ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 42(4): 589-598, December 2017

REMEDIATION OF HEAVY METAL POLLUTED SOIL THROUGH ORGANIC AMENDMENTS

H. M. NASER[1], M. Z. RAHMAN[2], S. SULTANA[3]
M. A. QUDDUS[4] AND M. A. HAOQUE[5]

Abstract

This study was conducted to determine the effects of organic materials to remediate contaminated soil with heavy metals. A pot study was performed by growing maize (*Zea mays*) in metal contaminated soil (10 kg pot^{-1}) and soils amendments with cow manure dust, poultry manure dust, vermicompost dust, fern dust, water hyacinth dust, mustard stover dust and barnyard grass dust each at 5 g kg^{-1} soil. The results showed that Pb, Cd, Ni, Cr and Co uptake by maize depended on the organic materials type. Water hyacinth dust, fern dust, mustard stover dust, and barnyard grass dust addition led to decreased metal content in maize, and this decrease was better expressed with 20.5 to 33.3% for fern dust, 17.3 to 22.0 % for water hyacinth, 18.6 to 21.3% for mustard stover dust, 17.33 to 20.5% for barnyard grass dust. Cow manure dust, poultry manure dust and vermicompost dust led to increased metal content in the maize, and this increase was 6.80 to 18.7 % for cow manure, 18.9 to 86.7 % for poultry manure and 17.4 to 16.0 % for vermicompost. The different effectiveness of organic amendment on metal uptake by maize plant could be due to the nature of organic matter where water hyacinth dust, fern dust, mustard stover dust, and barnyard grass dust were mainly originated from plant. On the other hand, cow manure, poultry manure and vermicompost were mainly the excreta collected from cattle, poultry and earthworms. However, immobilization and phytoextraction techniques might be used to remediate soils which are contaminated with heavy metal.

Keywords: Remediation, heavy metal, organic amendments and maize.

Introduction

A major environmental concern stemming from the unplanned establishment of industrial units and unscientific disposal of effluent generated by human activities is the contamination of soil and water with salts, metals, organics, and pathogens in developing countries (Ahmad *et al.,* 2011). Land contamination/degradation is a threat to sustainable agricultural development and food security in developing countries. Among all the degraded lands, those contaminated with heavy metals are largely irreversible and where reversibility is attempted, it is at high cost (Oldema, 1994). It has therefore become imperative that the environment and its resources should be managed judiciously to enhance sustainable national and socio-economic development (Adejumo *et al*., 2011).

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[1]Principal Scientific Officer, Soil Science Division, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur-1701, [2]Assistant Professor, School of Business Studies, Southeast University, Dhaka, [3]Scientific Officer, Soil Science Division, BARI, Joydebpur, Gazipur-1701, [4]Senior Scientific Officer, HRC, BARI, Gazipur-1701, [5]Chief Scientific Officer, Soil Science Division, BARI, Joydebpur, Gazipur-1701, Bangladesh.

Toxic metals are biologically magnified through the food chain. They infect the environment by affecting soil properties its fertility, biomass and crop yields and ultimately human health. It is a big issue of accumulation of heavy metals in soils as a result of industrial effluents (Mudgal *et al.,* 2010). With greater public awareness of the implications of contaminated soils on human and animal health there has been increasing interest in developing technologies to remediate contaminated soils.

Addition of organic matter amendments, such as compost, fertilizers and wastes, is a common practice for immobilization of heavy metals and soil amelioration of contaminated soils (Clemente *et al.,* 2005). The effect of organic matter amendments on heavy metal bioavailability depends on the nature of the organic matter, their microbial degradability, salt content and effects on soil pH and redox potential, as well as on the particular soil type and metals concerned (Walker *et al.,* 2003, 2004).

At least 45 families have been identified to hyperaccumulate heavy metal from soil; some of the families are Brassicaceae, Fabaceae, Euphorbiaceae, Asteraceae, Lamiaceae and Scrophulariaceae. *Brassica sp*. commonly called Indian mustard; it is a promising plant for phytoremediation (Dushenkov, 2003; Henry, 2000). Aquatic plants such as the floating *Eichhornia crassipes* (water hyacinth) have been investigated for use in rhizofiltration (Karkhanis *et al*., 2005). Recently, a fern *Pteris vitatta* has been shown to accumulate as much as 14,500 mg kg^{-1} arsenic in fronds without showing symptoms of toxicity (Ma *et al*., 2001). Large quantities of organic amendments, such as cow manure, water hyacinth compost are used as a source of nutrients and also as a conditioner to improve the physical properties and fertility of soils. These organic amendments can be used as a sink for reducing the bioavailability of heavy metals in contaminated soils through their effect on the adsorption, complexation, reduction and volatilization of metals (Hussain, 2000). The role of organic matter on the metal absorption, transportation and assimilation is known from literature but a little is known about accumulation of heavy metal through organic amendments. For this reason this study was undertaken (i) to evaluate the efficiency of organic amendments as an accumulator for heavy metal in contaminated soil; (ii) to determine the uptake pattern of heavy metal in the tested crop as influenced by various organic amendments; and (iii) to quantify the heavy metal status of polluted soils.

Materials and Methods

Soil Sampling

Polluted soil from Kalakoir, Konabari, Gazipur was chosen for the experiment. The site was irrigated with the Turag river water. The river Turag is highly polluted by industrial effluents, sewage sludge, municipal waste water and urban pollution. Five composite topsoil samples (0–20 cm depth) were randomly collected from farmer's field (10 individual samples). The sampled soil was air-dried and passed through a 2 mm sieve to obtain homogeneous particle size.

Soil and organic amendment preparation

Two types of organic amendments were used - animal excreta category includes cow manure dust, poultry manure dust and vermicompost dust. And plant materials category includes fern dust, water hyacinth dust, mustard stover dust and barnyard grass dust. The dried organic samples were homogenized by grinding using an electric grinder. Soil samples were mixed by adding organic materials as per treatment at the rate of 5 g kg^{-1} soil. Samples of contaminated soil were thoroughly mixed with the organic amendments resulting in eight treatments: (i) contaminated soil + cow manure dust, (ii) contaminated soil + poultry manure dust, (iii) contaminated soil + vermicompost dust, (iv) contaminated soil + fern dust, (v) contaminated soil + water hyacinth dust, (vi) contaminated soil + mustard stover dust, (vii) contaminated soil + barnyard grass dust, and (viii) contaminated soil as control.

Experiment setup

The experiment consisted of a total of 24 plastic pots, each containing 10 kg soil. Pots were placed in a completely randomized design with three replications per treatment at a shade house of Soil Science Division, BARI, Joydebpur, Gazipur. Maize (*Zea mays* var. BARI hybrid Bhutta-7) seeds were sown directly in pots at a density of 6 seeds per pot on 31 December 2015. Twelve days after sowing the seedlings were thinned to 2 plants per pot. All the pots were fertilized two days before sowing with N: 90 mg kg^{-1} soil, P: 75 mg kg^{-1} soil, K: 140 mg kg^{-1} soil, S: 30 mg kg^{-1} soil, Zn: 2 mg kg^{-1} soil, B: 1 mg kg^{-1} soil. Urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate monohydrate ($ZnSO_4$. H_2O) and boric acid were used as a source of N, P, K, S, Zn and B, respectively. Nitrogen was applied in two equal splits, the first split before sowing and the remaining splits at 6-8 leaf of plants after sowing. Wetting cycles (at field capacity) and air-drying every week were performed, during a period of about three months.

The plant was harvested at 80 days following seeding, when it had attained reproductive maturity (before flowering). Soil was removed from the roots by careful and plants were washed with tap water followed by deionized water.

Preparation and preservation

The clean plant samples were air-dried and placed in an electric oven, dried at 85 °C for 72 h, weighed for dry biomass. The dried plant samples were homogenized by grinding using a ceramic coated grinder and used for metal analysis. Samples of contaminated soils were spread on plastic trays and allowed to dry at ambient temperature for 8 days. The dried samples of soils were ground with a ceramic coated grinder and sieved through a nylon sieve. The final samples were kept in labeled polypropylene containers at ambient temperature before analysis.

Digestion and Analytical Procedure

One gram of each sample was weighed into 50-ml beakers, followed by the addition of 10 ml mixture of analytical grade acids HNO_3: $HClO_4$ in the ratio 5:1, and left overnight for complete contact of material. Next day, the digestion was performed at a temperature of about 190 ºC for 1.5 h. After cooling, the samples were transferred into 100 ml volumetric flask and solution was made up to a final volume raised up to the mark with distilled water. The metal concentrations were determined by atomic absorption spectrometry using a VARIAN model AA2407 Atomic Absorption Spectrophotometer (AAS). Analysis of each sample was carried out three times to obtain representative results and the data reported in µg g^{-1} (on a dry matter basis).

Bioconcentration factor (BCF)

To compare the accumulation and transfer of metals in the different plant parts and soils, two indices were calculated according to the procedure described by Li *et al.* (2009). The bioconcentration factor (BCF) was calculated according to the following equation:

$$BCF = [M\ stem\ or\ M\ leaves\ or\ M\ root]/[M\ soil] \quad (1)$$

Statistical analysis

The experiment was designed in completely randomized (CRD) with 8 treatments and three replications. Treatment effects were determined by analysis of variance with the help of statistical package STATISTIX-10 and mean separation was tested by Tukey HSD.

Results and Discussion

The results of pre-potting soil analyses are presented in Table 1. Nickel (Ni) and chromium (Cr) occurred in greater concentrations than those lead (Pb), cadmium (Cd) and cobalt (Co). The concentration of Pb was 17.8 µg g^{-1}, Cd–1.76 µg g^{-1}, Ni–41.3 µg g^{-1}, Cr –33.7 µg g^{-1} and Co – 15.0 µg g^{-1}. These levels (Cd, Ni and Cr) were extremely high when compared with the levels of these metals in uncontaminated soil reported by Bowen (1966), except Pb.

Metal content of different applied organic materials are presented in Table 2. The effects of the organic material applications on uptake levels of Pb, Cd, Ni Cr and Co from the contaminated soil samples by maize are given in Table 3. The results indicated that application of organic material originated from plant materials corresponded to a reduction of levels of metals uptake by the maize plants. On the other hand, the metal contents of maize were elevated by the application of animal excreta. Putwattana *et al.* (2010) found a significant increase in shoot Cd concentration and the total Cd uptake of plants when cow manure was applied. Similar result was also observed by Awotoye *et al.* (2011).

Table 1. Initial heavy metal status of the industrial effluents polluted soil used in potting media

Soil heavy metal	Heavy metals content (µg g^{-1}) of soil samples				
	Pb	Cd	Ni	Cr	Co
Result	17.8±2.59	1.76±0.50	41.3±5.51	33.7±4.39	15.0±1.70
Uncontaminated soil [a]	100	3	50	100	50
Uncontaminated soil [b]	50	1	1	30	-

[a] Ewers, U. (1991); [b] Bowen, (1966).

Table- 2. Metal content of different applied organic materials

Materials	**Concentration (µg g^{-1} dry wt.)**				
	Pb	**Cd**	**Ni**	**Cr**	**Co**
Animal excreta					
Cow manure dust	5.21	0.36	4.70	3.52	5.80
Poultry manure dust	9.3	0.60	6.20	6.78	8.60
Vermicompost dust	10.3	0.42	11.4	8.32	9.15
Plant materials					
Fern dust	2.40	0.25	5.90	2.50	3.22
Water hyacinth dust	2.56	0.39	4.22	3.10	4.43
Mustard stover dust	1.14	0.36	6.10	1.98	3.30
Barnyard grass dust	1.16	0.22	3.50	2.00	2.71

If plant uptake levels adequately described the effectiveness of metal immobilization, the results in Table 2 suggest that the effectiveness of immobilization varied in the order of water hyacinth dust > fern dust > mustard stover dust > barnyard grass dust. Metal content increased in maize by addition of animal excreta was doubles as compared to the plant materials application.

Narwal and Singh (1998) reported a significant increase in metal concentration in wheat when pig manure was the organic matter (OM) source. On the contrary, organic amendment such as cow or pig manure can decrease the bioavailability of heavy metals in soil (Tordoff *et al*., 2000). Organic matter has been reported to show different effects on metal extractability, which may depend on the sources of OM, rate and plant species (Angelova *et al.,* 2010). The different effectiveness of organic amendment on metal uptake by maize plant in our study could be possible due to the nature of organic matter where water hyacinth dust, fern dust, mustard stover dust, and barnyard grass dust were mainly originated from plant. On the other hand, cow manure, poultry manure and vermicompost are mainly the excreta collected from animal.

Table 3. Effect of organic amendment application on metal content by maize from contaminated soil

Applied material (5 g kg^{-1} soil)	Level of metal content (±, standard deviation) by maize (μg g^{-1} of dry wt.)				
	Pb	**Cd**	**Ni**	**Cr**	**Co**
Contaminated control	5.20±0.77ab	0.75±0.14bc	26.4±1.25abc	16.6±3.44bc	4.61±1.13ab
Animal excreta					
Cow manure dust	4.81±0.17abc	0.89±0.27ab	28.2±2.44ab	21.3±2.29b	4.60±1.12ab
Poultry manure dust	6.34±0.58a	1.40±0.17a	31.4±5.22a	33.6±4.59a	6.14±1.47a
Vermicompost dust	5.04±0.72ab	1.32±0.28a	31.0±2.85a	26.1±6.86ab	5.44±1.64a
Plant materials					
Fern dust	3.26±0.70c	0.62±0.11bc	21.0±1.39bc	10.4±0.93c	2.18±0.32bc
Water hyacinth dust	3.16±0.51c	0.50±0.10c	20.6±1.33c	8.49±2.25c	1.64±0.24c
Mustard stover dust	3.29±0.57c	0.59±0.08bc	21.5±1.78bc	8.03±2.76c	2.20±0.84bc
Barnyard grass dust	3.84±0.59bc	0.62±0.09bc	21.2±1.95bc	10.4±1.38c	2.30±0.42bc
CV (%)	13.8	20.2	10.3	21.0	28.2

Mean values in the same column followed by the same letters are not significantly different ($P < 0.05$).

The metal concentrations decreased in maize plant with the addition of water hyacinth dust, fern dust, mustard stover dust, and barnyard grass dust, which might have immobilized the metal through adsorption, complexation, and precipitation phenomena, resulting in reduced phytotoxicity and accumulation in plants (Cao *et al*., 2003; Geebelen *et al*., 2002; Seaman *et al*., 2003). According to the literature the content of organic substance in soil has a significant impact on absorption and translocation of heavy metals in soil and their uptake by plants. Metals (Cu, Zn, Pb and Cd) are adsorbed on organic matter, which generate stable forms and lead to their accumulation in organic horizons of soil (Kabata-Pendias, 2001). The results obtained by us showed that Pb, Cd, Ni, Cr and Co uptake by maize depended on the organic materials type.

Table- 4. Metal uptake decreased in maize compared with contaminated control

Applied material (5 g kg^{-1} soil)	**Metal uptake decreased (%) compared with contaminated control**				
	Pb	**Cd**	**Ni**	**Cr**	**Co**
Metal aspect	7.36 to 22.0	32.0 to 86.8	7.0 to 19.1	29.0 to 103	(-0.28) to 33.1
	Cow manure	Poultry manure	Vermicompost	-	-
Animal excreta	6.80 – 18.7	18.9 – 86.7	16.0 – 17.4	-	-
Applied material (5 g kg^{-1} soil)	Metal uptake decreased (%) in maize compared with contaminated control				
	Pb	Cd	Ni	Cr	Co
Metal aspect	26.3 to 39.1	17.3 to 33.5	18.2 to 21.8	37.3 to 46.0	50.0 to 64.5
	Fern	Water hyacinth	Mustard stover	Barnyard grass	-
Plant materials	20.5 – 33.3	17.3 – 22.0	18.6 – 21.3	17.3 – 20.5	-

Table 5. Bioconcentration factor of heavy metals from soil to maize plant as influenced by organic material applications

Applied material	**Name of metal**				
	Pb	**Cd**	**Ni**	**Cr**	**Co**
Contaminated control	0.292	0.426	0.638	0.493	0.308
Animal excreta					
Cow manure dust	0.271	0.562	0.682	0.633	0.307
Poultry manure dust	0.357	0.795	0.760	0.998	0.410
Vermicompost dust	0.284	0.753	0.749	0.776	0.363
Plant materials					
Fern dust	0.184	0.355	0.509	0.309	0.146
Water hyacinth dust	0.178	0.283	0.499	0.252	0.109
Mustard stover dust	0.185	0.334	0.522	0.239	0.147
Barnyard grass dust	0.216	0.352	0.513	0.308	0.154

The percentage (%) of metal uptake decreased in maize with addition of plant originated organic material compared with contaminated control were Pb – 26.3 to 39.1, Cd – 17.3 to 33.5, Ni – 18.2 to 21.8, Cr – 37.3 to 46.0 and Co – 50.0 to 64.5. It was Pb – 7.36 to 22.0, Cd – 32.0 to 86.8, Ni – 7.0 to 19.1, Cr – 29.0 to 103 and Co – (-0.28) to 33.1 increment in animal excreta application treatments (Table 4). Water hyacinth dust, fern dust, mustard stover dust, and barnyard grass dust addition led to decreased metal content in maize, and this decrease was better expressed with 20.5 to 33.3% for fern dust, 17.3 to 22.0 % for water hyacinth, 18.6 to 21.3% for mustard stover dust, 17.3 to 20.5% for barnyard grass dust. Cow manure dust, poultry manure dust and vermicompost dust led to increased metal content in the maize, and this increase was best expressed with 6.80 to 18.7 % for cow manure, 18.9 to 86.7 %.for poultry manure and 16.0 to 17.4 % for vermicompost. Addition of organic materials to contaminated soil did not totally restrict the uptake of metal by maize plants but the total level recorded in the plant tissues from all the plant originated organic materials treated plants were significantly lower than those treated with animal excreta and contaminated control. The present study found a significant increase in metal uptake of plants when animal excreta were applied.

Soil-to-plant transfer ratio (amount of metal in plant to the pseudo-total amount in soil) or Bioconcentration factor (BCF) is an important aspect of phytoextraction. The effect of the organic amendment application on the BCF of metals from the contaminated soil to maize is shown in Table 5. As with the amounts of the metals uptake by maize, the proportions of the metals in the soil that were absorbed by the plants decreased with applications of organic amendments and were water hyacinth dust > fern dust > mustard stover dust > barnyard grass dust. The highest values of TC (0.998) was found in plant grown in poultry manure dust treatment and lowest was in water hyacinth dust treatment. Putwattana *et al*. (2010) reported that sweet basil (*Ocimum basilicum*) grown in Cd contaminated soil and soil amendments with animal excreta (cow manure) showed increases in TF values with the exposure time.

Conclusion

Application of plant originated organic materials has been shown to immobilize metals in soil and decreased the metal content of plants. On the other hand, animal excreta had significant impact on phytoextraction of metal from soil. Immobilization and phytoextraction techniques might be used to remediate soil contaminated with metal. The plant originated organic amendments are of great interest for the purpose of phytostabilization. Evaluation of their potential, however, requires further study of the effect of organic amendments on a wider range of agricultural crops.

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