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RETENTION OF ARSENIC, LEAD AND CADMIUM IN SOIL AND THEIR SUBSEQUENT UPTAKE BY PLANTS

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Abstract

A laboratory based column leaching experiment was set up to study the retention of As, Pb and Cd in three Bangladesh soils (Ghatail, Tejgaon and Sonatola soil series) and their subsequent uptake by plants (*Ipomoea aquatica*). The higher the clay contents and the pH values in soils, the higher was the elements retained by the soils and lesser was the transfer of the elements to the growing plant. Retention of As, Pb and Cd followed the order: Ghatail>Tejgaon>Sonatola while the transfer to plant was in the order of Sonatola> Tejgaon> Ghatail. Retention of As showed a decreasing tendency at high solution concentration whereas Pb and Cd retentions showed an increase with increasing solution concentrations.

Key words: Arsenic; Lead; Cadmium; Retention; Leaching; Plant uptake

Introduction

Waste disposal from various industries, municipal dumping in the urban areas and increased use of agrochemicals are of great environmental concern. Indiscriminate disposal of industrial wastes, urban city wastes, sewage sludge etc. are generally major sources of heavy metal contamination in soils and water bodies (Singh and Kansal 1985). Cadmium contaminated phosphatic fertilizers (Cook and Morrow 1995), industrial effluents and sewage sludge applied to soils for crop production (Rao and Mathur 1999) have alarmed environmentalists about harmful accumulation of these elements in soils. Besides, arsenic is a major contaminant of groundwater in Bangladesh. One of the potential exposure pathways to As ingestion is through the food chain where arsenic contaminated groundwater is used for irrigation and there is a possibility for increased concentrations of the element in soils (Imamul Huq *et al.* 2003). In addition, these elements enter into the food chain through their accumulation in vegetables, fruits and cereal crops (Imamul Huq *et al.* 2000) and ultimately end up in human and animal bodies causing various disorders. Much research have been conducted on soil heavy metal pollution from various anthropogenic sources such as industrial wastes (Ma and Rao 1997), mining activity (Xian 1989), urban city waste, improper land filling (Singh and Kansal 1985), sewage and industrial effluent irrigation (Wiger *et al.* 1999) and motor vehicles that use leaded gasoline (Imamul Huq and Nazrul Islam 1999). The movement of heavy metals in soil profiles has received considerable attention, since even a slow transport through surface and subsurface soils may result in increased leaching of heavy metals to the groundwater with consequent deterioration of ground water quality (Zhenbin Li and Shuman 1997).

The fate of these elements in soil is affected by the specific or exchange adsorption at mineral interfaces (Joardar *et al.* 2005a, b and c), the precipitation of sparingly soluble solid phases, and the formation of relatively stable organo-metal complexes or chelates with the organic matter in soil (NSF 1977). The objectives of the present study were to study the retention (sorption and/or chemically inactive) and leaching of As, Pb and Cd in soils with different clay contents and to see the relationship between the retained elements and the amount taken up by growing plants.

Materials and Methods

Soil samples of three different series *viz.* Sonatola, Tejgaon and Ghatail series were collected from three different locations on a composite soil sampling basis as suggested by Imamul Huq and Alam (2005). The samples were air dried and sieved through a 2.0 mm sieve, then mixed thoroughly and stored for the experiment and a portion of the samples was broken again and sieved through a 0.5 mm sieve for further analysis.

Experimental set-up

To observe the retention and consequently the leaching of As, Pb and Cd through a mass amount of soils, soil columns of different lengths were made. For the columns, PVC pipes of 5.08 cm diameter with different lengths were used. The length of the soil columns were chosen on the basis of soil texture and compaction. As such the length of the soil columns for Sonatola and Tejgaon soils each were 65 cm and for Ghatail soil it was 21 cm. There was a 10 cm height of water table above the three soil columns. So, the total length of the PVC pipe for Sonatola and Tejgaon soils was 75 cm and 31 cm for Ghatail soil. The volume of soil for Sonatola and Tejgaon soil was 1317.44 cubic centimeters and 410.25 cubic centimeters for Ghatail soil. The weight of the total soil in the column for both Sonatola and Tejgaon soil was 1.71 kg and 0.55 kg for Ghatail soil. Outlets were made at the bottom of the column to collect the leachate. Deionized water was used for control treatment and specified concentration of As, Pb and Cd in solution was used for the treatments. Three treatments (0, 0.5 and 1.0 mg /l) for each element and a sum of 3, 4 and 4 liters of solution were added to Ghatail, Sonatola and Tejgaon soil, respectively.

Table1. Some properties of the selected soils.

Parameters	**Sonatola**	**Tejgaon**	**Ghatail**
Sand (%)	19	59	6
Silt (%)	71	22	45
Clay (%)	10	19	49
Textural class	Silt loam	Sandy loan	Silt clay
pH	5.4	5.7	6.1
Field capacity (%)	25.5	26.7	21.7
Organic matter (%)	1.2	1.17	1.31
Total N (%)	0.09	0.10	0.1

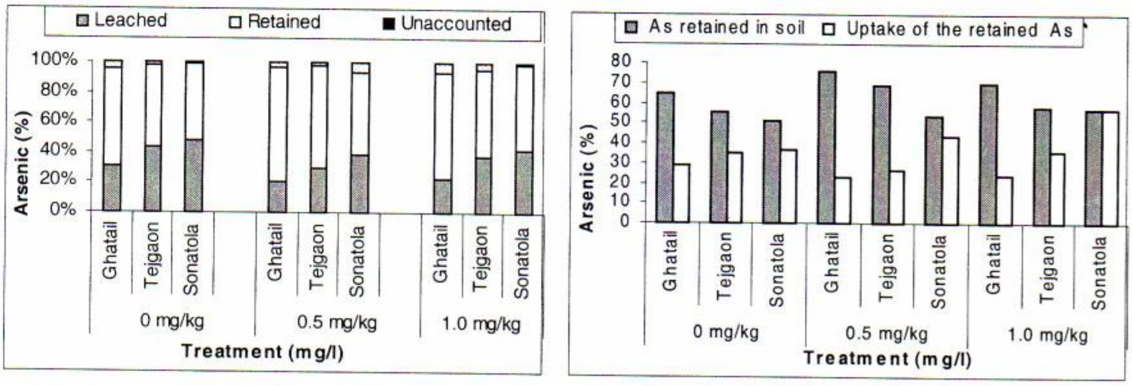
The leachate was collected for 24 hours since beginning of the experiment. The concentration of the element in collected leachates for each element was determined and from this, the retention and leaching capacity of the respective soils were calculated. After completion of the leaching experiment, the soil of the plastic pipe was air-dried and transferred to small plastic pots for plant growth. Four seeds of "Gima kalmi" (*Ipomoea aquatica*) were sown in each of the pots and allowed to germinate. The pots were arranged in the nethouse in a completely randomized design. Positions of the pots were changed every alternate day to allow equal exposure of each of the pots to sunlight. Plants received only tap water every alternative day from seed sowing till plant harvest. Adequate plant protection measures were taken. The plants were allowed to grow for three weeks after the emergence of plants. Then the plants were harvested by uprooting them. The harvested roots were washed with deionized distilled water several times to remove the soil adhering to them and to free the ions from the root free space. The aerial parts of plants were also washed. The collected plant samples were first air-dried and then oven dried at 70°±5°C for 48 hours and the dry weights of plant sample were measured. The dry plant samples were then ground and passed through a 0.2 mm sieve for further analysis. After harvesting, soil samples from each pot were also collected from the rhizosphere and prepared for further analysis as mentioned earlier.

Various physical, chemical and physiochemical properties of the soils were determined (Table 1) following procedures described by Imamul Huq and Alam (2005). Plant samples were extracted with HNO_3 while the soils were extracted with aqua-regia (Portman and Riley 1964) for As and other heavy metal analysis. Both plant and soil were analyzed for total arsenic by hydride generated atomic absorption spectrometry (HG-AAS), while lead and cadmium were analyzed by AAS. Certified reference materials were carried 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. Each batch of 20 samples was accompanied with reference standard samples to ensure strict QA/QC procedures.

Results and Discussion

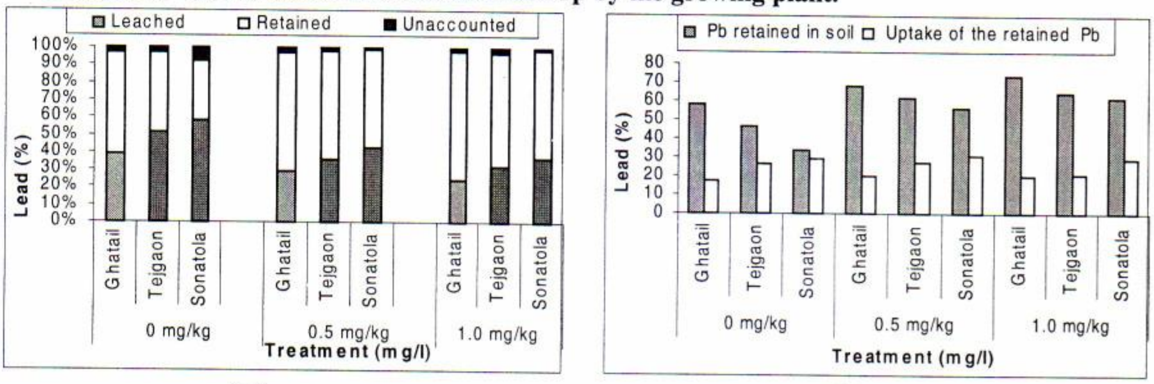
Leaching

Leaching of As, Pb and Cd in the selected soils as affected by clay content and solution concentrations are presented in the Figures 1, 2 and 3. It was observed that the maximum amount of As, Pb and Cd was leached through Sonatola soil followed by Tejgaon soil, whereas the least amount was leached through Ghatail soil. The highest As leaching was from Sonatola soil at control (48% of the total As present in the soil column) and the minimum was from the Ghatail soil at 0.5 mg As/kg treatment (21% of the total As in the column). Lead leaching was as high as 59% of the total amount present in the soil column of Sonatola soil at control and as low as 24% of the total amount from Ghatail soil at 1.0 mg As/kg treatment. Cadmium leaching followed the same as that of Pb with the maximum of 52% for Sonatola and the minimum of 20% for Ghatail of the total amount of Cd present in the soil column. The leaching of As increased with increasing As concentrations in solution.



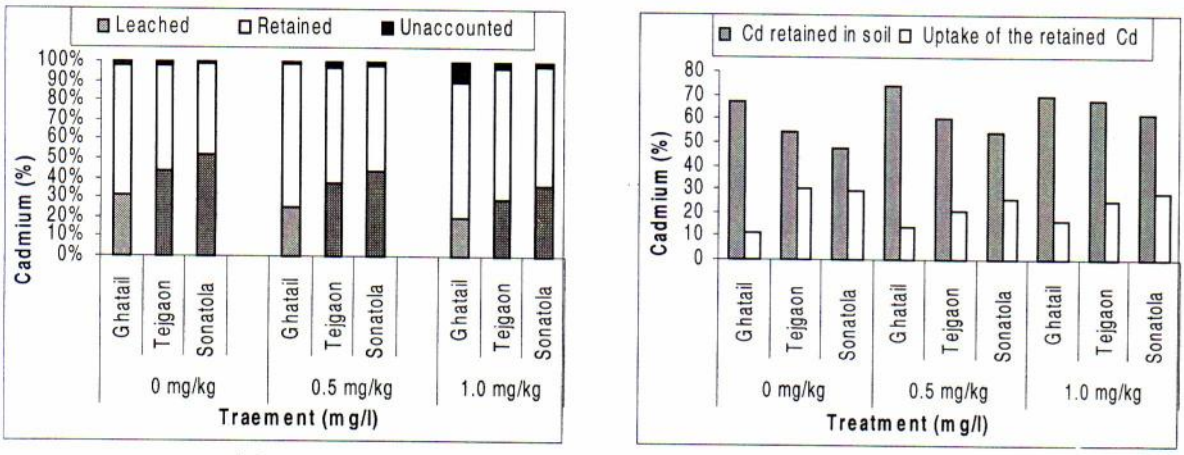
(a) (b)

Fig. 1 (a) Percent of applied As leached through soil column, retained and unaccounted for at different treatments. (b) Percent of retained As taken up by the growing plant.



(a) (b)

Fig. 2 (a) Percent of applied Pb leached through soil column, retained and unaccounted for at different treatments. (b) Percent of retained Pb taken up by the growing plant.



(a) (b)

Fig. 3 (a) Percent of applied Cd leached through soil column, retained and the unaccounted for at different treatments. (b) Percent of retained Cd taken up by the growing plant.

However, the contents of Pb and Cd in the leachate decreased with increasing solution concentrations. From the leaching study it became apparent that the leaching was controlled by the clay fraction present in the soil. For all the three elements, the amount leached out was inversely related to the clay contents of the soils. On the basis of clay content, the leaching was in the order: Ghatail > Tejgaon > Sonatola. For the individual elements, the leaching order: Sonatola> Tejgaon> Ghatail, respectively for As, Pb and Cd. The observation agrees well with the findings of Joardar *et al.* (2005a) for arsenic. They observed a positive relationship of adsorption between the clay and As content in the soil. It has been observed that Pb is highly immobile in clay dominated soil due to its adsorption to the clay surfaces (Joardar *et al.* 2005b). According to Joardar *et al.* (2005c) the mobility of Cd in clayey soil is mostly reduced due to adsorption to soil clays. Correlation between the clay content and the leaching of As, Pb and Cd were made. The 'r' values were -0.808, -0.522 and -0.787 for As, Pb and Cd, respectively. It needs to be mentioned here that the clay contents of the three soils were: Ghatail soil (49%), Tejgaon soil (19%) and Sonatola soil (10%).

The solution concentration of As, Pb and Cd also affected their leaching from the soil. It was observed that the leaching of As increased with increasing As concentrations in the solution while the leaching of Pb and Cd decreased with increasing concentrations of the elements in solution. This was noticed in all the cases. The solution effect was prominent in the present case. Correlation between the solution concentration of As, Pb and Cd and the leaching of each element was calculated. The values of 'r' were 0.306, -0.747 and -0.600 for As, Pb and Cd, respectively. The values for As was positively correlated but the values for Pb and Cd were negatively correlated *i.e.*, the more the solution concentration, the less the amount leached from the soil. It needs to point out here that the control soils showed leaching of some As. It has been observed that the water extractable fraction (if present) of As is bioavailable and may become more important than the total soil As (Imamul Huq *et al.* 2003).

Regression equations were calculated using the values of clay content of the soils, the solution concentrations and the amount of each of the elements in the leachate where clay content of the soil and the solution concentration were the independent variable-X_1 and X_2, the amount of the element in the leachate was the dependent variable Y. The equations were: $Y=48.37-0.44X_1-7.0X_2$ (for As), $Y=58.52-0.38X_1-19.33X_2$ (for Pb) and $Y=54.36-0.45X_1-14.0X_2$ (for Cd). The values of R^2 were 0.75, 0.91 and 0.98 for As, Pb and Cd, respectively.

Retention

The retention of As, Pb and Cd in all the soils was also estimated. The results are shown in the Figures 1, 2 and 3. It was observed that the maximum amount of As, Pb and Cd was retained in Ghatail soil followed by Tejgaon soil with the least in Sonatola soil. The retention of As was at the maximum in Ghatail soil with 76% of the applied As retained at 0.5 mg As/kg treatment while the least was in Sonatola soil with 51% retained at control. The maximum percent of Pb that was retained in Ghatail soil at 1.0 mg As/kg treatment was 74% and the minimum was 34% in Sonatola soil at control.

For Cd, the maximum (74%) retention occurred in the Ghatail soil while the minimum (47%) in the Sonatola soil. Clay content of the soils has been found to control the retention of As, Pb and Cd in soils. The higher the clay contents in soil, the higher were the elements retained in the soils. Ghatail soil containing 49% clay, which was more than either Tejgaon (19%) or Sonatola soil (10%), retained the maximum amount of each of the elements. The retention of As, Pb and Cd followed the order: Ghatail>Tejgaon>Sonatola. The results agreed well with the observations made by Joardar *et al.* (2005a) for arsenic, Joardar *et al.* (2005b) for lead and Joardar *et al.* (2005c) for cadmium. Correlation between the clay content and the amount of As, Pb and Cd retained by the soils were calculated. The values of 'r' were 0.532, 0.522 and 0.796 for As, Pb and Cd, respectively. The clay content of the soils and the amount of retained elements were positively correlated signifying the fact that a clayey soil will retain more of the contaminants. Besides, the pH of the corresponding soil had played an important role in the retention of the elements. The retention increased with increasing soil pH. The observation that pH has a role to play in the adsorption of As and other elements has been reported by Imamul Huq *et al.* (2003).

The solution concentration of As, Pb and Cd also affected the retention of each element in soils. It was observed that the retention of As showed an increase with increasing solution concentration at lower level but decreased at higher concentration (1.0 mg/kg). The maximum retention of As was observed at 0.5 mg As/kg treatment. It could be due to the fact that up to a certain limit the retention continues. Beyond this, the adsorption sites for As might have been saturated thereby causing a no adsorption situation. But in case of Pb the adsorption continued with increasing solution concentration. However, for Cd, observation similar to that for As was made. Correlation between the treatment concentration and the adsorption of As, Pb and Cd by soils was calculated and the values of 'r' were 0.330 for As, -0.763 for Pb and 0.584 for Cd.

Regression equations were calculated using the clay content, the treatment concentration and the retention of As, Pb and Cd. Here, the clay content of the soil and the treatment concentration were the two independent variables X_1 and X_2, the amount of each element retained in soil was the dependent variable Y. The equations were: $Y= 50.57 +0.26X_1 + 8.00X_2$ (for As), $Y= 38.84 +0.36X_1 + 21.67X_2$ (for Pb) and $Y= 34.71 +0.78X_1 + 14.33X_2$ (for Cd). The R^2 values were 0.45, 0.85 and 0.89 for As, Pb and Cd, respectively.

Uptake of As, Pb and Cd by the plants

The amount of the retained As, Pb and Cd taken up by the growing plant (*Ipomoea aquatica*) from the soils are presented in Figure 1, 2 and 3. It was observed that the maximum amount of As, Pb and Cd was accumulated from Sonatola soil followed by Tejgaon soil whereas the minimum was from the Ghatail soil. The plant accumulated as high as 57% of the retained As from Sonatola soil at 1.0 mg As/kg treated soil, whereas the minimum (23%) of the retained As was accumulated from Ghatail soil at 0.5 mg As/kg treatment. For Pb and Cd the maximum percent accumulation was not as high as As. Only 31% of the retained Pb was accumulated from Sonatola soil at 0.5 mg As/kg treated soil and 30% of the retained Cd was accumulated from Tejgaon soil at control.

The lowest accumulation of Pb was 17% in the control treatment of Ghatail soil while for Cd, it was only 11% in the same soil for the same treatment. Though Cd accumulation was high for Ghatail soil in all cases yet the maximum accumulation was found for Tejgaon soil in the control treatment. Clay was found to have a direct relation with the uptake of all the elements by plant. Because of high clay content in Ghatail soil, most of the As, Pb and Cd became immobile in this soil that caused a low bioavailability of the elements. Tejgaon soil has relatively higher clay content than that of Sonatola soil and consequently, the uptake was lower from Tejgaon soil compared to that from Sonatola soil. According to Oellen (1997), the uptake of Cd was higher from coarse textured soil than from fine textured soil. Correlation between the clay content and the uptake of As, Pb and Cd was computed. The values of 'r' were -0.735, -0.892 and -0.922 for As, Pb and Cd, respectively. The negative values of 'r' are indicative of the negative influence on bioavailability of these contaminants in soils.

The treatments seemed to have an effect on the subsequent uptake of the elements by the crop. Again, the soil properties like the pH and clay contents appeared to have played an important role in this regard too. The uptake of As from Sonatola soil increased with increasing As concentration, whereas from Tejgaon soil the level of As uptake decreased from control to treatment of 0.5 mg/kg but it slightly increased at higher treatment (1.0 mg/kg) and from Ghatail soil the As uptake decreased slightly with increasing treatment concentration. For Pb, from Sonatola soil, the uptake increased from control to treatment 0.5 mg/kg and it decreased slightly at higher treatment (1.0 mg/kg). The same trend was observed in Tejgaon soil. But in case of Ghatail soil the uptake increased slightly with increasing treatment concentration. For Cd, from Sonatola soil, the uptake decreased from control to treatment of 0.5 mg/kg and it increased slightly at higher treatment (1.0 mg/kg). A similar trend was observed in Tejgaon soil. But in case of Ghatail soil the uptake trend was similar to that of Pb. Correlation coefficients (r) between the uptake and applied concentration of As, Pb and Cd were found out, the 'r' values being 0.214, -0.52 and 0.021 for As, Pb and Cd, respectively.

Regression equations were calculated between uptake of the elements by kalmi (Y) and the clay contents of the soils (X_1) & the applied concentration of As, Pb and Cd (X_2). The equations were $Y=43.45-0.45X_1+5.33X_2$, $Y= 31.34-0.25X_1+0.13X_2$ and $Y = 31.92-0.37X_1+0.33X_2$ for As, Pb and Cd, respectively. The values of R^2 were 0.586, 0.798 and 0.85 for As, Pb and Cd, respectively.

It is apparent from the present experiments that the clay content of a soil will have a positive role to play against contamination of the groundwater by controlling the leaching of them, particularly As, Pb and Cd. Moreover, the adverse effect of the addition of these contaminants to soil and their subsequent entry into the food chain could also be contained in heavy soils. The lighter soils represent a greater risk to contaminate both the groundwater aquifers as well as the food chain.

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