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ARSENIC MOBILITY IN SALINE SOIL AND ITS IMPACT ON PLANT GROWTH

Sayeda Sabrina Ali[1], Monira Begum, Muhammad Harunur Rashid
and S. M. Imamul Huq*

Bangladesh Australia Centre for Environmental Research (BACER-DU), Department of Soil, Water and Environment, University of Dhaka, Dhaka-1000, Bangladesh

Abstract

A study was conducted to investigate the mobility of arsenic in saline soil and its consequences on plant growth. Two different types of saline soils, S_1 (2.0 dS/m) and S_2 (5.06 dS/m), collected from the south-western part of Bangladesh were used for the experiment. There were two parts in the experiment, *viz*., *in vitro* incubation study and pot experiment. Arsenic at the rates of 0, 0.05 and 1.0 mg/l was applied to the soil with water and for plant as irrigation water. The soils under incubation were sequentially extracted with seven different extractants *viz*., distilled water, 1M NH_4Cl, 0.01M $CaCl_2$, 0.005M DTPA, 0.1M EDTA, 0.1M HCl and 1M HCl. A local variety of rice, BRRI 41 was grown on the experimental soil as the test crop for pot experiment. The elevated arsenic concentration in the growth medium caused higher accumulation of arsenic as well as sodium in the plant.

Key words: Arsenic mobility, salinity, sodium, rice, plant growth

Introduction

The south-west coastal region of Bangladesh is prone to several types of disasters such as cyclones, tidal surges, floods, drought, salinity intrusions, repeated water-logging, and land subsidence. But impalpable disasters such as increased salinity and arsenic contamination affect local livelihoods and environments of this region. Out of 2.86 million hectares of coastal and off-shore land about 1.06 million ha of arable land are affected by varying degrees of salinity (SRDI 2000) and further degradation will have detrimental consequences on food chain. Salinity damage to rice plants occurs as a result of excessive transport of Na^+ and Cl^- to the shoots (Yeo *et al*. 1999). Salinity associated with excess sodium chloride adversely affects the growth and yield of plants by depressing the uptake of water and minerals and normal metabolism (Akhtar *et al*. 2001, Akram *et al*. 2001).Sodium chloride salts are quickly dissolved in water and play ionic effects in higher plant including rice crop (Nishimura *et al*. 2011). Excess Na^+ in plant cells directly damages membrane systems and organelles, resulting in plant growth reduction and abnormal development prior to plant death (Davenport *et al*. 2005, Quintero *et al*. 2007, Siringam *et al*. 2011).

The high level of arsenic in ground water of Bangadesh is geogenic in origin (Huq 2008). The development of strongly reducing conditions is believed to be responsible for the release of naturally occurring arsenic from the sediment into the ground water. Arsenite is the dominant form in flooded paddy soil (Takamatsu *et al*. 1982) which is considered to be the most toxic form. Upon

*Author for correspondence: <imamhuq@hotmail.com>. [1]Present address: Department of Soil & Environmental Sciences, University of Barisal, Barisal, Bangladesh.

soil flooding during rice cultivation, arsenic in soil is mobilized, taken up by roots, and accumulated in the edible portion of the grains. Arsenic toxicity is responsible for shorter plant height, weaker tillering, thinner leaf coloring, earlier root coloring to yellowish brown or brown, and curled leaves under sunlight in rice plants (Yamane 1989). During the dry season ground water moves upward by capillary action and leaves arsenic in the soil. In addition, dry season aggravate salinity condition too. Moreover, it is found that As acts as soluble salts (Rabbi *et al*. 2007) which increases the possibility of being absorbed by plants instead of local soluble salts. Thus, a possible interaction between salinity and arsenic on rice grown on saline soil may exist. With this view in mind the present work was done to observe the effect of Na on As mobility in two saline soils of Bangladesh.

Materials and Methods

Soil samples were collected from four sampling sites of Khulna, a district situated in the southern part of the country. The soils belong to two representative soil series, namely Dumuria and Bajoa series. According to the USDA soil taxonomy all the series belong to Typic Endoaquepts subgroup (Ali *et al*. 2016). The georeferences of the sampling sites are presented in Table 1.

Both the soil series belong to 'Calcareous Grey' Soils of 'Ganges Tidal Floodplain' physiography. The soil samples were collected following the standard procedures (USDA 1951). The collected soil samples were air-dried, debris were removed and larger aggregates were ground by gently crushing with a wooden hammer. Then the ground samples were sieved by passing through a 0.5 mm and 5 mm stainless steel sieve for *in vitro* incubation experiment and pot experiments, respectively (Ali *et al*. 2016).

Table 1. GPS location of the soil samples.

	Soils for Incubation experiment		Soils for pot experiment	
	S_1 (2-4 dS/m)	S_2(4-8 dS/m)	S_1 (2-4 dS/m)	S_2(4-8 dS/m)
GPS location	22º48'50" and 89º29'32"	22º47'45" and 89º26'55"	22º47'39.1" and 89º27'30.3"	22º46'17.7" and 89º28'10.3"
District	Khulna	Khulna	Khulna	Khulna
Soil series	Dumuria	Bajoa	Bajoa	Bajoa
Determined EC	2.0	5.061	2.1	5.18
Determined pH	6.35	7.28	6.28	7.32

Experimental set-up

Incubation experiment: The incubation experiment was carried out using the two types of saline soils. The detail of the experimental set up has been described in Ali *et al.* 2016. The extractability of Na and As of the soils were determined by sequential extraction process (Chowdhury *et al*. 2010). Seven different extractants were used in the extraction of the elements from the soils, *viz*.

water soluble (H_2O), NH_4Cl extractable (exchangeable) (Krishnamurti *et al*. 1995), $CaCl_2$ extractable (exchangeable) (Ahnstom and Parker 1999), DTPA extractable (organically bound) (Lindsay and Norvell 1978), EDTA extractable (organically bound) (Lindsay and Norvell 1978), 0.1M HCl extractable (CSTPA 1980) and 1M HCl (ANZEC 2000). Sodium content of the above mentioned samples were determined by flame photo analyzer (Huq and Alam 2005) and arsenic content by HG-AAS technique (Huq *et al*. 2008).

Pot experiment: The pot experiment was carried out in a net-house using air-dried soil in earthen pots. The detail of the experimental set-up has been described by Ali *et al.* 2016. The quality control/quality assurance (QC/QA) of the analyses was maintained following the standard procedure. Statistical analysis was done by using Microsoft Excel (2010) version.

Results and Discussion

Initial characteristics of the soil: Some common physical and chemical properties of soil samples were analyzed (Table 2) before the experiment, in order to know the initial status of the soil (Ali *et al*. 2016). In soil samples used for incubation experiment, both Na and As contents were higher in S_2 soil than S_1 soil while, for pot experiment, S_1 soil contained more As than S_2. This is because of the provenance of the experimental soil for the purpose. They were collected from a different spot in the saline area.

Table 2. Initial characteristics of soil.

Soil properties	Soils for incubation experiment		Soils for pot experiment	
	S_1	S_2	S_1	S_2
pH	6.4	7.3	6.3	7.3
EC (dS/m)	2.0	5.1	2.1	5.2
Available N (%)	0.16	0.12	0.22	0.13
Available P (mg/kg)	2.3	15.5	7.7	9.6
Available K(me/100g)	0.02	0.04	0.03	0.1
Available S (mg/kg)	337.4	558.4	100.3	253.8
Soluble Na "	230.1	350.9	121.8	270.3
Total As "	0.32	0.76	3.0	2.8

Interaction of As with Na in soil: Sequential extraction of the incubated soils by seven different extractants showed variation in the extractability of Na and As. This variation was due to different incubation period as well as to different extractants. Efficiency of the extractants can be observed by comparing the order of extractability of different extractants (Table 3). It can be seen that irrespective of soils and incubation periods, relative extractability of Na was higher. The nature of the extractants is supposed to give a better assessment of extractability of elements in soils. For example, 1M HCl is likely to yield a higher value than 0.1M HCl or any other

extractants used in this experiment. However, 0.1M HCl extracted more Na and As than any other extractants for any number of days of incubation (Fig. 1). On the other hand, the situation was quite different for DTPA which extracted the least (Fig. 2) amount of As and Na.

Table 3. Order of extractability of Na and As by extractants.

Treatment of arsenic	Soil type			
	S_1		S_2	
As_0	Na	0.1M HCl> EDTA> 1M HCl> NH_4Cl> H_2O> $CaCl_2$> DTPA	Na	0.1M HCl>1M HCl> NH_4Cl> H_2O> EDTA> $CaCl_2$> DTPA
	As	1M HCl> 0.1M HCl> EDTA> DTPA> NH_4Cl> H_2O> $CaCl_2$	As	0.1M HCl> 1M HCl> EDTA> DTPA> NH_4Cl> H_2O> $CaCl_2$
$As_{0.05}$	Na	0.1M HCl> 1M HCl> EDTA> NH_4Cl> H_2O> $CaCl_2$> DTPA	Na	0.1M HCl> 1M HCl> EDTA> NH_4Cl> H_2O> $CaCl_2$>DTPA
	As	1M HCl> 0.1M HCl> EDTA> NH_4Cl> DTPA> H_2O> $CaCl_2$	As	0.1M HCl> 1M HCl> EDTA> NH_4Cl> $CaCl_2$> DTPA> H_2O
As_1	Na	0.1M HCl> 1M HCl> EDTA> NH_4Cl> H_2O> $CaCl_2$> DTPA	Na	0.1M HCl> 1M HCl> NH_4Cl> EDTA> H_2O> $CaCl_2$> DTPA
	As	1M HCl> 0.1M HCl> EDTA> NH_4Cl> DTPA> H_2O> $CaCl_2$	As	0.1M HCl> 1M HCl> NH_4Cl> EDTA> DTPA> $CaCl_2$> H_2O

The matrix of Na and As extracted by 0.1M HCl and DTPA are shown in Table 4 (a, b) and 5 (a, b) for two soils. It is found from the matrices that 0.1M HCl extracted more Na and As from S_2 soil than S_1 soil. The values being 6,485 ppm for Na and 1.207 ppm for As, both obtained at 60th day of incubation. The high efficiency of 0.1M HCl for extraction of elements was also found by Kashem *et al.* (2007).

Extractability of Na in absence of As in S_1 soil showed that the solubility of Na reduced at 60th day of incubation along with a sharp change from 30th day. Conversely, the condition was reverse for the extracted As. However, with the application of As in soil as treatment at a rate of 0.05 and 1 mg/l caused increasing extractabilities of Na with increasing content of As in soil. The situation was also similar for S_2 soil. The reason behind the phenomenon could be due to the fact that As in soil might form soluble complex with Na. Hence, addition of As can accentuate solubility of Na in soil as sodium arsenite ($NaAsO_2$). Moreover, it is found that the use of 0.1M HCl solution (CSTPA 1980) may reflect bioavailability of elements (Huq *et al*. 2008). It is thus expected that, there is a synergistic interaction between the two elements.

Similar trend was observed for 1M HCl, NH_4Cl, H_2O and to some extent for DTPA. The unbuffered salt solutions like NH_4Cl are able to release metals into solution which are associated with the exchange sites on the soil solid phase (Kashem *et al*. 2007, McLaughlin *et al*. 2000) which make them rapid and simple procedure to extract bioavailable metals (Kashem *et al.* 2007; Beckett 1989). On the other hand, in most cases EDTA showed a contrasting result. This could be

due to the fact that the chelating agents, such as DTPA and EDTA, form complexes with free metal ions in solution and thus reduce the concentration of the free metal ions in solution (Kashem *et al*. 2007).

Table 4 (a). Matrix of Na and As for S_1 soil extracted by 0.1M HCl.

Treatment of As	Extractability of Na (ppm) at three incubation days			Extractability of As (ppm) at three incubation days		
	T_0	T_{30}	T_{60}	T_0	T_{30}	T_{60}
As_0	1155.74	1875.0	389.34	0.0785	0.0275	0.4745
$As_{0.05}$	1278.69	1670.08	2182.38	0.0822	0.0480	0.5110
As_1	1160.86	2643.44	2489.75	0.1970	0.0430	0.5310

Table 4 (b). Matrix of Na and As for S_2 soil extracted by 0.1M HCl.

Treatment of As	Extractability of Na (ppm) at three incubation days			Extractability of As (ppm) at three incubation days		
	T_0	T_{30}	T_{60}	T_0	T_{30}	T_{60}
As_0	1027.66	2131.15	2028.69	0.0915	0.2345	0.5670
$As_{0.05}$	1145.49	2182.38	1567.62	0.2460	0.3622	0.7545
As_1	1242.83	2387.3	6485.66	0.1160	0.3965	1.207

Table 5 (a). Matrix of Na and As for S_1 soil extracted by DTPA.

Treatment of As	Extractability of Na (ppm) at three incubation days			Extractability of As (ppm) at three incubation days		
	T_0	T_{30}	T_{60}	T_0	T_{30}	T_{60}
As_0	23.46	0.0	265.14	0.0333	0.0	0.0415
$As_{0.05}$	23.46	0.0	0.0	0.0545	0.0167	0.2280
As_1	28.55	0.0	0.0	0.1155	0.0	0.0912

Table 5 (b). Matrix of Na and As for S_2 soil extracted by DTPA.

Treatment of As	Extractability of Na (ppm) at three incubation days			Extractability of As (ppm) at three incubation days		
	T_0	T_{30}	T_{60}	T_0	T_{30}	T_{60}
As_0	64.25	0.0	301.85	0.1140	0.0	0.0980
$As_{0.05}$	13.26	0.0	0.0	0.0667	0.0	0.0682
As_1	64.25	0.0	480.31	0.0270	0.0	0.1110

Accumulation of sodium (Na) in rice: Rice grown from this experiment showed significant accumulation of Na in plant root and stem (Table 6). Uptake was calculated by multiplying total

concentration with dry matter production of plant. It is found from Table 6 that, distribution of Na within plant is not homogenous and accumulation of Na is the highest in roots than stem and grain. This result is supported by similar observation by Yamanouchi *et al*. (1987).

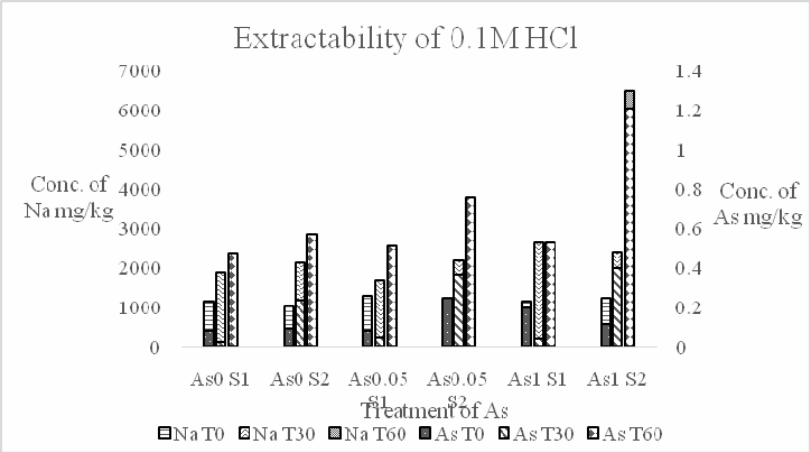

Fig. 1. Extractability of 0.1M HCl for S_1 and S_2 soils for different As treatments.

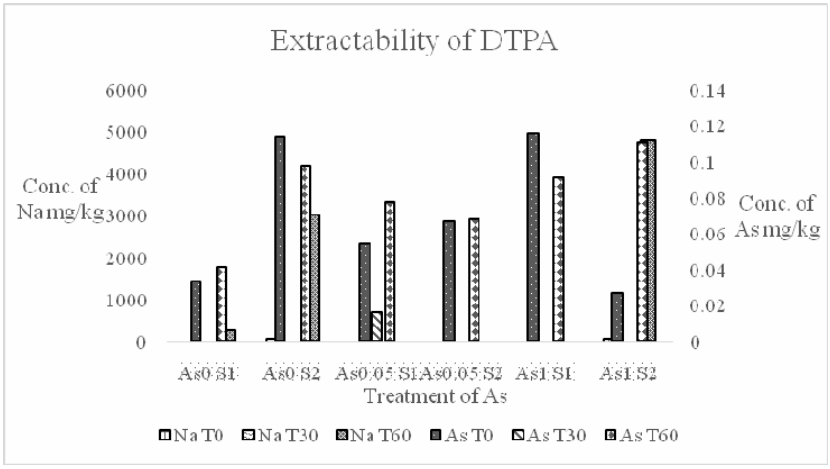

Fig. 2. Extractability of DTPA for S_1 and S_2 soils for different As treatments.

It is also observed from Table 6 that Na content in rice roots and stem increased with As treatments. Thus there might be a synergistic effect between Na and As in plant body. On the contrary, grain of rice had little or no Na and As. This observation corroborates with the results reported by Rabbi *et al*. (2007), which showed that grain of rice contains very little of As. Therefore, it is found that in arsenic treated soil, salinity appeared to have restricted the arsenic

Table 6. Concentration and accumulation of Na in rice.

As treatment	Concentration of Na (mg/kg)				Dry weight of plant (g/100 plants)	Accumulation of Na (mg/100 plants)
	Root	Stem	Grain	Total plant		
As_0	3438.98	862.77	0	4185.42	29.54	123.05
$As_{0.05}$	3489.334	920.97	0	4386.28	163.6	717.60
As_1	5122.987	723.91	318.56	6165.46	63.03	388.61

Table 7. Correlation coefficient between 0.1M HCl extracted Na of soil and Na content of plant.

T_0	Soil Na – Plant root Na	– 0.4434
	Soil Na – Plant stem Na	0.7020
	Soil Na – Plant grain Na	–0.4677
T_{30}	Soil Na – Plant root Na	0.9742**
	Soil Na – Plant stem Na	0.9959***
	Soil Na – Plant grain Na	0.9799**
T_{60}	Soil Na – Plant root Na	0.6332
	Soil Na – Plant stem Na	0.3364
	Soil Na – Plant grain Na	0.6127
T_0	Soil Na – Plant (root+stem) Na	–0.4112
T_{30}	Soil Na – Plant (root+stem) Na	0.6612
T_{60}	Soil Na – Plant (root+stem) Na	0.9653**
T_0	Soil Na – Plant (root+stem+grain) Na	–0.4212
T_{30}	Soil Na – Plant (root+stem+grain) Na	0.9899**
T_{60}	Soil Na – Plant (root+stem+grain) Na	0.6528

accumulation in grain of rice. Besides the significant positive relationship between Na content of 0.1M HCl extracted soil and Na content of plant suggests that 0.1M HCl could be used to indicate the bioavailability of Na to rice (Table 7**)**. The strong positive correlation indicates that increasing solubility of Na in soil can cause higher accumulation of Na in plant. Again, solubility of Na is a factor of availability of As in soil.

Conclusion

The results indicate a synergistic effect between Na and As which lead us to conclude that a high concentration of arsenic in the soil might augment the presence of Na in salt affected soils. Both salinity and arsenic affected plant growth. The higher was the arsenic concentration in soil, the higher was the solubility of Na in soil and consequently higher Na accumulation in plant. But grain of rice was free from both As and Na toxicity. The present study reveals a synergistic impact of As and Na on plant growth. Further studies are needed at field level to substantiate these observations.

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