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Phytoremediation of metal-contaminated industrial soil using sunflower

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ABSTRACT

During the past decades, heavy metal pollution in urban soil from industrial activities and its impact on human health has been becoming one of the most important environmental problems in Ulaanbaatar Mongolia. The average concentrations of Cr, Ni, Pb, Zn, Cu and As were 1986.9, 110.5, 111.0, 110.5, 53.5, 16.4 mg/kg, respectively in study area. Heavy metal contamination can occur when soil particles are swept away from the initial pollution areas by the wind. Therefore, it is necessary to take measures to reduce soil pollution and encourage phytoremediation. A phytoremediation trial was made to study the use of Sunflower (Helianthus annuus) plant species to extract Cr out of contaminated soils. Plant species tested in this study namely Sunflower (Helianthus annuus) were grown on two different polluted soil types (Technogen sandy soil, accumulated with contaminated sludge for more than 30 years and subjected to effluent leather processing factories for more than 50 years) in a complete randomized block experimental design. Calculation of recovery percentage based on Cr removed from the soil by whole plant after cultivation ranged between 39.1 to 40.5% of total initial Cr, respectively. However, the percentage of Cr removed by plant shoots from the total Cr -removed by whole plant varied between and 37.9 to 32.8% of the removed Cr, respectively. As expected plant roots exhibited higher Cr accumulation than in shoots by 1.7–2.34 folds, respectively. It is worth to mention, that roots tend to accumulate 64.8 to 67.2% of Cr accumulated in plant biomass respectively .

Keywords: *Contaminated soil, phytoremediation, sunflower, Ulaanbaatar, Mongolia.*

1. INTRODUCTION

Heavy metal pollution of soil is a global problem; it will transport to the soil around the repository and pose a great threat to the ecosystem, agro-system and people's health [1]. Many of these trace elements are toxic even at very low concentrations because of their non-biodegradable nature, long biological half-life, and potential to accumulate inside the living bodies [2]. Excessive deposits of heavy metals in urban soils may not only result in soil contamination but also heavy metal uptake by air and water quality affecting quality and human health [3].

Therefore, cleaning up of polluted soils is a subject of utmost concern to human beings. In addition, diffuse contamination of large areas causes particular difficulties, since most classical engineering technologies directed at soil decontamination traditionally involve excavation of soil, and thus are expensive, invasive, and pose a threat to the nutritional and microbial balance of soil [4]. As chemical hazards, heavy metals can remain almost indefinitely in the soil environment, however, their availability to biota can change considerably depending on their chemical speciation in the soil. The adequate protection and restoration of the soil ecosystems, therefore, require the characterization and remediation of soils that are contaminated with heavy metals. The release of toxic heavy metals such as Chromium (Cr) into the environment is a serious pollution problem affecting soil and water qualities, therefore presenting a direct hazard to human health. Ions of chromium and cadmium which are frequently present in the wastewaters can cause renal dysfunction as well as chronic alterations in the nervous system and gastrointestinal tract [2]. In order to overcome these problems, one of promising strategies for treating the large scale, low-level contamination is use of plants to extract metals from soil (Phytoextraction) [1].

Phytoextraction is an environmentally sound and cost-effective technology for cleaning up soils contaminated with toxic metals. This technique has repeatedly been suggested as a novel clean-up technology. It has the potential to provide cost effective, renewable alternatives to previously used remediation techniques while preventing the loss of topsoil which occurs through the excavation process [5]. As suggested by Robinson et al. (2000), a different approach lies in the use of plants which are fast growing, deep-rooted, easily propagated and accumulate the target metal, combined with an increase of the phytoavailability of the metals in soil [6]. Research has focused, therefore, on crops such as maize (Zea mays), tobacco (Nicotiana tabacum), Indian mustard (Brassica juncea), oat (Avena sativa), barley (Hordeum vulgare), pea (Pisum sativa), poplar (Populus spp.) and sunflower (Helianthus annuus) [7]; [8]. Unfortunately, the main disadvantage of the phytoremediation techniques is the long time required for cleanup of metal contaminated soils.

The success of phytoextraction depends on the ability of plants to produce large amounts of biomass. The success of phytoextraction also, is primarily dependent upon the bioavailability of the contaminants of concern for plant uptake. In addition, plants must be tolerant to the target metals and be efficient to translocate metals from roots to the aboveground organs. The effectiveness of phytoextraction also depends upon site and metal species. However, the amount of metals extracted by plants is basically decided by (1) the metal concentration in dry plant tissues and (2) the total biomass of the plant. Certain varieties of high-biomass crops have been found to have the ability to clean up the contaminated soils.

When phytoextraction is practiced, metal-accumulating plants are seeded or transplanted into metal polluted soil and are cultivated according to the established agricultural practices. The roots of established plants absorb metal elements from the soil and translocate them to the aboveground shoots where they accumulate. After sufficient plant growth and metal accumulation, the aboveground parts of the crop are harvested and removed from the contaminated site.

This technology is applicable only to sites that contain low to moderate levels of metal pollution, because plant growth is not sustained in heavily polluted soils. The aim of the present work is to investigate the potential and the engineered use of sunflower (H. annuus) to extract Cr from contaminated soils.

2. MATERIALS AND METHODS

2.1. Soil sampling preparation and analysis

Two soil samples were chosen from different contaminated locations at south greater (industrial zone) Ulaanbaatar, Mongolia to represent two different soil types (alluvial and sandy) as well as two different sources of contaminated soil (sewage sludge and industrial effluent) as follows: (A) Sandy polluted soil from the waste water treatment area (accumulated with contaminated water and sludge for more than 30 years due to direct discharge of leather industrial sludge to soil). (B) Sandy loam polluted soil from the Leather processing factory area (subjected to industrial technogen influence for more than 50 years). Surface soil samples were collected (i.e. 0–20 cm). The samples were air-dried, crushed to pass a 2.0 mm sieve and then analyzed for main physical and chemical properties. Soil texture was determined by the Bouyoucos hydrometer method.

The pH and electrical conductivity (EC) were measured after mixing samples vigorously 20 min at 1: 2.5 solid: deionized water ratio using digital meters (Elico, Model LI-120) with a combination pH electrode and a 1-cm platinum conductivity cell respectively. The organic carbon was determined by using the Walkley–Black method. Available Cr were determined by the DTPA method according to Lindsay and Norvell (1978). For total soil Cr determinations, 0.5 g of dried soil was digested with 4 ml of concentrated sulfuric acid (~7 min) and subsequently with 10 ml of a H2 O solution (50% w/w in H_2O) at 440 °C (~12 min). Then, the digest was diluted to 100 ml with deionized water. Total Cr contents were determined by using an inductively coupled plasma (ICP) technique. Table 1 shows some physical and chemical properties of the tested soil samples. Table 2 shows Cr total contents and extractable DTPA of Heavy metals (mg/kg) in studied soil.

Table 1. Some physical and chemical properties of the investigated soils.

Soil properties	A	B
Sand, %	49.85	54.24
Silt, %	36.29	32.48
Clay, %	13.86	13.28
pH*	7.67	7.32
EC**, dS/m	0.612	3.68
CaCO3 (%)	13.09	12.72
OM (%)	3.51	4.83

EC, electrical conductivity: OM, organic matter.

* In the soil water suspension (1:2.5).

** In the extract of saturated soil paste.

2.2. Experimental setup

A pot experiment was carried out to investigate the potential use of plants to extract Cr from polluted soils. Five kg of each air-dried surface soil sample (0–20 cm) were packed in plastic containers (20 cm internal diameter and 20 cm height) with three replicates. The Sunflower (H. annuus) were grown on tested soil and arranged in a complete randomized block experimental design. The tested plant species were in Sunflower (H. annuus). Nitrogen and phosphorus fertilizer doses were applied to each soil before the cultivation of the plants at the recommended rates. Ten seeds per pot were planted. After 7 days, the seedlings were thinned to 5 plants/pot. The soils were irrigated to maintain soil moisture at about 80% of the soil field capacity during the 2 month (8 weeks) growth period of the experiment. To prevent loss of nutrients and trace elements out of the pots, plastic trays were placed under each pot and the leachates collected were put back in the respective pots. Plant shoots were harvested after 60 days (8 weeks) by cutting the stems approximately 2 cm above the soil surface. The roots were collected, sieved to get rid of soil particles and washed with running water and distilled water. Another soil sample was taken for total Cr content analyses. Plant samples (shoots and roots) were dried at 60 °C to a constant weight, grounded into fine powder, sieved with a 2 mm wire mesh. 0.5 g of the powdered samples was digested with 4 ml of concentrated sulfuric acid (~7 min) and subsequently with 10 ml of a H_2O solution and analyzed for Cr concentrations using an inductively coupled plasma (ICP) technique.

Table 2. Initial total content and extractable DTPA of heavy metals, mg kg -1, in investigated soils.

Heavy metal	A	B
Total content (mg^{-1})		
Cr	213	83
Extractable content (mg^{-1})		
Cr	3.8	5.4

2.3. Translocation ratio (TR) and transfer factor (TF)

This parameter is necessary for environmental transfer models which are useful in prediction of the pollutant concentrations in agricultural crops for estimating dose intake by man. TR is calculated by the relation: the ratio of concentration of metal in the shoot to the concentration of metal in the roots (Cui et al., 2007).

TR = (Concentration of metals) shoot / (Concentration of metals) roots (1)

TF is given by the relation: the ratio of the concentration of metal in the shoots to the concentration of metal in the soil [9]. The transfer factor (TF) is a value used in evaluation studies on the impact of routine or accidental releases of pollutant into the environment.

TF = (Concentration of metals) shoot / (Concentration of metals) soil (2)

These factors were used to evaluate the Cr phytoextraction capacity of plant.

2.4. Statistical analysis

Data were statistically analyzed to test the ANOVA (two way and three way) and least significant different LSD using MSTAT software according to the standard statistical methods.

3. RESULT AND DISCUSSION

The concentration level of Cr (2823 and 3318 mg/kg for soils A and B respectively) (Table 3) exhibited higher levels than reported normal Cr levels in Ulaanbaatar city soils and MNS 5850:2019 standard **[10]** results showed wide Cr-variation due to soil type. Total Cr in heavy textured soils ranged between 38 and 81.5, while it ranged between 4.6 and 71.5 in light textured soil and to lesser Cr levels in calcareous soils, whereas it ranged from 2.9 to 1239.3 mg/kg in Ulaanbaatar. In another study twenty nine surface (0–10 cm) soil samples were collected from different locations in industrial area representing highly polluted soils **[3]**. The purpose of this study was to determine the concentration and health risk of heavy metals in soils wastewater treatment plants (WWTP) for a leather processing area of Ulaanbaatar, Mongolia. The average concentrations of Cr were 1986.9 mg/kg. The PER of Cr indicated high ecological risk in the study area. The HI values for almost all the metals were higher than 1, indicating that there was a carcinogenic risk for children and adults. The RI values of two metals (Cr, As) contribute to a higher risk of development of cancer in humans. Heavy metal contamination can occur when soil particles are swept away from the initial pollution areas by the wind. Therefore, it is necessary to take measures to reduce soil pollution and encourage rehabilitation.

A calculation of the recovery percentage based on Cr removed from the soil after cultivation (calculated on 5 kg soil bases) ranged between 39.1 and 40.5% of the total initial Cr. It is worthy to mentioned that that the sunflower shoots exhibited the highest Cr uptake (37.9 and 32.8 mg/kg for A and B soils respectively) compared to other tested species at any investigated soil. A high effect of soil texture and plant species on Cr uptake was observed. It could be noticed that Cr uptake by shoot was higher in the fine textured soil (A) compared to soil (B) at any tested plant species. The recovery percentage of Cr by root varied between 64.8

and 67.2% of re [11]moved Cr from total Co-up taken by whole plant. Roots accumulated the highest amount of Cr for the five tested plant species, irrespective of soil type. In this regard, our results are in agreement with those reported by [8] where they found that most of the metals (Cu, Cr, Co and Cd) were found at higher levels in the root than the shoot. Therefore, it was assumed that roots have a barrier effect that impedes or strongly limits Cr uptake and translocation from roots to shoots [11]. It is worthy to mention that the transfer factor (TF) of Cr was affected by soil type, where the highest values were always recorded in the coarse textured soil (B-0.49) compared to the fine textured soil (A-0.58). This holds true with any tested plant species. In contrast with TF, the highest translocation ratio (TR) of Cr were always recorded in the fine textured soil (A) compared to the coarse textured soil (B). Moreover, the TR of Cr was slightly higher than other heavy metals TR with any of the tested plant species. Plants of high TF greater than one, accumulates metals in the root with less or poor translocation to the aerial parts (shoot), they mainly restrict metal in their roots. This could be explained by the fact that the root system provides an enormous surface area that not only absorbs and accumulates the water and nutrients that are essential for growth, but also absorbs other non-essential contaminants [12]. Even after entering into the roots, many heavy metals form sulfate, carbonate, or phosphate precipitates and immobilize these metals in apoplectic (extracellular) and simplistic (intracellular) compartments.

Table 3. Recovery percentage of Cr removed from tested soils by plant

Plant species	Cr-soil initial (mg kg $^{-1}$)	Cr-soil final (mg kg $^{-1}$)	Total -Cr uptake by whole plant (mg kg $^{-1}$)	Cr-Removal* by whole plant (%)	Cr uptake by shoot (mg kg $^{-1}$)	Removal** by shoots (%)	Cr uptake by roots (mg kg $^{-1}$)	Removal** by roots (%)
Sunflower								
A	2823	1720	1103	39.1	417.6	37.9	714.5	64.8
B	3318	1973	1345	40.5	441.1	32.8	903.9	67.2
LSD								
S=Soil	-	2.23	1.17	-	1.21	-	1.31	-
P=Plant	-	3.42	2.31	-	2.16	-	2.44	-
SxP	-	5.18	4.11	-	4.33	-	3.99	-

Apoplastic transport of metals is further limited by the high cation-exchange capacity of cell walls [13] The highly insoluble nature of most of the hazardous metals interrupts their free movement in the vascular system of the plant.

Therefore, translocation to the aboveground shoots where their accumulation has taken place is also restricted. It was found that soil properties, plant absorption ability and both the form and concentration of heavy metals in the soil comprehensively impact the uptake capability of heavy metals from the soil by the corresponding cultivated plant. Observation in this study revealed that the TR values for either Cr were found to be less than 1 after 8 weeks from planting [14], in a study with temperate plants confirmed that Cr was poorly taken up into the aerial tissues but was held predominantly in the root. Similarly the five tested plants in this study expressed high levels of Cr in their roots.

One of the mechanisms by which uptake of metal occurs in the roots may include binding of the positively charged toxic metal ions to negative charges in the cell wall [15] and the low transport of heavy metal to shoots may be due to saturation of root metal uptake, when internal metal concentrations are high [11].

5. CONCLUSSIONS

This study therefore has proved the possibility of using the five tested plant species for phytoremediation especially Sunflower whose shoots and roots exhibited the highest and Cr uptake compared to the other tested species at any investigated soil.

The time required for remediation is dependent upon the type and extent of metal contamination, the length of the growing season, and the efficiency of metal removal by plants [5]. In addition, as this is essentially an agronomic approach, some agronomic practices, such as, plant selection, possibility of cultivation, fertilization and irrigation, etc., could also play a crucial role in successful cleaning of a contaminated site [16].

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