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Effect of Iron Dust on Arsenic Accumulation and Nutrient Status of *Ipomoea aquatica* Grown in Arsenic Contaminated Soil

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ABSTRACT

A pot experiment was conducted to evaluate the effect of iron dust on arsenic accumulation and nutrient status in *Ipomoea aquatica* considering the fact that the iron has the ability to react chemically with arsenic and to form different complexes which can reduce the bioavailability of arsenic. The experimental soil was artificially contaminated with sodium metaarsenite ($NaAsO_2$) at the rate of 50 mg kg^{-1}. Three treatments (1, 2 and 3%) of Fe-dust were applied to the arsenic contaminated soil along with the control. The plant *Ipomoea aquatica* under the family of Convolvulaceae was cultivated in the present experiment. Twenty four days after seed sowing, the plant was harvested and analyzed for arsenic and other elements. The arsenic concentration in the edible part of the plant was measured as 7.12±0.91, 8.19±0.81 and 4.16±0.5 mg kg^{-1} in 1, 2 and 3% iron-dust applied plants, respectively and the As concentration was 11.06±0.52 mg kg^{-1} in control plant. It was found that both the arsenic concentration (mg kg^{-1}) and arsenic uptake (mg $plant^{-1}$) was decreased significantly ($p<0.05$) with the application of Fe-dust in arsenic contaminated soil. Potassium and zinc concentration was significantly ($p<0.05$) decreased in the plant part. The results showed that the application of iron dust in the arsenic contaminated soil could be an effective strategy in reducing arsenic uptake in plant.

Key words: Arsenic, soil, iron-dust, *Ipomoea aquatica*, nutrient

INTRODUCTION

Arsenic is one of the most toxic elements of the environment (Hudson-Edwards *et al*., 2004). Arsenic contaminated groundwater is used for cultivation by the farmer as irrigation water during the dry season. Many researchers reported that long-term irrigation with As-contaminated water resulted in arsenic accumulation in the soil. Imamul Huq *et al*. (2003) reported that the concentration of soil arsenic in some parts of Bangladesh is more than 30 mg kg^{-1}. This arsenic accumulation in soil varied depending on the arsenic concentration in irrigation water. Hence, arsenic contaminated groundwater when used for irrigation, led to the accumulation of arsenic in soil and the eventual exposure of the food chain through plant uptake and animal consumption (Imamul Huq and Naidu, 2005), ultimately poses long term risk to human health

(Duxbury *et al.*, 2003). So, it is required to reduce the bioavailability of arsenic to hinder the entering into the food chain. There are several strategies for removing arsenic from drinking water. But there is no available technology to reduce arsenic if the soil is contaminated with arsenic. It is also difficult to clean and remove the arsenic from the arsenic contaminated soil. Kumpiene *et al.* (2007) reported that soil amendments can absorb, bind, or co-precipitate the contaminating elements in soil. Several iron-bearing additives are used for remediation of arsenic from arsenic contaminated soil like goethite (α-FeOOH), iron grit, iron (II) and (III) sulphates (plus lime) and lime (Hartley *et al.*, 2004). Ford (2002) reported that arsenic is formed complex by co precipitating with Fe oxides. Hartley *et al.* (2004) also reported that the binding of arsenic to the amendment material reduces its mobility and bioavailability in the soil, making the long-term stability of the new compounds formed. Baked pig manure (Joardar *et al.*, 2013), asclite (Joardar *et al.*, 2014) and some P containing materials (Joardar *et al.*, 2013) are also used for reducing arsenic uptake in plant. Lidelow *et al.* (2007) suggested that the efficiency of the remediation treatments depends on the soil characteristics, the sorption capacity of the Fe source used as amendment and the environmental conditions to which the treated soil is exposed. Among the numerous inorganic amendments in reducing arsenic availability, Fe minerals and Fe industrial by-products are considered to be the great potential for *in situ* remediation (Mench *et al.*, 1998) of arsenic. To keep this in mind that the present study was conducted with iron-dust, collected from steel making factory, to develop a cost-effective, non-toxic, environmental friendly soil additive that could reduce the As concentration in plants through uptake from arsenic contaminated soil and to observe the changes of nutrient concentration in plant at that time.

MATERIALS AND METHODS

Experimental design: The pot experiment was carried out under glasshouse condition. The experimental design was Complete Randomize Block Design (CRD).

Soil collection and preparation: Soil was collected from the agricultural field situated behind the Khulna University, Khulna, Bangladesh (22°48'12.9"N 89°31'46.1"E), following the composite soil sampling method as suggested by the soil survey staff of the USDA (Soil Survey Staff, 1951). The soils were air dried, grinding and sieved through a 2 mm sieve. A small portion of the soil samples was stored for laboratory analysis. The characteristics of the soils used in the experiment are presented in Table 1.

Table 1: Physical and chemical properties of soil used in the experiment

Parameters	Result
Soil texture	Silty clay loam
pH	5.70
EC (mS m^{-1})	0.75
Available N (%)	0.045
Available P (mg kg^{-1})	2.12
Available K (mg kg^{-1})	77.24
Available S (mg kg^{-1})	46.69
Available Fe (%)	0.02
Available Mg (%)	0.061
CEC (meq/100 g soil)	19.30
OM (%)	1.94
Total As (mg kg^{-1})	1.04

Experimental set-up: There were a total of 15 pots in the experiment. Six hundred gram of soil was taken in each of the pot with 700 mL size. Then iron oxide was mixed thoroughly with soil of each pot except control. Three rates of iron-dust (1, 2 and 3%) were applied and in each cases 3 replications were done. Soil was artificially contaminated with arsenic at the rate of 50 mg kg^{-1} to the each of the pot except control. Sodium metaarsenite ($NaAsO_2$) salt was used as a source of arsenic. After the application of arsenic it was incubated for two weeks. After incubation period, 12-15 seeds were sown in each experimental pot and the pots were arranged in randomly and rearranged every four days for uniform distribution of sun light. Six days after seeds sowing, seedlings were thinned and only five seedlings were remained. After 20 days, second thinning were done and only three plants remaining. The plants were harvested 42 days after seed sowing.

Plant processing: After harvesting the plants, samples were washed with distilled water to remove the adhering soil particles. The plant samples were then dried in a fan-forced oven at 60±5°C for 48 h, grinding using a stainless steel grinder, sifted through a 0.2 mm sieve and stored in plastic vials for further analysis.

Measurement of arsenic and other elements: The plant samples were digested with a mixture of concentrated nitric acid and perchloric acid. The soil sample was digested with aqua regia [HCl:HNO_3, 3:1, (v/v)]. The digested plant and soil samples were analyzed for As and other elements using an atomic absorption spectrophotometer (Thermo Scientific iCE 3000 Series Atomic Absorption Spectrometer) according to the previously published protocols (Imamul Huq and Alam, (2005). Reagent blanks and internal standards were used to ensure the accuracy and precision of the analyses. The arsenic concentration was expressed as mg kg^{-1} DW whereas the arsenic uptake was expressed as mg $plant^{-1}$.

Statistical analyses: The data was statistically analyzed by using the common statistical software MINITAB 14.0 and the graphs were drawn by using Microsoft Excel.

RESULTS AND DISCUSSION

Effect of iron-dust on the concentration of plant arsenic: Arsenic concentration (mg kg^{-1} DW) in the edible part of the plant was found to be decreased due to the application of iron-dust in the arsenic contaminated soil. In the control plants, the arsenic concentration was found as 11.06±0.52 mg kg^{-1} which was higher than that of the arsenic concentration of all iron-dust applied plants (Fig. 1). Arsenic concentration in the plant part was measured as 7.12±0.91, 8.19±0.81 and 4.16±0.5 mg kg^{-1} after the application of 1, 2 and 3% iron dust, respectively. In all the cases of iron dust applied soil, the arsenic concentration of plant part was reduced significantly as compared to the control plant. Among the iron dust applied plants the arsenic concentration of 3% applied plants was reduced significant higher than that of 1 and 2% applied plants. But there was no significant differences between 1 and 2% iron dust applied plants. The results showed that the arsenic concentration in plant part was attenuated with the application of iron dust mixing with the arsenic contaminated soil. This result might be due to the complex formation of arsenic with Fe oxide which attenuates the availability of arsenic for plant. The present study data agrees with the findings of other researchers (Hartley and Lepp, 2008; Yang *et al.*, 2007). Smith *et al.* (1998) reported that arsenic has a high affinity for Fe and Al oxides. Yang *et al.* (2007) also reported that the surface complexation of arsenic on ferric hydroxide is the major mechanism for reducing the availability of arsenic to plant through the fixation process.

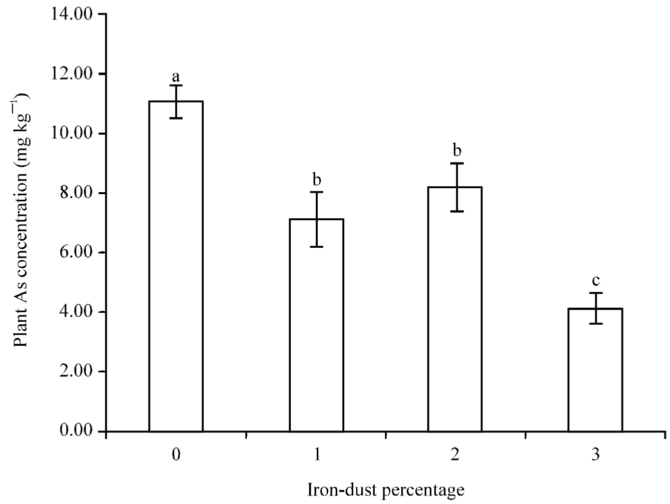

Fig. 1: Arsenic concentration (mg kg^{-1}) in the edible part of *Ipomoea aquatica* after the application of iron-dust, Different letters on bars indicate the significant difference ($p<0.05$). Error bars represent the standard deviations (SDs)

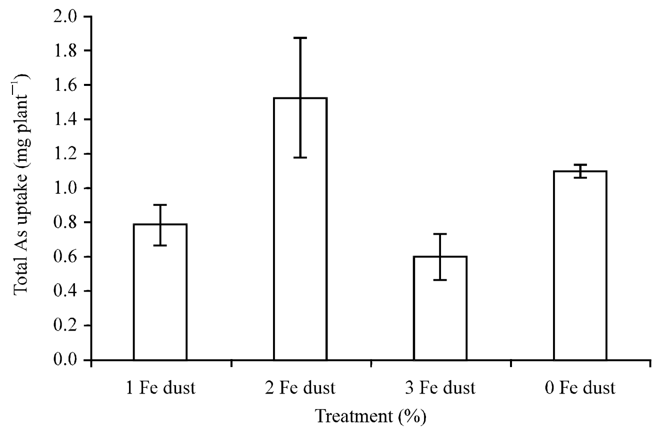

Fig. 2: Total arsenic uptake (mg plant^{-1}) in the edible part of *Ipomoea aquatica* after the application of iron-dust in arsenic contaminated soil. Different letters on bars indicate the significant difference ($p<0.05$). Error bars represent the standard deviations (SDs)

Effect of iron-dust on plant arsenic uptake: Arsenic uptake (mg plant^{-1}) in the edible part of the plant was observed to be decreased due to the application of iron-dust in the arsenic contaminated soil. In the control plants the arsenic uptake was determined as 1.1±0.62 mg plant^{-1} which was higher than that of the arsenic uptake of all iron-dust applied plants except 2% iron-dust plants. Arsenic uptake in the plant part was found as 0.79±0.12, 1.53±0.35 and 0.6±0.13 mg plant^{-1} after the application of 1, 2 and 3% iron-dust, respectively. Among the iron-dust applied plants the arsenic uptake of 2 and 3% applied plants was reduced significantly ($p<0.05$) compare to control plants (Fig. 2). The experiment outcome showed that the arsenic uptake in plant part was attenuated with the application of iron-dust mixing with the arsenic contaminated soil. This finding might be due to the complex formation of arsenic with Fe oxide which attenuates the availability of arsenic for plant. McBride (1994) suggested that arsenic form ternary complexes with Fe and Al oxide surfaces which reduces its bioavailability for plant. Yang *et al.* (2007) also reported that the surface complexation of arsenic on ferric hydroxide is the major mechanism for reducing the availability of arsenic to plant through the fixation process. The present result was supported by the outcome of other researchers (Hartley and Lepp, 2008).

Effect of iron-dust on the concentration of plant potassium: Except 1% iron-dust applied plant, potassium percentage in the edible part of the plant was found to be decreased due to the application of iron-dust in the arsenic contaminated soil. In the control plants the potassium percentage was measured as 8.33±0.66 which was higher than that of the potassium concentration of 2% (4.79±1.85%) and 3% (6.15±0.49%) iron-dust applied plants (Fig. 3), but less than that of 1% (10.44±3.6%) iron-dust plant. In case of 2 and 3% the iron-dust applied plants the potassium concentration in plants part was reduced significantly ($p<0.05$) compared to control. But there was no significant ($p<0.05$) differences between 2 and 3% iron-dust applied plants for potassium concentration. The present findings revealed that the potassium concentration in plant part was attenuated with the application of iron-dust mixing with the arsenic contaminated soil. No reports are available regarding to potassium concentration in plant at different iron-dust application in arsenic contaminated soil.

Effect of iron-dust on zinc concentration in plant: Percentage of zinc in the vegetative part of the iron-dust applied plant was determined to be decreased due to the application of iron-dust in the arsenic contaminated soil. Zinc concentration in all the iron-dust applied plants was lower than that of control plants as 0.28±0.12% (Fig. 4). Zinc concentration in the plant part was found as 0.12±0.007, 0.09±0.053 and 0.05±0.017% after the application of 1, 2 and 3% iron-dust, respectively. In all the cases of iron-dust applied soil, the zinc concentration of plant part was reduced as compared to the control plant. Decreasing rate of zinc concentration in plant might be due to the antagonistic relationship between zinc and iron (Malvi, 2011). The present study agrees with the study of other researchers as excessive iron reduces zinc uptake (Malvi, 2011).

Effect of iron-dust on concentration of plant Na, Mn and Fe: Except 1% iron-dust applied plant, sodium percentage in the edible part of the plant was found to be decreased due to the

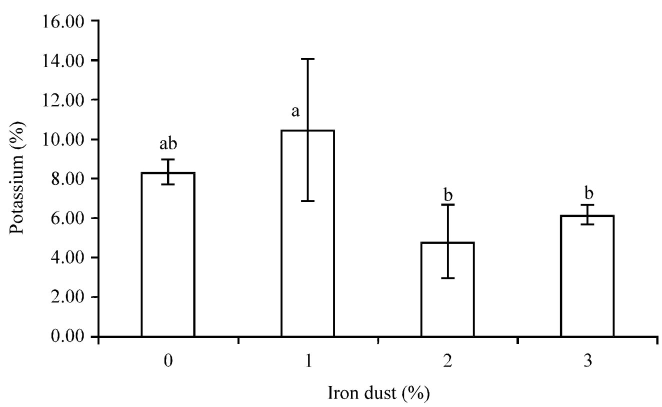

Fig. 3: Potassium concentration (mg kg^{-1}) in the edible part of *Ipomoea aquatica* after the application of iron-dust. Different letters on bars indicate the significant difference ($p<0.05$). Error bars represent the standard deviations (SDs)

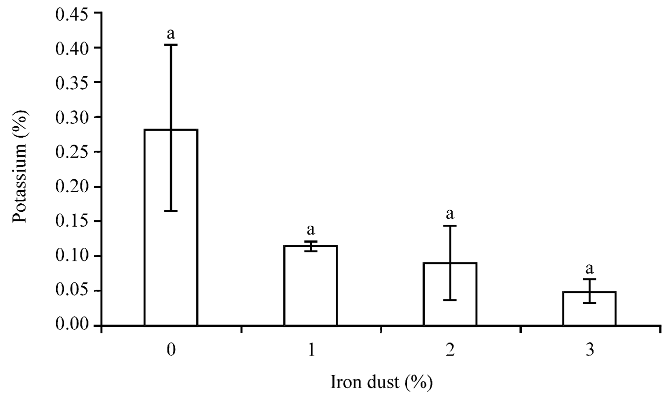

Fig. 4: Zinc concentration (%) in the edible part of *Ipomoea aquatica* after the application of iron-dust in arsenic contaminated soil. Different letters on bars indicate the significant difference ($p<0.05$). Error bars represent the standard deviations (SDs)

Table 2: Na, Mn, Fe concentration (%) in vegetative plant part after the application of different concentration of iron-dust in arsenic contaminated soil

Treatment (%)	Na (%)	Mn (%)	Fe (%)
0 Fe dust	2.37 ± 0.52^{b}	0.01 ± 0.0017^{a}	0.07 ± 0.010^{ab}
1 Fe dust	3.35 ± 0.55^{a}	0.02 ± 0.0028^{a}	0.09 ± 0.009^{a}
2 Fe dust	1.45 ± 0.23^{bc}	0.02 ± 0.0140^{a}	0.05 ± 0.022^{b}
3 Fe dust	1.34 ± 0.15^{c}	0.01 ± 0.0029^{a}	0.05 ± 0.007^{b}

*Mean±SD, n = 3*Different letters after the values in the table indicate significant difference ($p<0.05$)

application of iron-dust in the arsenic contaminated soil. In the control plants the sodium percentage was measured as 2.37±0.52 which was higher than that of the sodium concentration of 2% (1.45±0.23%) and 3% (1.34±0.15%) iron-dust applied plants (Table 2) but less than that of 1% (3.35±0.55%) iron-dust applied plant. In case of 3% the iron-dust applied plants the Na concentration in plants part was reduced significantly ($p<0.05$) compared to control. But there was no significant ($p<0.05$) differences of 2% with control and 3% iron-dust applied plants for Na concentration. The present findings revealed that the potassium concentration in plant part was attenuated with the application of iron-dust mixing with the arsenic contaminated soil. No reports are available regarding to sodium concentration in plant at different iron-dust application in arsenic contaminated soil. Another elements Mn concentration in all over the plants more or less same concentration of Mn was found and no significance difference among the plant Mn concentrations in arsenic contaminated soil was observed (Table 2). No reports are available regarding to Mn concentration in plant at different iron-dust application in arsenic contaminated soil. But in case of Fe concentration was decreased for 2 and 3% iron-dust application compare to control (Table 2). The reduction of these percentage of iron in vegetative part of plant with application of iron-dust was significant ($p<0.05$). But there was no significant ($p<0.05$) difference between 2 and 3% iron-dust applied plants for iron concentration after the application of Fe dust in arsenic contaminated soil.

CONCLUSION

From the present study it was found that the arsenic concentration as well as the arsenic uptake was significantly reduced in the edible part of the plant *Ipomoea aquatica* grown in arsenic contaminated soil after the application of iron-dust. It was might be due to the absorbed mechanism of Fe oxide to the arsenic that reduced the bioavailability of arsenic in soil. The result revealed that the application of iron-dust in arsenic contaminated soil would be one of the effective, environmental friendly strategies in reducing arsenic uptake in plants which would ultimately be the safe guard for food safety.

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