

Phytoextraction of Nickel from Contaminated Soils by Employing Bioamendments

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Abstract

Phytoremediation is an emerging technology in which the plants are employed to absorb and bio-magnify elements from polluted environments and metabolize them into various biomolecules. Once inside the plant, chemicals can be stored in roots, stems, or leaves or changed into less harmful chemicals within the plant or changed into gases that are released into the atmosphere. A number of amendments are used either to mobilize or immobilize heavy metals in soils. The basic principle involved in the mobilization technique is to release the metals into soil solution, which is subsequently removed by plants. In contrast, in the case of the immobilization technique the metal concerned is removed from soil solution either through adsorption, complexation and precipitation reactions, thereby rendering the metals unavailable for plant uptake and leaching to groundwater. In the present study, a pot experiment was conducted with marigold to determine the effect of different bio amendments such as farmyard manure, composted poultry manure, press mud compost and prosopisbiochar on phytoextraction of Ni from contaminated soil. The experiment was carried out by using completely randomized design and the results were statistically scrutinized. Of marigold, the highest Ni content ($103 \mu\text{g g}^{-1}$) in the above ground biomass was found in the plants grown on soil amended with press mud compost (T₄) followed by composted poultry manure (T₃). In contrast, the root biomass of marigold had significantly higher Ni content due to the application of farmyard manure (T₂) followed by prosopisbiochar (T₅). There was a positive correlation between the Ni uptake by marigold and bioavailable fractions of Ni in soil. However, marigold showed greater potential in tolerating and accumulating higher concentration Ni and therefore could be employed along with bioamendments for phytoextraction of Ni from contaminated soil.

Keywords: Bioamendments, Marigold, Nickel, Phytoextraction, Phytoremediation

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Introduction

Phytoextraction is the major mechanism through which metal is absorbed by plants and accumulated in their biomass. Then the plants may be harvested and metals recovered by burning/ incinerating the plant biomass. The major criteria for selecting plant species for phytoremediation are hyperaccumulating, fast growing species with high biomass. Usually Ni is stable in the soil and cannot readily be taken up by the plants. Bioavailability of Ni is the prime factor that decides the phytoextraction process. Plant absorption of Ni and other metals is influenced by soil pH, cation exchange capacity, soil organic matter, lime and concentration of micro- and macro-nutrients in soils (Seregin and Kozhevnikova, 2006). The soil organic matter is the most important as it could influence other soil physical and chemical properties which ultimately determine phytoavailability of Ni and other metals. Organic matter plays important role in accumulation and transportation of Ni and other metals through formation of chelates of various stabilities. Therefore, in the current study different bioamendments were used to examine their effect on bioavailability of Ni in soil and subsequent uptake (removal) by Marigold (*Tagetes erecta*) plants was examined

by conducting pot experiments. Since the food crops have been restricted for using phytoremediation/phytoextraction process, flower crop was selected for this study. The higher biomass production characteristics of marigold are one of the major reasons for the selection.

Materials and Methods

The effect of different organic amendments on the bioavailability of Ni in contaminated soil was studied by conducting a pot experiment with marigold. The soil sample was collected from the Ni contaminated area nearby Nanjundapuram, Coimbatore where large number of industries including electroplating industries exist. Then the soil sample was analyzed for the initial Ni content and it was found as 300 mg kg^{-1} . The bioamendments were added as per the following treatment schedule such as T₁. Control - Soil* (No amendments); T₂. Soil* + Farmyard manure (12.5 t ha^{-1}); T₃. Soil*+ Composted poultry manure (5 t ha^{-1}); T₄. Soil*+ Press mud compost (5 t ha^{-1}); T₅. Soil*+ Prosopisbiochar (5 t ha^{-1}) and uniformly mixed. The Marigold seedlings were transplanted after three days incubation of bioamendments addition. Periodically a known amount of water was added uniformly to all pots

to compensate moisture loss. The plants were grown up to active vegetation stage and harvested to examine the Ni accumulation in the plants. Soil and plant samples were collected at the end of the experiment for various analyses. The experiment was carried out by using completely randomized design and the results were statistically scrutinized as suggested by Gomez and Gomez (1984). The plant samples (marigold) collected from the pot culture at harvest stage were cleaned with water and separated into roots and above ground biomass. The samples were kept in paper covers and shade dried and later oven dried (70° C). After recording the dry weight, each sample was ground in a Wiley mill and sub-samples were obtained for laboratory analysis. The plant materials (root, stem, leaves and flowers) were weighed (0.5-1g) and digested with 10 ml of concentrated HNO₃. The total Ni in the acid extract of plant materials was determined using a Perkin Elmer 200 Atomic Absorption Spectrophotometer with air-acetylene flame.

Results and Discussion

Nickel content and uptake by crops

Plants can accumulate Ni usually less than 0.1 per cent of total dry weight. Nickel is very mobile and can be accumulated in vegetative and reproductive parts. The results from marigold experiment showed that the press mud application resulted in the highest Ni content in plants (Table 1). Plants grown on control soil had the lowest Ni content. Relatively higher concentration of Ni was observed in root biomass than in above ground biomass. In general, the plants grown on the control soil had greater amount of Ni in root biomass than in the above ground biomass. In the above ground biomass the highest Ni content (103 µg g⁻¹) was found in the plants grown on soil amended with press mud compost followed by composted

poultry manure. The lowest Ni (3.32 µg g⁻¹) in above ground biomass was observed in the control. In contrast the root biomass of marigold had significantly higher Ni content due to the application of farmyard manure followed by prosopisbiochar and the lowest Ni content in the root biomass was found in the plants grown on soil amended with composted poultry manure. The uptake of Ni by marigold had shown similar effect of bioamendments. A positive correlation was obtained between Ni uptake by marigold and bioavailable fractions of Ni in soil (R² for Water soluble Ni=0.887; R² for Exchangeable Ni=0.941).

All the bioamendments significantly increased the biomass of marigold and in turn it increased the Ni uptake of the plant. Because the Ni uptake was calculated by multiplying Ni content of the plant with the plant biomass. The higher biomass production in the bioamendments added treatments could be due to addition of plant nutrients particularly nitrogen released during decomposition of bioamendments and improvement in the soil physical properties. The plants grown on soil amended with press mud compost had shown relatively higher biomass. This could be due to its higher nutrients and organic matter contents, which on mineralization can supply additional nutrients, improve buffering capacity and enhance nutrient cycling and thus can improve plant growth (Clemente *et al.*, 2007). While prosopisbiochar was found to reduce the Ni concentration in marigold, press mud compost and composted poultry manure were found to increase Ni content and uptake by plants. This could be due to the immobilization of Ni with prosopisbiochar in the soil compared to other amendments as evidenced from less exchangeable fractions of Ni in soil amended with prosopisbiochar.

Table 1: Nickel accumulation in Marigold

Treatments	Total Ni content in marigold (µg g ⁻¹)	Ni content in above ground biomass (µg g ⁻¹)	Ni content in root biomass (µg g ⁻¹)	Biomass of Marigold (g)	Ni uptake (µg/plant)
T ₁	87.4	3.31	84.1	7.17	635
T ₂	107.3	5.71	101.6	8.25	883
T ₃	127.9	79.1	48.9	11.26	1441
T ₄	157.5	103	54.9	12.37	1948
T ₅	112.5	24.9	87.6	9.21	1037
Mean	118.5	43.1	75.4	9.65	1189
SEd	7.62	7.18	9.16	0.59	110.15
CD (0.05)	17.00**	16.00**	20.40**	1.33**	245.41**

Bioconcentration factor and Translocation factor

The mobility of Ni from the polluted soil into the roots of marigold and the ability to translocate the Ni from roots to above ground parts were evaluated by computing the Bioconcentration factor (BCF), the translocation factor (TF) and enrichment factor (EF) as follows (Lorestani *et al.*, 2011);

$$\text{BCF} = \text{Ni in roots (mg kg}^{-1}\text{)} / \text{Ni in soil (mg kg}^{-1}\text{)}$$

$$\text{TF} = \text{Ni in stover/stalks (mg kg}^{-1}\text{)} / \text{Ni in roots (mg kg}^{-1}\text{)}$$

$$\text{EF} = \text{Ni in stover/stalk (mg kg}^{-1}\text{)} / \text{Ni in soil (mg kg}^{-1}\text{)}$$

The ability of marigold to tolerate and accumulate Ni is useful for phyto extraction and thus for phyto remediation. Plants with both BCF and TF greater than one have the potential to be used in phyto extraction. Besides, plants with BCF greater than one and TF less than one have the potential for Phyto stabilization. The lesser values of BCF may suggest the restriction in soil-root transfer at this Ni concentration in the soil (Gafoori *et al.*, 2011). The hyper accumulator plant should have EF greater than 1, or TF >1. The results obtained from the pot experiments are presented in Table 2 and showed that the BCF and EF were less than one for marigold but the TF was greater than one in plants grown on soil amended with bioamendments. Therefore, they may be considered as Ni hyperaccumulator. Heavy metal tolerance with high TF and low BCF value was suggested for phytoaccumulator for contaminated soil (Yoon *et al.*, 2006). However, marigold showed greater potential in tolerating and accumulating higher concentration Ni and therefore could be integrated along with bioamendments for phytoextraction and thus phytoremediation of Ni contaminated soil.

Table 2: Bioconcentration factor (BCF), Translocation coefficient factor (TF) and Enrichment factor (EF) for marigold

Treatments	Marigold		
	BCF	TF	EF
T ₁	0.280	0.042	0.011
T ₂	0.339	0.056	0.019
T ₃	0.163	1.921	0.264
T ₄	0.183	1.866	0.342
T ₅	0.292	0.285	0.083
Mean	0.2514	0.834	0.1438

Conclusion

The application of bioamendments to the Ni contaminated soil enhanced the bioavailability of Ni in the contaminated soil. After soil application, the bioamendments form complexes with fulvic acid and humic acid fractions of SOM. While fulvic acid complex would enhance the bioavailability by mobilization of Ni ions, the humic acid complex results in immobilization of Ni and enhances the adsorption of Ni ions on soil exchange sites. The other benefits of bioamendments include improvement in soil physical characteristics and enhancement of soil cation exchange capacity besides adding nutrients to the soil, which favours better growth and biomass production of plants. Thus the study has demonstrated that a phytoremediation strategy could be developed by integrating bioamendments and hyper accumulators (Marigold) for remediation of Ni contaminated soil.

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