Research Article

Evaluation of nickel phytoremediation potential of *Rumex dentatus*: a greenhouse experiment

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Abstract

Nickel is used in the production of many modern technologies, including stainless steel, electroplating and batteries. With the rapid development of these industries, Ni pollution is becoming an increasing problem. Nickel metal is carcinogenic, mutagenic and neurotoxic. The current study was planned to evaluate the nickel phytoremediation potential of *Rumex dentatus* grown in Ni contaminated soil. The plant *Rumex dentatus* was grown in control and Ni contaminated soil. Nickel metal was analyzed in the soil and plant parts (Root and Shoot). The highest concentration of Ni was found in the roots of the plants grown in Ni contaminated soil (108.01 mg/kg) while its highest concentration was found in the shoots of the plants grown in control soil. Bioconcentration factor (BCF), translocation factor (TF) and bioaccumulation factor (BAC) of the plants grown in control and metal contaminated soil was calculated for Ni metal. The highest BCF value was found in the plant grown in control soil and high TF was found in the plants grown in 258.01 mg/kg Ni contaminated soil. High BAC was found in the plants grown in control soil. Overall the plant was not found hyperaccumulator for Ni metal but based on BCF *Rumex dentatus* was found best for the phytostabilization of Ni contaminated soil up to the concentration of 8.02 mg/kg Ni while the same plant was found feasible for the phytoextraction of Ni from Ni contaminated soil having up to 108.01 mg/kg Ni.
Keywords: Phytoremediation; Phytostabilization; Phytoextraction; Nickel contaminated Soil

Introduction

The metal Ni was first isolated by Cronstedt (A Swedish chemist) in 1751. In the earth's crust it is the 22nd most abundant element [1, 2] and occurs as a free metal or together with iron in igneous rocks. This metal can exist in a number of different oxidation states but under environmental conditions its usual oxidation state is Ni (II), nickel in the +2 valence state. Other valences (+4, +3, +1, and -1) are also encountered, although less frequently [3, 5]. Salts of nickel like chloride, nitrate, sulphate and carbonate, acetate, oxide and hydroxide are of greatest commercial importance [6, 7]. Generally the naturally occurring concentrations of this metal in surface waters as well as in soil are lower than 0.005 and 100 ppm, respectively [8]. Due to anthropogenic activities like metal mining, fossil fuel burning, disposal of household, smelting, vehicle emissions, industrial and municipal wastes and fertilizer applications

Ni is released into the environment [9, 10]. Mainly it is used as a raw material in the electroplating and metallurgical industries, as a catalyst in the food and chemical industry as well as a component of electrical batteries [11]. Recently Ni contamination has been reported from across the world, including Asia [12], North America and Europe [16, 18].Water and Soil contamination with Ni has become a global problem [19, 20].

The average level of airborne Ni in remote area is 0.00001-0.003 µg/m3; in urban areas having no metallurgical industry is 0.0030.03 µg/m^3 and in nickel processing areas is 0.07-0.77 µg/m3 [21, 22]. Drinking water contains Ni at concentrations generally less than 10 µg/l. Supposing a daily intake of 1.5 l of H_2O and a level of 5-10 µg Ni/l, the mean daily intake of Ni from H_2O for adults would be between 7.5 and 15.0 µg. [23]. Acidic beverages and soft drinking water may dissolve Ni from containers and pipes. Corrosion or leaching processes may increase significantly to oral Ni intake, intermittently up to 1 mg/day [24]. It is easily accumulated in the biota, particularly in the phytoplankton's and other aquatic plants which are sensitive to water pollution. Ni can be deposited in the sediment by processes like complexation, precipitation and adsorption on clay particles and through uptake by biota [25, 26].

Accumulation of Ni tremendously affects the yield of plants, significantly decreasing the numbers of seeds/pod [27]. The total plant biomass might be decreased when plants are exposed to Ni stress [28, 29], possibly due to reductions in leaf density and leaf blade area [30], with accompanying reductions in fruits and flowers numbers [31]. Generally, plant yield reductions can be attributed to reduced supply of nutrients to the reproductive parts and poor plant development [32]. It has been reported that chlorosis of plants and leaf necrosis are caused due to Ni beyond allowable level [33, 35]. Vein necrosis and chlorosis appeared in newly developed leaves of spinach in Ni stress condition [36]. The concentration of Ni at 0.5 mM produced necrotic spots along the leaf margins and decreased transpiration rate as well as water potential and leads to wilting and necrosis of the leaves of cabbage [29].

Phytoremediation; the use of plants for the decontamination of nickel contaminated soil is an outstanding and widely acceptable approach. This paper represent feasibility of *Rumex dentatus* for the elimination of Ni from Ni-contaminated soil. The plant was grown in the control and different concentration of Ni contaminated soil. The concentration of the metal was analyzed in the soil, and plant parts. BCF, TF and BAC of the plant for Ni metal was calculated. Based on the calculated BCF, TF and BAC, nickel phytoremediation potential of the research plant was evaluated for the phytostabilization and phytoextraction of Ni metal.

Materials and methods
Experimental design

A greenhouse experiment was conducted in the botanical garden of the Department of Botany, University of Malakand. A total of eighteen pots were used in the experiment. About six kg of soil was added into each pot. Pots were divided into six group's i.e Control, group A, group B, group C, group D and group E. One was control group (three pots) to which no metal was added. In the rest of the soil of the five groups different concentration of nickel (50 ppm, 100 ppm, 250 ppm, 500 ppm and 1000 ppm) was added. Three pots were used for the each concentration of nickel metal in order to significantly assess the uptake potential of the plants in control and different concentration of nickel contaminated soil. After the addition of the concentration of nickel to the pots of five groups, seeds of the plants were sowed in them as well as in control pots. The same water was used for the germination and

growth of the research plant up to maturity in the green house. Upon maturity the plants were carefully uprooted, labelled and dried in shade for a week. Plant parts (root and shoots) were separated and grinded into powder form through electrical grinder for the preparation of samples for the analysis of nickel metal.

Analysis of nickel in the soil

The background concentration of the nickel metal was analyzed in the soil which was used in the experiment. Metal in the soil was determined using the standard method [37]. According to the protocol 5g of soil was taken in a beaker (100 mL) and H_2O_2 (3 mL of 30%) was transferred to it. The soil with hydrogen peroxide was then left as such in the beaker for one hour up to the vigorous reaction stopped. Then HCl (0.5 M) of 75 mL was added into the soil and used hot plate to heat it for about 2 hours. It was cooled and filtered through filter paper (Whatman). The filtrate obtained was diluted up to 50 ml using distil water and used as sample for the purpose of nickel metal determination in them. Nickel in the sample was determined using atomic absorption spectrometry (AAS) in the laboratory of soil sciences, the University of Agriculture. This step was conducted in triplicate. Results were shown as mean ± SD.

Analysis of nickel in plant samples

The plant parts were initially washed thoroughly with tape H_2O and then with distilled H_2O in order to get rid of soil and dust and particles. Oven at 105°C was used to dry parts of the plants (roots and shoots) for 24 hours. The plant parts were grinded with the help of electrical grinder. The powder was digested using the standard procedure [38]. Plant part in powder form (0.5 g) was taken into a beaker (100 mL) and 65% concentrated HNO_3 (5 mL) as well as $HClO4$ (2 mL) were added to it. It was heated using hot plate till the digest became clear. The mixture was cooled and filtered through filter paper (Whatman). The filtrate was collected in a volumetric flask (50 mL). It was diluted with distilled H_2O up to 50 ml. The filtrate was used as sample for the determination of nickel by AAS in the laboratory of soil sciences, the University of Agriculture. As previously mentioned, each step was conducted in triplicate and results were shown as mean ± SD.

Statistical analysis

Excel and Graph pad prism 6 was used for statistical analysis.

Results and discussion

Concentration of nickel in the root and shoot of *Rumex dentatus*

The plant of *Rumex dentatus* was grown in control soil (to which no nickel was added) and in different concentration of nickel contaminated soil (50 ppm, 100 ppm, 250 ppm, 500 ppm and 1000 ppm). The Concentration of nickel was analyzed in the plant parts (Roots and Shoots) grown in different concentration of nickel contaminated and control soil. Farm soils contain about 3-1000 mg Ni / kg^{-1} [39, 40]. The concentration of nickel in the roots was found in the order; Control root > root of group A plants (grown in 50 ppm nickel contaminated soil) < root of group B plants (grown in 100 ppm nickel contaminated soil) < root of group C plants (grown in 250 ppm nickel contaminated soil) > root of group D plants (grown in 250 ppm nickel contaminated soil) < root of group E plants (grown in 1000 ppm nickel contaminated soil). The concentration of nickel in shoot of the plant was found in the order; Control shoot > group A shoot < group B shoot < group C shoot > group D shoot < group E shoot (Figure 1). The concentration of nickel in plant leaves ranges from 0.05 to 5 mg kg^{-1} and its concentrations > 10 ppm are generally considered to be toxic to sensitive species or cultivars [41].

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Bioconcentration factor, translocation factor and bioaccumulation coefficient

Bioconcentration factor (BCF), translocation factor (TF) and bioaccumulation coefficient (BAC) of the *Rumex dentatus* grown in control and different concentration of nickel contaminated soil was calculated. The calculated BCF, TF and BAC values of the plant grown in control and nickel contaminated soil was used for the evaluation of the plants for the phytostabilization and phytoextraction of nickel metals. Bioconcentration factor (BCF) was calculated as nickel concentration ratio of plant roots to soil [42, 44]. BCF of the root of the plants for nickel metal was found in the order; Control > group A < group B > group C < group D > group E. Sheoran *et al.,* [45] stated that the plants are not feasible for the phytoextraction of metal if bioconcentration factor is less than one. Fitz and Wenzel [46] demonstrated that plants exhibiting BCF value less than one are unsuitable for the phytoextraction of metals. The Translocation Factor (TF) was calculated as ratio of nickel metal in plant shoot to that in plant root [43, 44, 47, 48]. The TF values of the same plants was found in the order; Control > group A < group B < group C > group D < group E.

Translocation factor value > than one indicates translocation of metal from root to above ground part [49]. Bioaccumulation Coefficient (BAC) was calculated as ratio of nickel metal in shoots to that in soil [43, 44, 47, 48]. Bioaccumulation coefficient of the analyzed plants for the nickel metal was found in the order; Control > group A < group B > group C > group D < group E. Only plant species with BCF, BAC and TF > than one have the potential for the remediation process [44]. Overall the plants of *Rumex dentatus* grown in control soil was found efficient for the uptake of nickel metal from the soil but the same plant was found to have the potential to be used for the phytostabilization of nickel contaminated soil which having nickel concentration up to 58.01 mg/kg. The plant *Rumex dentatus* was found feasible for the phytoextraction of nickel metal from nickel contaminated soil which have nickel concentration up to 108.01 mg/kg. It was found that increase in the concentration of nickel in the soil beyond 108.01 mg/kg decreases the absorption capacity of the root of the plant due to which the phytostabilization and phytoextraction potential of the plant for nickel metal decreases (Figure 1 & Table 1).
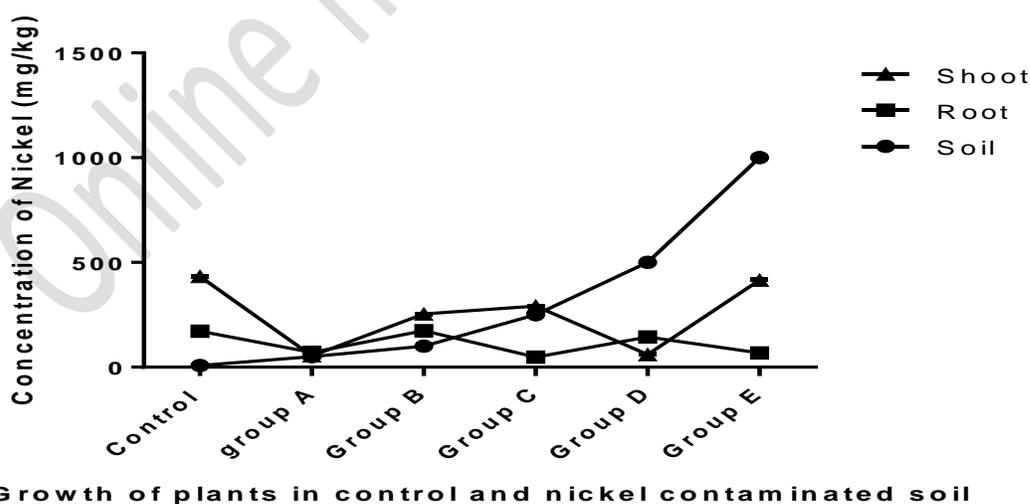

Figure 1. Nickel concentration in *Rumex dentates* (root and shoot) grown in control and nickel contaminated soil

Table 1. Bioconcentration Factor, Translocation Factor and Bioaccumulation Coefficient of *Remex dentatus* for nickel metal

Group	Concentration of Nickel in Soil (mg/kg)			Bioconcentration Factor, Translocation Factor and Bioaccumulation coefficient		
	Background concentration	Concentration added to the soil	Total concentration	BCF	TF	BAC
Control	8.01	0	8.01	21.43[*]	2.52	54.08[*]
A		50	58.01	1.21	0.78	0.95
B		100	108.01	1.61	1.46	2.35
C		250	258.01	0.19	6.13[*]	1.13
D		500	508.01	0.28	0.42	0.12
E		1000	1008.01[*]	0.07	6.08	0.41

* Represent maximum value in respective column

Conclusion

Based on findings of the current research work it is concluded that the highest concentration of nickel was found the root of the plant grown in Ni contaminated soil (Group B) while its highest concentration was found in the shoot of the plant grown in control soil. BCF, TF and BAC of the plants grown in control and Ni contaminated soil was calculated. The highest BCF value was found in the plant grown in control soil and high TF value was found in the plants grown in the soil of group C. High BAC value was found in the plants grown in control soil. Based on BCF *Rumex dentatus* was found best for the phytostabilization of nickel contaminated soil containing Ni up to the concentration of 8.02 mg/kg while the same plant was found feasible for the phytoextraction of nickel from nickel contaminated soil up to 108.01 mg/kg concentration of nickel.

Authors' contributions

Conceived and designed the experiments: MS Khan & MA Sajad, Performed the experiments: MA Sajad, Analyzed the data: MS Khan & MA Sajad, Contributed materials/ analysis/ tools: MS Khan & MA Sajad, Wrote the paper: MA Sajad, ZU Nisa & MA Saleem.

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