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Phytoremediation as an Effective Technology for the Removal of Heavy Metals from Dump Yard Soils

V. Divya Vijayan*† and P. K. Sushama**

*Land Use and Cover Monitoring Division, National Remote Sensing Centre, Balanagar, Hyderabad, 500 037, India

**Department of Soil Science and Agricultural Chemistry, College of Horticulture, Kerala Agricultural University, Vellanikkara, Kerala, India

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ABSTRACT

A study was conducted for the comparative evaluation of different plants and their parts on the phytoaccumulation of heavy metals from the contaminated soil of Laloor, a major waste dump yard of Thrissur city Kerala, India. Initial content of heavy metals under study for the soil is 198.6 mg kg^{-1} for Pb, 11 mg kg^{-1} for Co, 57 mg kg^{-1} for Ni, 105 mg kg^{-1} for Cr and 0.5 mg kg^{-1} for Hg. A pot culture study was conducted with vetiver, marigold and sunflower plant. Upon harvest, the different plant parts were harvested, cleaned, separated and analysed for total heavy metal content using ICP OES. Results revealed that vetiver was found to be a translocator of Cr and other metals like Ni, Pb, Co and Hg were mostly stabilized in the root. Marigold translocated all the heavy metals from soil except Co, whereas sunflower behaved as phytostabiliser for Pb and translocated Co, Ni and Cr. The bioconcentration factor was higher for vetiver compared to sunflower and marigold. On the basis of removal ratio, vetiver was found to be the most efficient in the removal of heavy metals as per the order Cr>Ni>Co>Pb.

INTRODUCTION

Due to continuous disposal of diverse types of wastes in the waste dumping yards, the soils of this area are continuously being contaminated with toxic chemicals and pollutants like heavy metals. Heavy metals are harmful because of their non-biodegradable nature, long biological half-lives and their potential to accumulate in the body parts. Even low concentration of heavy metals has damaging effects as there is no good mechanism for their elimination from the body of man and animals (Ideriah et al. 2010). There are various techniques for heavy metal reduction like isolation, immobilization, toxicity reduction, physical separation and extraction. Raymond & Felix (2011) have listed out some key factors for the applicability and selection of any of the available remediation technologies and concluded that among the different techniques, phytoremediation is one of the best demonstrated available technologies (BDATs) for heavy metal-contaminated sites. Phytoremediation is innovative, economical and environmentally compatible method for heavy metal remediation. It was widely applied to large areas and is useful for solving a wide variety of contaminants (Padmavathiamma & Li 2007). Phytoremediation study conducted by Angelova et al. (2004) found that vetiver was the most suitable candidate for detoxification of the Cu contaminated soils, thus avoiding the entry of heavy metals in food chain. The physiology behind each plant for each heavy metal will be different. In general, at low metal concentrations, the plant cell could resort to a number of avoidance mechanisms such as metal exclusion, translocation and complexation in the cytoplasm (Vangloveld & Clijsters 1994). At high concentrations when primary barriers were broken down, avoidance was insufficient, free metal concentration increased and both redox and non redox species could stimulate the production of reactive oxygen species (ROS) imposing oxidative stress (Aust et al. 1998). Investigating the efficiency of vetiver for phytoremediation technique, Roongtanakiat (2009) concluded that in low to moderately contaminated soil, vetiver can be used efficiently, as the harvested vetiver (after phytoremediation) can be used safely for bioenergy production, compost or even as material for handicrafts, but for extremely polluted sites, it was found to be more suitable to use in conjunction with other remediation methods. A pot culture study was conducted during 2011-2012 with different types of crops to find out the suitability of phytoremediation in removing the heavy metals from the materials collected from waste dumping yard at Laloor, Thrissur.

MATERIALS AND METHODS

Phytoremediation experiment was conducted with the soils from the waste dump yard of Laloor, Thrissur, Kerala. A completely randomized design trial was conducted with three different economic crops-vetiver (*Chrysopogon zizanioides*), sunflower (*Helianthus annuus)* and marigold

(*Tagetes erectas*). Fifteen concrete pots each with a capacity of 100 kg were used for the study. Soils collected from Laloor (50 kg) and sand (25 kg) in the ratio 2:1 was used for filling the pot. The heavy metal contents of the initial material was 198.6 mg kg^{-1} for Pb, 11 mg kg^{-1} for Co, 57 mg kg^{-1} for Ni, 105 mg kg^{-1} for Cr and 0.5 mg kg^{-1} for Hg. Vetiver crop was harvested after one year and the harvested roots and shoots were separated, cleaned and oven dried for further analysis. Marigold and sunflower were harvested after flowering and the shoots, leaves, flower and root separately harvested, cleaned, dried and ground for plant analysis of heavy metal. The heavy metals Pb, Co, Ni, Cr and Hg were extracted using HNO_3: $HClO_4$ (2:1) and estimated using ICP-OES (Optima 8000). The soil after phytoremediation was also analysed for the same heavy metals. Based on the heavy metal accumulation in different parts of the plants, the following indices were worked out for comparison of their phytoremediation potential.

Translocation factor (TF): The metal concentration in shoots/the metal concentration in roots.

Bioconcentration factor (BCF): The heavy metal concentration in the plant/initial concentration of metal in soil. (Subhashini et al. 2013) (calculated based on whole plant total heavy metal uptake)

Removal ratio: $RCr = (B_s \times C_s + B_r \times C_r)/C_T \times$ Weight of initial material taken. Where, B (g) is biomass. C (mg g^{-1}) is the concentration of heavy metal, the subscript of B or C represents shoot (s), root (r) and treated soil (T).

RESULTS AND DISCUSSION

After growing different crops (treatments), the content of heavy metal in the soil was determined and the results of the analysis are presented in Table 1.

The Pb content in soil after phytoremediation with three different crops ranged from 93.88 mg kg^{-1} in soils phytoremediated with vetiver to 175 mg kg^{-1} in soils treated with marigold, and the Pb content was 178.08 mg kg^{-1} for soils treated with sunflower. There was significant difference in the phytoremediated soil for vetiver, but the treatment with sunflower and marigold was on par with each other. Cobalt content of the soil before treatment was 11 mg kg^{-1} and there was no significant difference in Co content in marigold (10.18 mg kg^{-1}) and sunflower (9.8 mg kg^{-1}). The soil phytoremediated with vetiver showed Co content of (8.78 mg kg^{-1}); there was no significant difference in Co content of the different treatments. After phytoremediation, the soils showed reduction in Ni content which varied from 49.28 mg kg^{-1} in marigold treated soil to 32.62 mg kg^{-1} in soil treated with vetiver, which was significantly different. The treatments with marigold and sunflower showed no significant difference between them. The initial content of chromium in the soils was 105 mg kg^{-1} and after phytoremediation it ranged from 49.6 mg kg^{-1} in soils grown with vetiver, 70.0 mg kg^{-1} for soils grown with sunflower and 71.4 mg kg^{-1} in soils grown with marigold. There was significant difference in soils treated with vetiver and other two treatments were on par with each other. The soil grown with marigold had 0.49 mg kg^{-1} and that grown with sunflower had a content of 0.52 mg kg^{-1} which was not significantly different with each other. The soils treated with vetiver had a mercury content of 0.34 mg kg^{-1}, which was significantly different from other treatments.

HEAVY METAL CONTENT OF DIFFERENT PLANTS/ PARTS USED FOR PHYTOREMEDIATION

The details of the result of plant analysis for heavy metals of different plant parts are given in Table 2.

The analytical results of heavy metal content of the different crops, revealed that the sunflower root showed the highest accumulation of Pb (23.62 mg kg^{-1}), followed by marigold (14.9 mg kg^{-1}) and vetiver (13.6 mg kg^{-1}) root, which was not significantly different. Vetiver roots are poor accumulator of Pb. Among shoots, vetiver was the highest accumulator of Pb (6.95 mg kg^{-1}), than sunflower (5.6 mg kg^{-1}) and marigold (3.3 mg kg^{-1}). All the treatments showed significant difference in accumulation of Pb in the shoot. Sunflower leaf had the highest accumulation of Pb (13.66 mg kg^{-1}) than marigold (9.25 mg kg^{-1}), but marigold flower (4.7 mg kg^{-1}) had highest Pb content than sunflower (2.84 mg kg^{-1}). There was no significant difference in the heavy metal accumulation of the leaf and flower parts of the two plants (Fig. 1). Chromium accumulation was higher in vetiver roots (50.38 mg kg^{-1}) followed by marigold root (37.68 mg kg^{-1}) and sunflower root (34.62 mg kg^{-1}), and there was significant difference in accumulation of Cr in the root part of different plants. Among the different shoots, vetiver shoots had the highest accumulation of chromium (54.95 mg kg^{-1}) followed by sunflower shoot (19.7 mg kg^{-1}) (Fig. 2.) and marigold shoot (28.7 mg kg^{-1}) (Fig. 3). The chromium content of vetiver shoot was significantly different from each other. Marigold and sunflower shoots were on par with each other. Marigold leaf had higher Cr content (23.18 mg kg^{-1}) than sunflower leaf (22.84 mg kg^{-1}); however the values were on par with each other. Marigold flower accumulated the highest content of Cr (40.08 mg kg^{-1}) than sunflower flower (18.86 mg kg^{-1}). The highest nickel content was reported in the vetiver roots 21.2 mg kg^{-1} which was not significantly different from sunflower (13.96 mg kg^{-1}) and marigold roots (12.83 mg kg^{-1}). Among the different plant shoots the highest content was in vetiver (12.03 mg kg^{-1}) followed by sunflower (5.85 mg kg^{-1}) and marigold

Table 1: Heavy metal content (mg kg^{-1}) of the soil after phytoremediation with different crops.

Soil after treatment with different crops	Pb	Co	Ni	Cr	Hg
Vetiver	93.88	8.78	32.62	49.6	0.34
Sunflower	178.08	9.8	48.58	70.0	0.52
Marigold	175.00	10.18	49.28	71.4	0.49
CD at 5 %	28.57	1.37	5.27	17.14	0.12

Table 2: Heavy metal contents (mg kg^{-1}) in the different plants/parts used for phytoremediation.

Plants/plant parts used for phytoremediation	Pb	Co	Ni	Cr	Hg
Roots					
Sunflower	23.62 (4.49)	0.98 (1.18)	13.96 (3.62)	34.62 (5.79)	Traces (0.71)
Marigold	14.9 (3.89)	0.83 (1.15)	12.83 (3.53)	37.68 (6.73)	0.023 (1.19)
Vetiver	13.6 (3.73)	1.68 (1.46)	21.2 (4.59)	50.38 (7.41)	0.12 (1.89)
CD at 5 %	2.32	0.39	1.77	0.6	0.6
Shoots					
Sunflower	5.6 (2.43)	0.2 (0.84)	5.85 (2.52)	19.7 (4.45)	Traces (0.71)
Marigold	3.3 (1.92)	traces (0.71)	3.05 (1.79)	28.82 (5.19)	0.029 (0.79)
Vetiver	6.95 (2.72)	0.6 (1.04)	12.03 (3.36)	54.95 (7.42)	0.06 (1.42)
CD at 5 %	0.18	0.003	0.73	1.39	0.013
Leaf					
Sunflower	13.66	0.44	7.5	22.84	Traces
Marigold	9.25	0.23	4.43	23.18	0.027
CD at 5 %	NS	1.32		NS	
Flower					
Sunflower	2.84	0.42	5.68	18.86	Trace
Marigold	4.7	0.50	17.97	40.05	0.015
CD at 5 %	NS	NS	3.9	4.4	

The value in () indicates 0.5 square root transformed data.

(3.05 mg kg^{-1}), which was significantly different from each other. Sunflower leaf had higher Ni content of 7.5 mg kg^{-1} than marigold leaf 4.43 mg kg^{-1}, but marigold flower accumulated higher (17.97 mg kg^{-1}) Ni than sunflower flower (5.68 mg kg^{-1}), these were found to be significantly different. Among the three different roots analysed for the Co content, the maximum accumulation was reported in vetiver root (1.68 mg kg^{-1}) followed by other crops, sunflower (0.98 mg kg^{-1}) and marigold (0.83 mg kg^{-1}), the values were on par with each other. The result of cobalt content in the shoot showed that the highest Co content in vetiver shoot (0.6 mg kg^{-1}) followed by sunflower 0.2 mg kg^{-1} and only trace accumulation of Co seen in marigold shoot. There was significant difference in accumulation of Co in the shoot parts of the different plants. The sunflower leaves accumulated maximum amount of Co than marigold leaf which was found to be significantly different. There was no significant difference in accumulation of Co content in the flowers of sunflower (0.42 mg kg^{-1}) and marigold (0.50 mg kg^{-1}). There was only trace accumulation of Hg in sunflower plant. Among roots, only vetiver root accumulated Hg (0.12 mg kg^{-1}). Among shoots, vetiver accumulated 0.06 mg kg^{-1} and marigold accumulated less amount (0.029 mg kg^{-1}) of Hg, which was found to be significantly different. Marigold leaf and flower accumulated Hg content at an extent of 0.027 and 0.015 mg kg^{-1} respectively.

FACTORS FOR COMPARING PHYTOREMEDIATION EFFICIENCY OF THE DIFFERENT CROPS

The three main factors considered for assessing the phytoremediation potential of the different crops are translocation factor, bioconcentration factor and removal ratio. The translocation factor is a ratio indication of the ability of the plant to translocate metals from the roots to the aerial parts (stem, leaf and flower) of the plants and it was calculated based on the heavy metal content in the different plant parts. Bioconcentration factor (BCF) was used to determine the quantity of heavy metals absorbed by the plant from the soil. The removal ratio of heavy metals with respect to different plants was also calculated. This factor was calculated based on total plant uptake/pot basis. The results of the translocation factor and bioconcentration factor for the crops (treatments) and removal ratio for the different heavy metals are presented in Table 3.

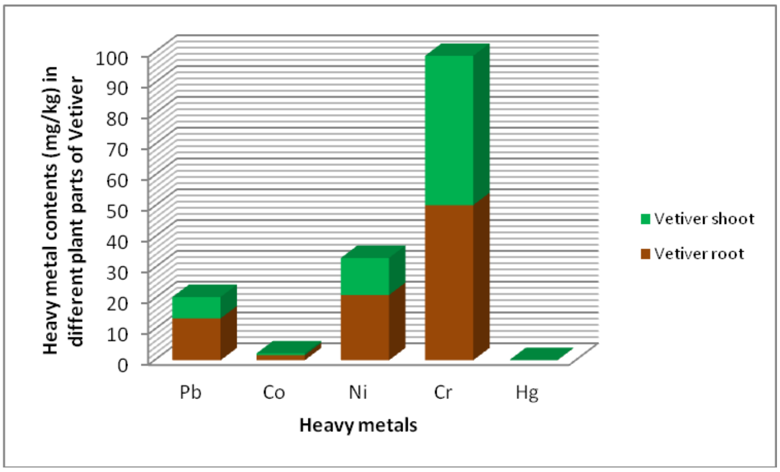

Fig. 1: Comparison of heavy metals in the different parts of vetiver.

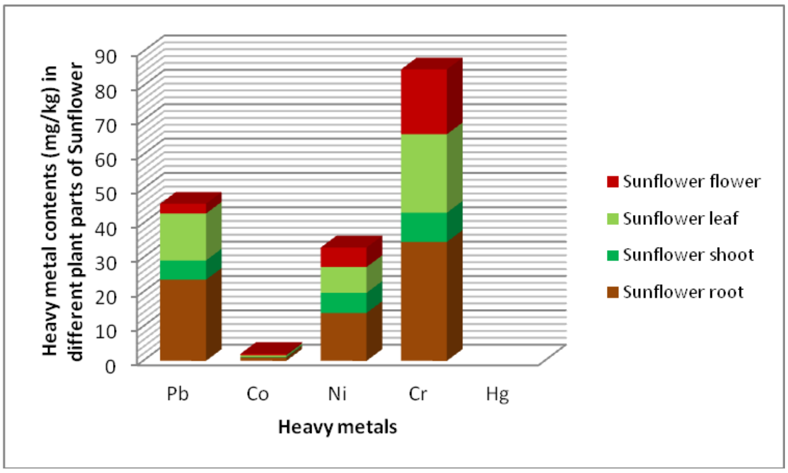

Fig. 2: Comparison of heavy metals in the different parts of sunflower.

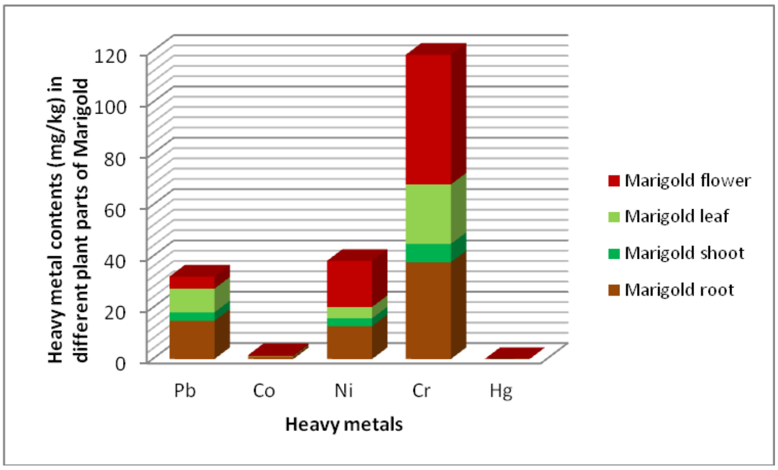

Fig. 3: Comparison of heavy metals in the different parts of marigold.

Table 3: Phytoremediation potential of the crops under study.

Heavy metals	Translocation Factor	Bioconcentration factor	Removal ratio
Sunflower			
Pb	0.9	0.02	0.04
Co	1.1	0.02	0.03
Ni	1.4	0.06	0.11
Cr	1.8	0.10	0.23
Hg	Traces	Traces	Traces
Marigold			
Pb	1.2	0.05	0.08
Co	0.9	0.04	0.07
Ni	2.1	0.24	0.41
Cr	2.5	0.47	1.02
Hg	1.2	0.08	0.11
Vetiver			
Pb	0.5	0.35	1.10
Co	0.4	0.73	1.30
Ni	0.6	2.10	5.44
Cr	1.1	3.21	10.01
Hg	0.5	2.94	0.65
Pb	0.5	0.35	1.10

The results showed that the Pb content was least in the pot grown with vetiver. Hence, the removal was maximum in the soil grown with vetiver, followed by sunflower and it was least removed by marigold. The removal ratio followed the range, vetiver (1.1) > marigold (0.08) > sunflower (0.04). Considering the uptake of heavy metals, vetiver extracted more Pb from soil than sunflower and marigold.

The removal of Cr was found to be maximum in the soil grown with vetiver, followed by sunflower and marigold. The removal ratio followed the order, vetiver (10.01) > marigold > (1.02) sunflower (0.23). As the range for Cr is higher in vetiver, it was found to be a good phytoextractor of Cr. The removal of Ni was found to be maximum in the material grown with vetiver followed by sunflower and marigold. The removal ratio followed the order, vetiver (5.44) > marigold > (0.41) sunflower (0.11). Vetiver is a good phytoextractor of Ni. The removal of Co was maximum in the material grown with vetiver, followed by sunflower and marigold. The removal ratio followed the order, vetiver (1.3) > marigold (0.07) > sunflower (0.03). The removal of Hg was mainly by crops vetiver and marigold. The removal ratio followed the order, vetiver (0.65) and marigold (0.11).

The Pb content in the root parts showed that the highest accumulation was in sunflower followed by marigold and vetiver. Among the different shoots, the vetiver was the best accumulator of Pb followed by sunflower and marigold. Among leaves, sunflower accumulated more Pb than marigold, but for flowers, marigold flowers accumulated more Pb than sunflower. In general, when the different plant parts are compared, it was revealed that there was maximum accumulation of Pb in sunflower roots, significantly different from other plant parts. It has been reported that Pb can adhere to root cell wall, especially in pyrophosphate form (Marschner 1995). It is inevitable that the Pb accumulation in roots may be a factor which enhances tolerance against Pb toxicity. The translocation factor of Pb was maximum for marigold (1.2) followed by sunflower (0.9) and vetiver (0.5). Translocation factor was found to be lower for vetiver.

In general, the vetiver root accumulated more Cr followed by marigold and sunflower. Shoots also followed the same trend vetiver > marigold > sunflower. On comparison of heavy metal contents in the leaf and flower, it was noticed that for both leaf and flower of marigold was better accumulator. The translocation factor of Cr followed the order marigold (2.5) > sunflower (1.8) > vetiver (1.1). For Cr, all the three crops are hyperaccumulators. On perusal of the data it was found that Cr has got some affinity towards marigold plant and the flower accumulated more Cr than other parts.

The Ni content was found to be higher in vetiver roots followed by sunflower and marigold. The same trend followed for shoots also. There was no significant variation in the content of Ni in vetiver roots, whereas the content in shoots was significantly different. Sunflower and marigold treatments were on par with each other. Comparing the accumulation of Ni in the leaf and flower parts, sunflower leaf accumulated more Ni than marigold, but not significantly different. Marigold flowers accumulated more Ni compared with sunflower which was significantly different. The translocation factor was the highest for marigold (2.1), followed by sunflower (1.4) and vetiver (0.6).

The Co content was found to be more in vetiver root, followed by sunflower and marigold. There was no significant difference between vetiver and other crops. The same trend was noticed for shoot part with less accumulation of Co. The Co content of the soil was also below the threshold level, and hence the Co content was less in the plant parts. Co accumulated more in roots with a translocation factor of 0.6 for vetiver and sunflower (0.9) and for marigold (0.4). Mercury mainly accumulated in vetiver and to a lesser extent in marigold shoot and upper parts (leaf and flower). The translocation factor for vetiver was (0.65) and for marigold (1.2).

For the different heavy metals under study, the same crop behaved in different ways. It can be concluded that vetiver had good phytoremediation potential with a bioconcentration factor more than 2 for metals like Ni, Cr and Hg. The phytoremediation study with the three different crops (sunflower, marigold and vetiver) showed vetiver as a good phytostabilizer compared to others. Vetiver was found to be a translocator of Cr, since Ni, Pb, Co and Hg were mostly stabilized in the root. Marigold translocated all these heavy metals from soil except Co, whereas sunflower behaved as phytostabiliser for Pb and translocated Co, Ni and Cr. The bioconcentration factor (the heavy metal concentration in the plant/ the heavy metal concentration in the soil) was higher for vetiver compared to sunflower and marigold. On the basis of removal ratio (based on heavy metal content in treated soil) vetiver was found to be the most efficient in the removal of heavy metals as per the order Cr>Ni>Co>Pb. Marigold had removal ratio of 1.02 for Cr and less than 1.00 for others. The sunflower had low removal ratio for all the heavy metals under the study.

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