grass		Yellow nut sedge		*Joina*		*Chesra*		Water cress		*Malancha*		Water taro		*Topapana*	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
T_0	0.44a	0.35a	0.57a	0.52a	0.67a	0.54a	0.84a	0.38a	0.80a	0.46a	0.70a	0.38a	1.03a	0.89a	0.62a	0.43a
T_1	0.31bc	0.32ab	0.51ab	0.28b	0.60a	0.33b	0.77b	0.33a	0.71b	0.37ab	0.59ab	0.36ab	0.60b	0.56c	0.49b	0.43a
T_2	0.35b	0.28ab	0.47ab	0.24bc	0.36b	0.34b	0.51b	0.22b	0.65b	0.34ab	0.54ab	0.34b	0.60b	0.51c	0.33c	0.32ab
T_3	0.27bc	0.23b	0.48b	0.21bcd	0.33b	0.30b	0.44b	0.22b	0.59cd	0.29bc	0.51abc	0.28b	0.55b	0.48cd	0.29cd	0.24bc
T_4	0.25c	0.23b	0.44b	0.21bcd	0.31b	0.35b	0.36c	0.15bc	0.51d	0.29bc	0.34bc	0.22c	0.53b	0.41d	0.23cde	0.30ab
T_5	0.24c	0.22b	0.28c	0.18cd	0.31b	0.29b	0.31cd	0.14bc	0.37e	0.18c	0.31c	0.19c	0.65b	0.50cd	0.18de	0.18bc
T_6	0.16d	0.11c	0.27c	0.13d	0.30b	0.22b	0.27d	0.11c	0.35f	0.18c	0.30c	0.18c	0.69a	0.62b	0.13e	0.11c
SE	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.07	0.03	0.03	0.03

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