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A Comparative Study of Phytoextraction Efficiency of Different Plants for Remediation of Heavy Metals from Soil

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ABSTRACT: The present research on plants efficacy for phytoextraction of metals was conducted at the Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi. This study envisages the efficacy of plants, information about heavy metal removal efficiency and their specificity. Correspondingly identify efficient suitable plants for remediation of heavy metals from polluted soils. A greenhouse pot experiment consisted of surface soil sample was collected from Godwa village, Udaipur district, Rajasthan and four crops *i.e.* mustard, sunflower, guinea grass, napier grass which were replicated five times in a completely randomised design (CRD). This soil mainly contaminated with lead and cadmium heavy metals. The crops were harvested at maximum vegetative growth stage and post-harvest soil was used for further chemical analysis. Lead content in crop shoot were 2.08, 1.26, 0.82 and 0.66 mg kg^{-1} and cadmium were 3.25, 2.42, 1.81 and 1.64 mg kg^{-1} in mustard, sunflower, napier grass and guinea grass, respectively. While in crop root total lead content were 0.85, 0.70, 0.58 and 0.49 mg kg^{-1} and cadmium were 0.70, 0.59, 0.50 and 0.41 mg kg^{-1} in mustard, sunflower, napier grass and guinea grass, respectively. The study revealed that mustard and sunflower are significantly superior overnapier grass and guinea grass. Therefore, both mustard and sunflower having ability to accumulate more amounts of lead and cadmium in its shoot and roots.

Keywords: CRD, Efficacy, Heavy metal, Phytoextraction.

INTRODUCTION

Heavy metals are group of metals and metalloids associated with toxicity and pollution in soil becomes serious issue in the present time. Heavy metal contamination in the soils increasingly significant problem in the environment and there remediation is costly and difficult (Abdelhafez and Li 2014). The main sources of heavy metal contamination are crustal materials (major natural source of heavy metals) and anthropogenic sources are use of leaded gasoline, sewage sludge, metal smelting industries, municipal solid wastes, industrial effluents, burning of fossil fuels, pesticides etc. (Abou-Shanab, 2011; Abdelhafez *et al.*, 2012). Metals and metalloids are introduced to the soil by sources both moderate to severe extent of metal contamination have been reported from various parts in India. Tannery and smelting are as are majorly contains lead and cadmium contamination (Rattan *et al.*, 2002). These metals are non-biodegradable nature, high atomic weight and high density (>6 Mg m^{-3}). They are non-essential elements for the plants and toxic even at a very low concentration (<1 ppb) affected the growth and productivity of crop (Roy *et al.*, 2005; Oves *et al.*, 2016). They exist into the soil for a long time period after their introduction and pose a serious concern to the environment through their action as carcinogenic and mutagenic compounds (Wu *et al.*, 2018).

Several heavy metals contaminated soils remediation technologies are mainly categorized into three types physical, chemical and biological. Physical remediation mainly consist of soil isolation, soil replacement and vitrification technologies (Douay *et al.*, 2008; Dellisanti, 2016), chemical remediation comprised of soil washing technologies, encapsulation and stabilization/solidification (Ucaroglu and Talinli 2012; Park and Son 2017) and biological remediation through biosorption and metal uptake by plants and microorganisms (Fauziah *et al.*, 2017). But most of the remediation technologies need intensive works, too costly and may generate secondary contaminants to the surrounding environment or may lead to adverse effect to biological activities, soil structure and infertility problems. Therefore, there is a need for a less expensive and environmental friendly and cleanup technique for heavy metals contaminated soils remediation.

Phytoremediation is an environmental friendly and economically effective and cleanup technique that using hyper accumulator plant and allied soil microorganism to reduce the toxic level or concentrations of metals and metalloids in the environments (Abou-Shanab, 2011; Sharma *et al.,* 2014). Phytoremediation approach are different ways *i.e.* phytostabilization, phytoextraction, phytovolatilization, rhizofiltration and phytodegradation. Phytoextraction is a sub process of phytoremediation in which plants are used for uptake of contaminants from soil by plant roots and their translocation to shoot and accumulation in above ground biomass. Subsequently, it can be easily and safely processed or recycled, through ashing, composting or drying. All plants are different in nature in their accumulation ability of different heavy metals (Kacalkova *et al.,* 2015); for this concern, the selection of plant species for phytoextraction of heavy metals depends mainly on the ability of tolerant capacity and the biomass of the selected plant (Rezania *et al.,* 2016). But major constraints in phytoextraction are slow metal removal rate (Abbas and Abdelhafez 2013). To remediate the contaminated sites usually time consuming, normally ranges from one to twenty years. This is mainly because of low solubility of metals in soil. In the present study this phytoextraction techniques used different ways mainly used mustard having low biomass with high metal accumulation capacity, sunflower having high biomass plant with high metal accumulation and grasses such as napier grass and guinea grass having high growth rate, short life cycle, tolerance against abiotic stresses and more biomass production (Ali *et al.,* 2013).

MATERIALSANDMETHODS

The present study on efficacy of different plants for phytoextraction of metals was conducted at the Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi.

Site and soil: The surface soil samples at 0-15 cm depth were collected from Godwa village, Udaipur district, Rajasthan situated at latitude 24˚36´11.7”N and longitude 73˚50´27.4”E. Soil were alluvial and Aridisol order, contaminated with heavy metals mainly lead and cadmium.

Soil samples preparation: The collected soil samples were processed and break into fine particles using wooden mortar and pestle. Air dried soil samples were sieved through 2 mm sieve. Finally processed homogenized soil sample were used for soil properties analysis and pot experiment.

Soil analysis: Soil texture was analyzed by hydrometer method (Bouyoucos, 1962) followed by texture of the soil determined by textural triangle proposed by USDA (Brady and Weil 2001). The soil pH was analyzed in 1:2 (soil: water) suspension using digital pH meter (Datta *et al.,* 1997) and electrical conductivity (EC) using conductivity meter at 25°C room temperature and expressed in dSm^{-1}. Organic carbon content of soil was determined by wet oxidation digestion method (Walkley and Black 1934). Cation exchange capacity (CEC) of soil were estimated by neutral normal ammonium acetate method (Hesse, 1971) followed by flame photometer (Bower *et al.*,1952). CEC of soil expressed as cmol (p^{+}) kg^{-1}. Calcium carbonate of soil was analyzed by rapid titration method (Puri, 1949). Diethylenetriamine pentaacetic acid (DTPA) extractable metal content in soil determined by (1:2:: soil: extractant) (Lindsay and Norvell 1978) followed by atomic absorption spectrophotometer (AAS).

Greenhouse pot experiment: For pot experiment, 5kg capacity of plastic pots filled by 4 kg of processed contaminated soil. All four crops *i.e.* Indian mustard (*Brassica juncea* var. Pusa Mustard-26), sunflower (*Helianthus annuus* var. PSH-2080) Guinea grass var. BG-1, Napier grass var. NB-1) were replicated five times using completely randomized design (CRD). The crops were harvested at maximum vegetative growth stage.

Soil and plant analysis: After harvesting, plant and root samples were firstly washed by tap water followed by dilute HCl (0.01 *N*) and finally rinsed with distilled water. Plant and root samples were dried in hot air oven at 60±5 ºC. Biomass yield was recorded after attaining constant weight. After harvesting of crop, processed soil samples were extracted using 0.005 *M* DTPA for cadmium and lead. Dried plant shoot and root samples were grind using wooden mortar and pestle used for further chemical analysis. Plant shoot and root samples were digested with HNO_3 and determination with AAS (Datta *et al.,* 2018).

RESULTSAND DISCUSSION

Initial characteristics of experimental soil was moderately alkaline in nature (pH 8.08) and non-saline (EC 0.38 dSm^{-1}), presented in Table 1. Organic carbon (OC) contentwas0.96%.Soil texture was sandy clay loam textural class containing sand 65.8%, silt 14.0%, and clay 20.2%. $CaCO_3$ and cation exchange capacity (CEC) of experimental soil were 3.25% and 20.1 cmol (p^{+}) kg^{-1}, respectively. DTPA extractable Pb and Cd were 6.40 and 0.14 mg kg^{-1}, respectively. Total Pb and Cd content in soil were 98.7 and 3.60 $mgkg^{-1}$, respectively.

A greenhouse pot experiment was conducted to study the different plants relative efficacy for phytoextraction of metals in polluted soil. Post-harvest soil was analyzed for different parameters *i.e.* DTPA-$CaCl_2$ extractable lead and cadmium, metal content in shoot and root of different crops and biomass yield. Fig. 1 and 2 showed that DTPA-$CaCl_2$ extractable lead content was 5.70, 6.12, 6.81 and 6.89 mg kg^{-1} and cadmium content was 0.08, 0.13, 0.20 and 0.18 mg kg^{-1} in mustard, sunflower, napier grass and guinea grass respectively (Table 2). Results showed that DTPA-$CaCl_2$ extractable lead and cadmium content was higher in napier grass and guinea grass over mustard and sunflower crops.

While total metal content of lead and cadmium in both mustard and sunflower crops significantly higher as compared to napier grass and guinea grass. Total metal content of lead in crop shoot were 2.08, 1.26, 0.82 and 0.66 mg kg^{-1} (Fig. 3) and cadmium were 3.25, 2.42, 1.81 and 1.64 mg kg^{-1} (Fig. 4) in mustard, sunflower, napier grass and guinea grass, respectively. While in crop root (Fig. 5) total lead content were 0.85, 0.70, 0.58 and 0.49 mg kg^{-1} and cadmium (Fig. 6) were 0.70, 0.59, 0.50 and 0.41 mg kg^{-1} in mustard, sunflower, napier grass and guinea grass, respectively (Table 3). Shoot biomass of crop (Fig. 7), 23.7, 31.3, 42.3 and 35.2 (g pot^{-1}) and root biomass (Fig. 8) were 1.34, 2.76, 5.36 and 4.12 (g pot^{-1}) in mustard, sunflower, napier grass and guinea grass, respectively (Table 4).

Due to different characteristics of plants also differ in their tolerance limit to heavy metals. Most of the plants are not hyper accumulator for heavy metals due to its impact on plant cellular activities. The obtained results showed that mustard and sunflower as compared to guinea grass and napier grass has the ability to accumulate Pb and Cd in its tissues (shoots and roots). However, the accumulation of Cd in plant shoot was more favorable than Pb. The translocation factor major emphasis on the ability of mustard and sunflower for higher accumulation of Cd and Pb. Similar type of study also studied, experimented and reported by various researchers Khalid *et al.*, 2018; Park *et al.*, 2012; Olatunji *et al.*, 2014; Ishii *et al.*, 2015). Park *et al.* (2012) reported that by using *Brassica juncea* crop, Cd and Pb concentrations in plant parts were 6 to 16 times and 15 times higher as compared to control, respectively. Khalid *et al.* (2018) conducted the pot experiments by using sunflower (*Helianthus annuus* L.) and recorded maximum concentration of Pb in shoot and root were 40.1 mg kg^{-1} and 107 mg kg^{-1}, respectively and Cd in shoot and root were 65.7 mg kg^{-1} and 71.3 mg kg^{-1}, respectively in the plant cultivated in soil amended with 200 mg kg^{-1} metal concentration. Mishra *et al.* (2019) studied the effect of selected organic and inorganic amendments on the solubility of cadmium (Cd) and lead (Pb) in polluted soil and enhancing the efficacy of phytoextraction of these metals by using Indian mustard (*Brassica juncea* cv. Pusa Vijay). Hence, mustard and sunflower selected out of four crops based on results of phytoextraction of metals grown in lead and cadmium polluted soil.

Table 1: Initial characteristics of experimental soil.

Parameters	Observations
$pH_{1:2}$	8.08
$EC_{1:2}$ (dS m^{-1})	0.38
Organic carbon (%)	0.96
Cation exchange capacity [cmol (p^+)kg^{-1}]	20.1
$CaCO_3$ (%)	3.25
Mechanical composition	
Sand (%)	65.8
Silt (%)	14.0
Clay (%)	20.2
Texture	Sandy Clay Loam
Total metal content	
Total Pb(mg kg^{-1})	98.7
Total Cd (mg kg^{-1})	3.60
DTPA extractable metals	
Pb(mg kg^{-1})	6.40
Cd (mg kg^{-1})	0.14

Table 2: DTPA-$CaCl_2$ extractable lead and cadmium contents in post-harvest soil of different crops.

Crop	Pb(mg kg^{-1})	Cd (mg kg^{-1})
Mustard	5.70[c]	0.08[c]
Sunflower	6.12[b]	0.13[b]
Napier grass	6.81[a]	0.20[a]
Guinea grass	6.89[a]	0.18[a]
LSD (*P* = 0.05)	0.40	0.02

Values followed by common letters are not significantly different (LSD, P=0.0)

Table 3: Total metal content of lead and cadmium in crop shoot and root.

Crop	Metal content in shoot (mg kg^{-1})		Metal content in root (mg kg^{-1})	
	Pb	Cd	Pb	Cd
Mustard	2.08[a]	3.25[a]	0.85[a]	0.70[a]
Sunflower	1.26[b]	2.42[b]	0.70[b]	0.59[b]
Napier grass	0.82[c]	1.81[c]	0.58[c]	0.50[c]
Guinea grass	0.66[d]	1.64[d]	0.49[c]	0.41[d]
LSD (*P* = 0.05)	0.11	0.12	0.10	0.06

Values followed by common letters are not significantly different (LSD, P=0.05)

Table 4: Biomass yield of shoot and root of different crops.

Crop	Shoot (g pot^{-1})	Root (g pot^{-1})
Mustard	23.7^{d}	1.34^{d}
Sunflower	31.3^{c}	2.76^{c}
Napier grass	42.3^{a}	5.36^{a}
Guinea grass	35.2^{b}	4.12^{b}
LSD (P = 0.05)	3.69	0.25

Values followed by common letters are not significantly different (LSD, P=0.05)

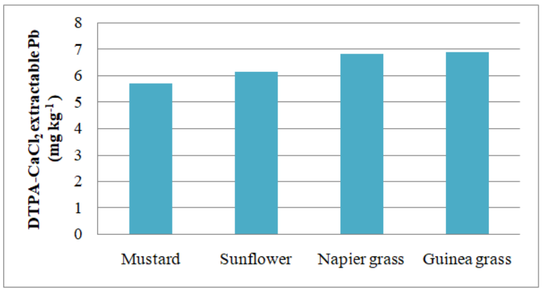

Fig. 1. DTPA-$CaCl_2$ extractable lead contents in post-harvest soil of different crops.

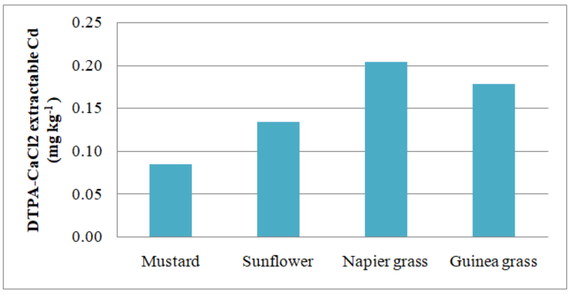

Fig. 2. DTPA-$CaCl_2$ extractable cadmium contents in post-harvest soil of different crops.

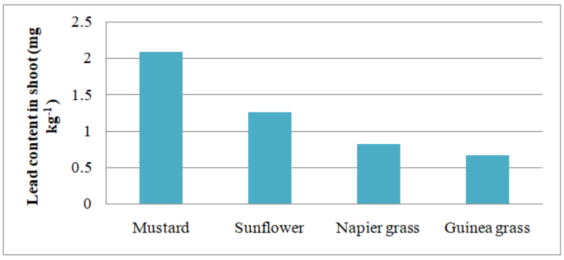

Fig. 3. Total lead content in different crop shoot.

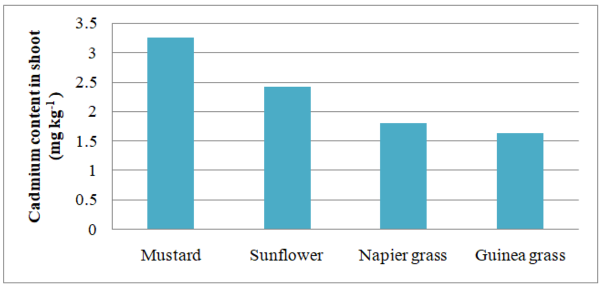

Fig. 4. Total cadmium content in different crop shoot.

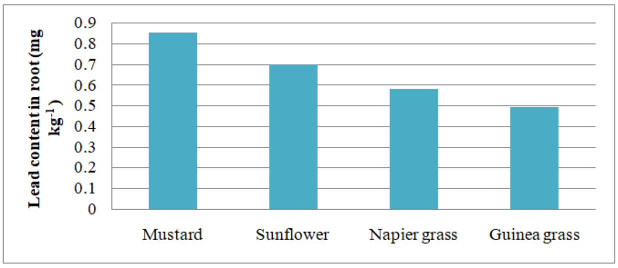

Fig. 5. Total lead content in different crop root.

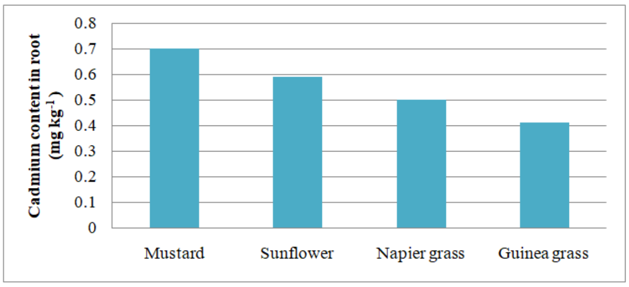

Fig. 6. Total cadmium content in different crop root.

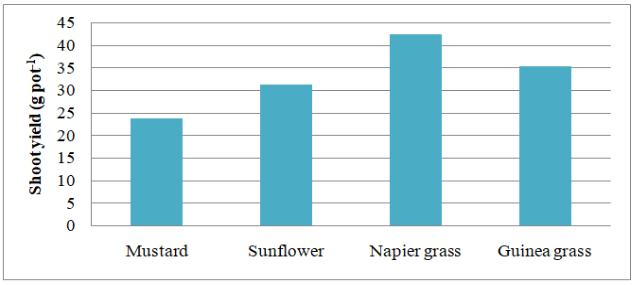

Fig. 7. Biomass yield of shoot of different crops.

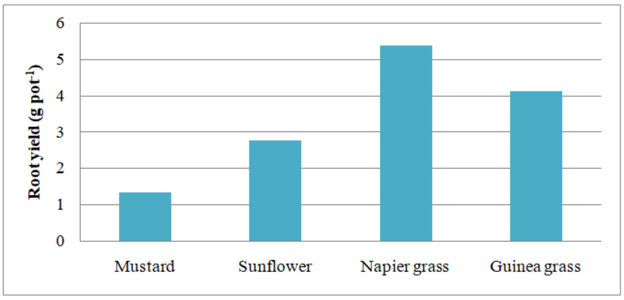

Fig. 8. Biomass yield of root of different crops.

CONCLUSIONS

The present study conducted to find about the efficacy of plants, heavy metal removal efficiency and their specificity. Present investigation concluded that both mustard and sunflower having ability to accumulate more amounts of lead and cadmium in its shoot and roots. Out of four crops mustard and sunflower are significantly superior over napier grass and guinea grass having ability to accumulate more amount of cadmium and lead in shoots and roots tissues. Therefore, mustard and sunflower selected out of four crops based on results of phytoextraction of metals.

FUTURE SCOPE

Evaluating the metal remediation potential of different crop plants can significantly contribute to more efficient phytoremediation strategies. This study helps to fulfill the knowledge gap of screening and identification of a suitable plant species showing higher metal uptake and tolerance. Identifying crops with specific traits that enhance metal accumulation and translocation could lead to more efficient phytoremediation strategies.

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Conflict of Interest. None.

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