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CAPABILITY OF *Iresine herbstii* IN PHYTOTREATING NICKEL-CONTAMINATED WATER

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Abstract

Pollution in water and soil by toxic substances, such as heavy metals, has increased and has become a frequent occurrence in the last decades due to industrialization activities. This research work was performed to determine the performance of a vegetated approach or phytoremediation using *Iresine herbstii* to extract nickel (Ni) from contaminated water. The variation of plant masses 7, 9.2, and 17 g and Nickel (Ni) concentrations of 2, 5, and 10 mg/L was studied by varying the mass ratio of plant to Ni (P_m/Ni_m) in the range from 2800 to 34000 for 21 days of exposure. Nine beakers of 400 mL volume are filled up with 250 mL of synthetic contaminated water with different Ni concentrations. Response surface methodology (RSM) was applied to determine the optimum conditions for the mass ratio of plant to Ni (P_m/Ni_m) and exposure time for the maximum removal efficiency of Ni using D-optimal design. The findings revealed that a Ni removal of 84.5% was achieved at a mass ratio of 2800 at day 16, giving evidence that *Iresine herbstii* is a potential plant to extract Ni from contaminated water.

INTRODUCTION

Environmental pollution encompassing air, water, and soil due to heavy metals is increasing daily due to rapid growth of industrialization and urbanization [1]. Pollution due to heavy metals is increasingly becoming a problem and has become of great concern due to their detrimental impacts on ecosystems and health problem [2]. The soil and water contaminations by toxic heavy metals and organic pollutants frequently occur as a consequence of human activities. Water pollution often originates from industrial wastewater release, sewage or from runoff containing chemical fertilizers and pesticides applied to farmland [3]. Several toxic metals including Cd, Cu, Ni, Mn, Hg, Pb, As, and Zn, from industrial wastewater and other human activities are directly or indirectly discharged into the environment [4]. Large quantity of organic and inorganic wastes are generated yearly in supply chain cycles and have not gone through proper treatment and disposal practices which later created a worldwide pollution [5]. Heavy metals are harmful to humans and other lives, and their existence in the environment can create contamination in soil and water medium [6]. They are difficult to remove from the environment due to their toxicity and non-biodegradable nature [4]. Thus, it is becoming increasingly serious worldwide and thus has become a hot spot in current research [7] to mitigate these issues.

In developing countries like Iraq, the conventional cleaning technologies (physicochemical) are being used for the remediation of heavy metal in wastewater. The main mechanisms for pollutant removal comprise assimilation, biodegradation, adsorption, complexation, flocculation, ion exchange, precipitation, and predation by microorganisms and pollutant reduction via complex biochemical reactions within microorganism metabolism [8]. These methods are expensive and do not lead to complete degradation of pollutants, forcing scientists and engineers to seek for cost-effective and more sustainable approach leading to the development of alternative remediation methods [9] and environmentally friendly cleaning technology. Environmentally friendly technologies based on natural resources to remove pollutants from aquatic ecosystems are becoming more popular. Phytotechnology or vegetated treatment, one of the environmentally friendly approaches, is a technique in which vegetations or plants are used to treat contaminated media with various type of wastes[10, 11]. For wastewater treatment, aquatic plant species are applied to degrade, accumulate, transform, mobilize/immobilize, or detoxify toxic pollutants [11]. This approach, shown to be an efficient method to remove contaminants of various kinds from polluted waters and soils, requires knowledge of native plants and associated microorganism [12]. The ultimate target of this research work was to remove nickel (Ni) from water using ornamental plant (*Iresine herbstii*) and its ability to endurance under changing condition. *Iresine herbstii* is a species of flowering plant in the family of *Amaranthaceae*. Some call this plant as "Chicken Gizzard" deriving its name from the color of its attractive red leaves, which is a strong perennial herbaceous plant, and for its ability to withstand the very hot weather in the summer of Iraq. Alyazouri et.al., (2014) used *Iresine herbstii* for contaminated calcareous desert land in the United Arab Emirates and found to be potential plants for phytoextraction of Pb(II) metal with bioconcentration factors (BCF) >1 [13]. It was used in this study to determine the percentage removal of Ni pollutants from simulated contaminated water containing Ni.

MATERIALS AND METHODS

Experiment Setup and Physical Parameters

Iresine herbstii was collected from a plant nursery in Baghdad. This study was performed from October to December in 2020 and conducted in an open natural condition at University of Baghdad. Nickel sulfate salt was used ($NiSO_4.6H_2O$) for its ability to quickly dissolved in water by mixing the salt in water at 800 rpm and 20°C. A total of nine beakers with each 400 mL volume were filled with 250 mL of synthetic wastewater contaminated with different nickel concentration of 2, 5, and 10 mg/L and plant masses (7, 9.2 and 17 g) (Figure 1). The plants were physically observed as being healthy, withered, or dead. The method was used to determine the suitable ratio of plant biomass to Ni mass that the ornamental plant (*Iresine herbstii*) has able to tolerate and remove Ni with high efficiency from the synthetic contaminated wastewater. The parameters of pH, Temperature (°C), Electrical Conductivity (EC), and Total dissolved solid (TDS) were recorded in the chemical lab for all beakers with and without plants with multi meter (ISOLAB Laborgeräte GmbH, Germany).

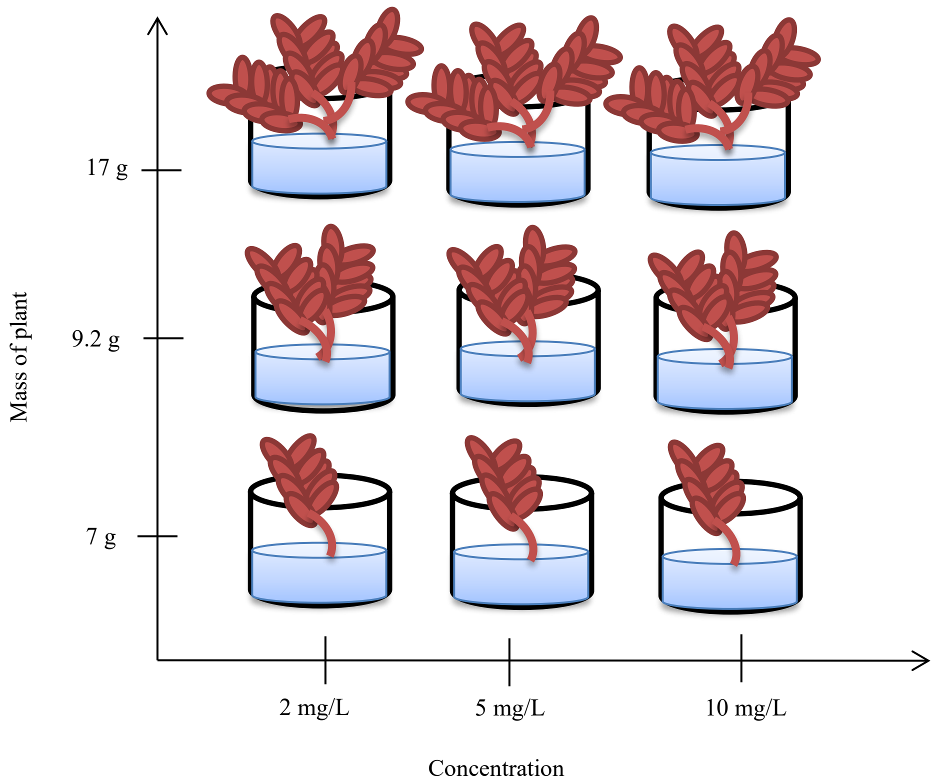

Figure 1: The experimental set-up for Ni extraction by *Iresine herbstii*.

As shown in Table 1, three different mass and Ni concentration, respectively, were used to get different ratio of biomass to Ni (P_m/Ni_m) which vary from 2,800 to 34,000, with goal to determine the sufficient biomass of *Iresine herbstii* to tolerate and uptake Ni for 21 days.

Ni Analysis in Water

Water sample of 20 mL was collected from each beaker on each sampling day (0, 6, 11, 16, and 21) and filled it in the clean tube. No nutrient was added during the test. The Ni analysis was done in the medium of water using Atomic Absorption Spectrophotometry device (Model AA-7000, Shimadzu, Japan). Ni removal on each sampling day was calculated using Equation (1):

$$\%\text{Nickel Re m oval} = \left(\frac{Ni_0 - Ni_d}{Ni_0}\right) \times 100 \quad (1)$$

with, Ni_0 is the concentration at day 0, and Ni_d is the concentration at day of each sampling.

Optimization of Ni Removal with D-Optimal Design (DOD)

The Design Expert version 10 (State Ease Inc., USA) with a DOD was applied for the optimization of Ni removal from water by *Iresine herbstii*. In the optimization process, the response was coupled to decide factors through linear or quadratic models [14]. All experiments for Ni removal from water by *Iresine herbstii*, designated as a response (dependent variable), *Y* were considered according to DOD with two independent variables of time (A) (1, 11, and 21 days) and ratio of plant biomass to Ni (B) (2,800, 18,400, and 340,00 g/g) (Table 2). The arrangement of independent variables is with lower (−1) medium (0) and upper (+1) levels as listed in Table 2. There were 12 total experimental runs simulated by the DOD, including two replicates, to include random error (Table 3). In this work, the mathematical relation between the response and the variables was best modelled by a quadratic model.

Table 1. Ratio of plant biomass to Ni mass applied in the phytoremediation runs.

Ni concentration (mg/L)	Mass of Nickel (g)	Mass of plant (g)	Ratio = Mass of plant (g) / Mass of contaminant (g)
2	0.0005	7	14,000
2	0.0005	9.2	18,400
2	0.0005	17	34,000
5	0.00125	7	5,600
5	0.00125	9.2	7,360
5	0.00125	17	13,600
10	0.0025	7	2,800
10	0.0025	9.2	3,680
10	0.0025	17	6,800

Table 2. Factors with levels in the phytoremediation experimental design.

Factor	Name	Units	Code levels		
			-1	**0**	**1**
A	Time	Day	11	1	21
B	Ratio of plant mass to Ni mass	(g/g)	18400	2800	34000

Table 3. Experimental runs according to DOD and response for Ni removal from water.

Run no.	Day	Ratio	Response (%)
1	1	34,000	3.8
2	1	2,800	7.5
3	11	18,400	49.4
4	11	34,000	82.4
5	21	2,800	76.4
6	21	34,000	67.7
7	11	2,800	83.4
8	1	18,400	18.5
9	21	18,400	74.9
10	21	34,000	67
11	1	34,000	3.5
12	1	2800	7

RESULTS AND DISCUSSION

Status of Plant and Physical Conditions

The effect of Ni toxicity on plant was monitored throughout 21 days. At day 1, the plant was fresh and healthy with the different biomass and Ni concentrations, while at day 16, the plant was semi withered. However, the growth status and stress was observed clearly and the plant was nearly dead in 5 and 10 mg/L Ni concentration for biomass of 9.2 and 17g with 21-day exposure duration (Figure 2).

The monitoring of physicochemical parameters (temperature, pH, EC, and TDS) was recorded throughout treatment of 21 days (Table 4). The water temperature ranged from 26 to 28℃ which is normal during February in Iraq. According to Mustapha et al. [15], the adsorption of the metal ions on the adsorbent increased as the temperature increased from 30 to 80 °C for lead (Pb) and cadmium (Cd) [15]. The pH of water medium in all beakers ranged from 7 to 9 for all the concentrations used (2, 5, 10 mg/L), indicating that pH did not differ significantly among the treatments and the *Iresine herbstii* preferred a neutral condition for nickel remediation due to the secretion of plant metabolites [6]. The EC and TDS values ranged between 39.3-560.0 µS and 21.3-394.0 mg/L, respectively. The increased in EC and TDS are due to impacts of heavy metals on plant growth throughout exposure time and caused impurity of solution due to increasing Ni concentration.

Day 0 Day 21

Figure 2: Condition of *Iresine herbstii* plant in beakers at day 0 and after 21days of Ni exposure.

Table 4. Physical parameters throughout 21days of test.

Parameter	With plants	Without plants
T (℃)	24.0-28.0	24.0-28.0
pH	7.0-8.0	7.0-9.0
EC (μs)	39.3-560.0	39.3-204.0
TDS (mg/L)	21.3-394.0	21.3-132.0

Ni Removal from Water

The removal percentage of Ni for different biomass treatments (7, 9.2 and 17 g) of Ni concentrations (2, 5, and 10 mg/L) is depicted in Figure 3. The best Ni removal performance was with 7 g of biomass. The increasing amount of Ni in contaminated water may decrease the Ni removal efficiency. After 11 days, the removal was 83.4% by *Iresine herbstii* for 7 g of biomass for Ni concentrations of 5 and 10 mg/L. A higher removal efficiency (85.6%) was observed in 7 g of biomass with 10 mg/L Ni concentration. For 9.2 and 17 g of biomass, the removal efficiency was the best at low Ni concentration of 2 mg/L (74.9 and 82.4%) after 21 and 16 days of treatment, respectively. According to a study which used *Phragmatis australis* to remove Ni, the removal efficiency was 84% over a 6-week period [6]. Researchers of Naghipour et al. [16], used *Azolla filiculoides* plant for phytoremediation of heavy metals (Ni, Cd, Pb), and obtained the highest removal efficiency for Ni with 76.82% using biomass of 0.8 g, contact time of 15 days, and initial metal concentration of 25 mg/L [16]. According to Khan et al. [17] when ornamental plant of *Nicotiana alata L*. exposed to 100 mM concentration of Cd, it had led to higher uptake but have negative impact on plant physiology and photosynthetic pigments [17]. In this study, it was observed not only biomass was affected on pollutants removal, but the ratio of biomass to contaminant should be considered to be proportionality together.

Optimization of Operational Conditions

In this study, the RSM model was applied using the results of the beaker test with independent parameters of time (A) and ratio of plant biomass to Ni (B) and response parameter of Ni removal. The R^2 correlation coefficient of the model was 0.933, demonstrating a high fit between the values of the experimental data and the regression model. In addition, the good value of adjusted R^2 coefficients (R^2_{adj}=0.875) gives evidence that the experimental results agreed well with the final prediction value [18, 19]. Through the RSM model (Figure 4), a quadratic equation by multiple regressions was fitted to the results and the following Equation (2) was obtained.

$$\text{Ni Removal} = +68.84 + 32.37 \times A - 2.79 \times B - 31.88 \times A^2 + 4.34 \times B^2 - 1.57 \times A \times B \qquad (2)$$

The analysis of variance, as listed in Table 5, compiles the regression model data for Ni removal by *Iresine herbstii*. The model with (R^2) of 0.932 and an adjusted coefficient (R^2_{adj}) of 0.875, suggesting that the model was satisfactorily accepted describing the hypothesis of the phytoremediation process of Nickel-polluted water by the ornamental plant of *Iresine herbstii*. The interactions effect of time and ratio of plant biomass to Ni-on-Ni removal was found significant with p-value<0.05 (Table 5).

The interaction between both factors shows that increasing exposure time had increased the Ni removal for all selected ratio until day 16 with the best removal efficiency was 85.6% for 7 g of biomass in 10 mg/L Ni concentration, as demonstrated in Figure 5.

Based on the regression model, the Ni removal from water was optimized at a ratio of plant biomass to Ni of 2,800 for 16 days. Under these conditions, the Ni removal was predicted with 84.5% efficiency. Such data is useful in the determine plant biomass required for phytoremediation of effluents industry wastewater contaminated with known value of heavy metal concentration. Heavy metal remediation by ornamental plants can simultaneously remove contaminants and get advantage of aesthetic value for the site [20].

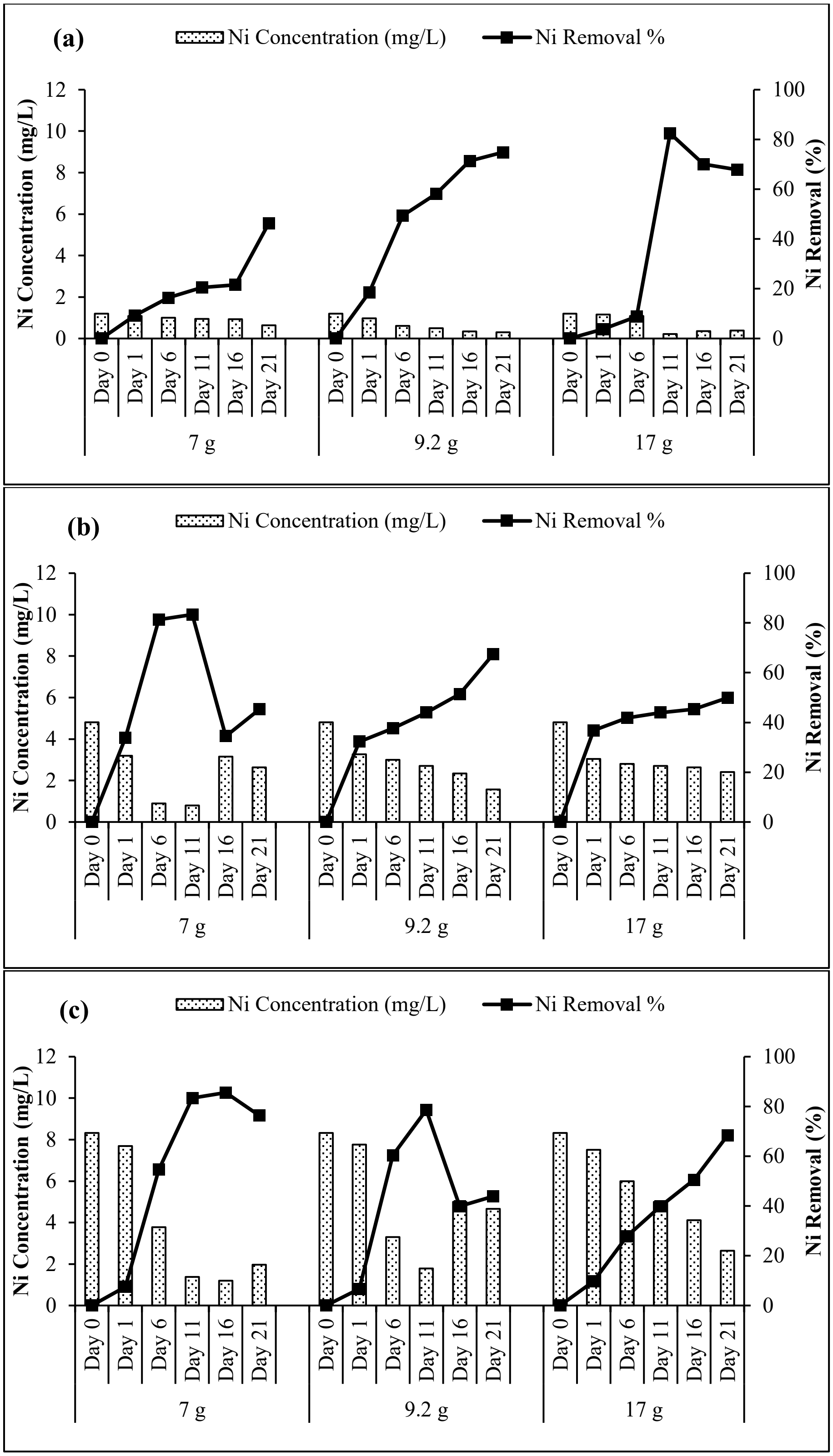

Figure 3: Ni phytoremediation by *Iresine herbstii* for different Ni concentrations, (a) 2 mg/L, (b) 5 mg/L and (c) 10 mg/L, according to varying plant biomass (7, 9.2 and 17 g).

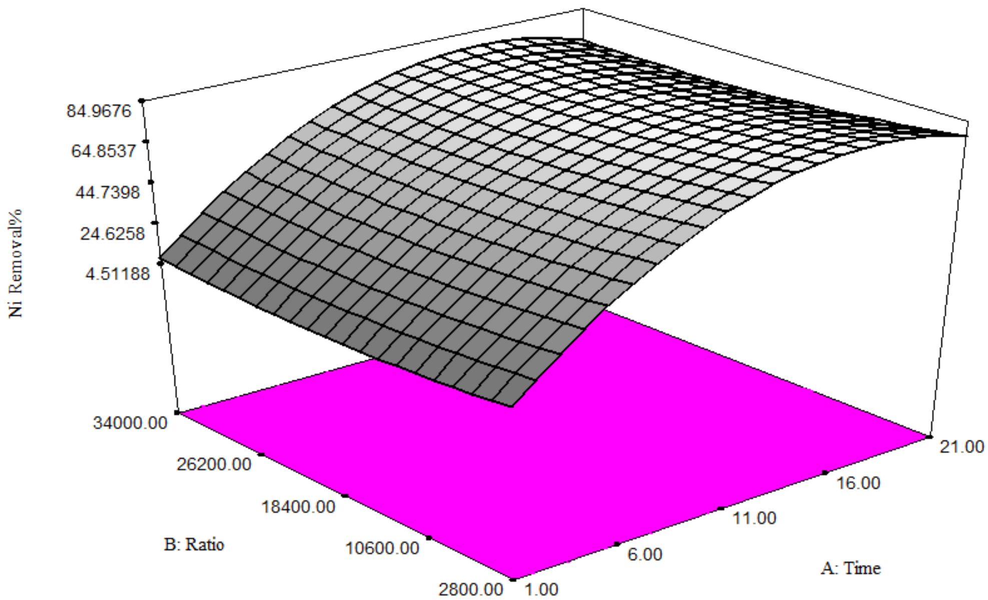

Figure 4: Response surface of Ni removal by *Iresine herbstii* with respect to time and ratio.

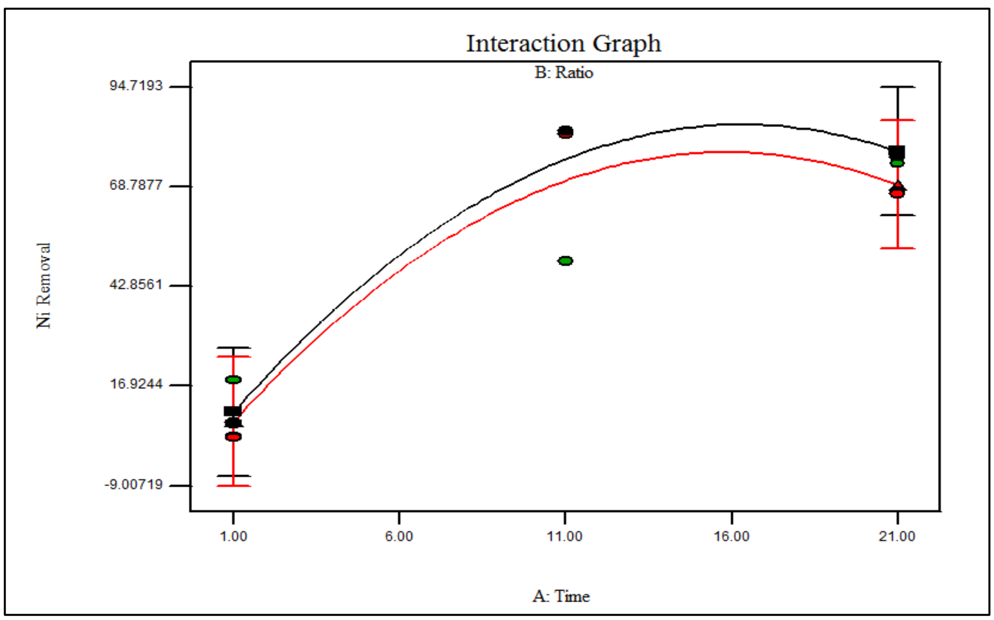

Figure 5: Interaction effects of time and ratio of plant biomass to Ni mass on Ni removal. Black line is low ratio (2,800) and red line is high ratio (3,400).

Table 5: Variance Analysis of the regression model for Ni removal by *Iresine herbstii*.

Source of Variation	Sum of Squares	DF	Mean Square	F-Value	P-Value
Model	11881.60285	5	2376.32057	16.49434	0.0019*
A	8885.407202	1	8885.407202	61.67473	0.0002*
B	65.94419782	1	65.94419782	0.457727	0.5239
A^2	2233.081141	1	2233.081141	15.5001	0.0077*
B^2	41.31532325	1	41.31532325	0.286775	0.6116
AB	16.01069385	1	16.01069385	0.111132	0.7502
Residual	864.413146	6	144.0688577		
Pure Error	0.415	3	0.138333333		
Cor Total	12746.016	11			

DF: Degrees of Freedom.
$R^2 = 0.933$, $R^2_{adj} = 0.875$, adequate precision = 8.652, *Significant at $p < 0.05$.

CONCLUSION

The study shows that the ratio of plant biomass to Ni can significantly optimize the phytoremediation process of Ni using *Iresine herbstii* species. In this study, the effects of plant biomass and different Ni concentrations on Ni removal were investigated through ratio of plant biomass to Ni and the optimum conditions of the best Ni removal were determined. The optimum conditions for Ni removal were obtained using 2,800 for the ratio of plant biomass to Ni and time of 16 days, indicating the low plant biomass is capable to remove Ni up to the relatively high Ni concentration of 10 mg/L. These results can be used to determine the plant biomass required to be applied in a pilot or field study to achieve the best removal efficiency for Ni by *Iresine herbstii* plant species.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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