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# The Determination of Phytoextraction Capacity Using Lavender (*Lavandula latifolia*) Plant in Nickel-Contaminated Soils

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**Abstract**
This study was conducted to evaluate the suitability of Lavender (*Lavandula latifolia*) plant for the remediation of soils contaminated with nickel (Ni). The Lavender plant has the potential to clean contaminated soils by absorbing pollutants through a method called phytoextraction. In the research, Ni-contaminated soils were prepared under controlled conditions, and Lavender plants were grown in these soils. The growth and development of the plants were monitored, and it was investigated whether the plants absorbed Ni from the soil and accumulated it on the plant. Increasing doses of Ni (0-200-400-600-800 mg $kg^{-1}$) were applied in solution form, and pot soils were incubated for one week at 60-65% of field capacity. Then, seedlings in peat medium were transferred to pots and grown under controlled conditions for 6 weeks. It was determined that the plant age, fresh and dry weight, and height increased with 200 and 400 mg Ni $kg^{-1}$ applications compared to the control groups, while there was a decrease with 600 and 800 mg Ni $kg^{-1}$ applications. The lowest concentrations of Ni (mg $kg^{-1}$) in plants and Ni content (µg $plant^{-1}$) were observed in the control group (0 mg Ni $kg^{-1}$), while the highest values were found in the 800 mg Ni $kg^{-1}$ application. It was found that the concentrations of 400 mg Ni $kg^{-1}$ (124 µg $plant^{-1}$), 600 mg Ni $kg^{-1}$ (137 µg $plant^{-1}$), and 800 mg Ni $kg^{-1}$ (150 µg $plant^{-1}$) exceeded critical levels for plants, yet the plants remained alive at these concentrations. The phytoextraction ability of plants refers to their ability to absorb and retain harmful or polluting substances from the soil. Lavender may be among the plants that have phytoextraction potential for metals like Ni. However, the phytoextraction ability can vary depending on the species of the plant, growth conditions, and the pollutant applied. The research results demonstrated that the Lavender plant effectively absorbed Ni from the soil and accumulated it on the plant. This suggests that Lavender can be used for the remediation of soils contaminated with Ni.

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## 1. Introduction

Our soils, which sustain our nutrition with today's technology, are becoming increasingly contaminated with each passing day. The increasing pollution poses a threat to agricultural activities, leading to a gradual decrease in the areas where farming is practiced (Syed, 2005). Soil pollution can occur due to many reasons, including primarily poor hygiene habits, excessive use of agricultural pesticides, inadequate methods for solid and liquid waste disposal, improper waste disposal through open dumping, unplanned urbanization, waste generated from livestock farming activities, industrial and mining waste, irrigation of agricultural lands with untreated polluted waters, radioactive contamination, and air pollution (TÇMO, 2018; Güler and Çobanoğlu, 1997).

Heavy metals are among the primary pollutants in soil pollution, which has become a global issue. It is reported that soil pollution, particularly due to heavy metals, is becoming an increasingly significant problem (Doelsche et al., 2005 a, b).

Heavy metals are distinguished from other toxic metals by the fact that they cannot be destroyed or created by humans. Therefore, they tend to accumulate in soils, solutions, clean water sources, and seawater (Karaçağıl, 2013).

The excessive and indiscriminate application of phosphorus fertilizers such as Diammonium Phosphate (DAP), Triple Superphosphate (TSP), and composite fertilizers to increase yield in soils used for agricultural activities leads to an increase in the concentration of toxic metals, especially in the upper layers of the soil (Dağdeviren, 2007).

Some heavy metals such as mercury (Hg), lead (Pb), cadmium (Cd), selenium (Se), and nickel (Ni) can transfer from soils to animal and plant-based foods. These substances are highly dangerous and toxic at high concentrations (Güler and Çobanoğlu, 1997).

Nickel (Ni), a heavy metal that is also a plant nutrient element, can be taken up by plants in its ion form from the soil. Nickel is present in small or large amounts in all soils, and among the primary sources of Ni in soils are minerals found in phosphorus-containing fertilizers and volcanic rocks (Brohi et al., 1995). Although Nİ is considered a plant nutrient element, its necessity for plants is not fully understood. However, it has been determined that plants cannot benefit from urea-based fertilizers in the absence of Ni because Ni is involved in the formation of enzymes such as urease and hydrogenase in plants (Kacar and Katkat, 2007). In humans, excessive intake of Ni beyond the threshold value can result in symptoms such as diarrhea, vomiting, shortness of breath, and damage to the liver and kidneys. Additionally, chronic Ni poisoning can lead to allergic reactions (Çağlarırmak and Hepçimen, 2010).

Indeed, heavy metals are difficult to break down, making their removal from the environment quite challenging (Tripathi and Ranjan, 2015). The removal of heavy metal pollution involves the use of physical, chemical, and biological methods (Fu and Wang, 2011). Biological remediation methods involve the environmentally friendly use of plants and organisms to restore polluted areas (Dindar et al., 2017). Phytoremediation, a method within biological remediation, involves the removal of organic and inorganic pollutants from soil and water through the roots of plants, transporting them to the aerial parts of the plant, and neutralizing them. This method is used to reduce environmental pollution by allowing natural plants to clean pollutants (Dağhan and Öztürk, 2015; Eren and Mert, 2017). Hyperaccumulator plants, referred to as accumulators, have the ability to accumulate more heavy metals in their above-ground parts than the levels present in the soil, making them hyperaccumulator plants used in phytoremediation to remove heavy metals from soils (Baker and Walker, 1990).

The use of hyperaccumulator plants in the remediation of areas contaminated with heavy metals is becoming increasingly important today, as is the identification of plants possessing these characteristics (Mulligan et al., 2001). The characteristics of a plant that can be used in phytoremediation include: (I) Plant selection; aims to capitalize on different plant characteristics for various phytotechnologies, (II) Fast growth capability; plants with rapid growth potential are preferred, (III) Competitiveness; the ability of plants to compete with other plant species is important, (IV) Resilient and pollution-tolerant; plants capable of withstanding and showing tolerance to pollution sources are preferred, (V) ability to thrive in high metal levels; The ability of plants exposed to high metal concentrations to survive is important, (VI) Easy harvestability; plants that can be easily harvested are preferred, (VII) High metal accumulation capability; the potential of plants to accumulate high amounts of metal in harvestable parts is important, (VIII) Strong and rich root system; plants with a strong and rich root system capable of producing high biomass in the field are preferred, (IX) Easy reproduction and accumulation capability; the ability of plants to reproduce easily and accumulate the targeted metal is important, (X) Important aspects for phytoextraction; the ability of plants to uptake, transport, and accumulate inorganic substances in harvestable tissues are crucial for phytoextraction. Plants with these characteristics are preferred in phytoremediation applications.

This study aimed to evaluate the suitability of Lavender (*Lavandula latifolia*), a medicinal aromatic plant known for its shallow roots and ability to grow in climates that are hot in summer and cool in winter, for the remediation of soils contaminated with Ni.

## 2. Materials and Methods

### 2.1. Plant material

In the study, Lavender (*Lavandula latifolia*) plant material was used. Lavender is preferred particularly for its shallow root system. It is not highly selective regarding soil type, preferring dry, light, and calcium-rich soils (Gülşen, 2017). The plant can thrive in soil pH ranging from 6.4 to 8.2 and is suitable for climates that are hot in summer and cool in winter. Lavender has moderate water requirements and is resistant to short-term drought (Mason, 2014).

### 2.2. Soil preparation

The Ni content of the soil was determined using the 0.05 M DTPA method (pH=7.3), as reported by Risser and Baker (1990), by calculating the ratio of 10 g of soil to 20 mL of DTPA. Heavy metal analysis and trace elements were determined using ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) for soil samples. Total N was determined using the Kjeldahl method (Bremner, 1965). Phosphorus content was determined according to the Olsen method (Olsen, 1954). Potassium analysis was performed using the method of 1 N ammonium acetate (pH:7) as reported by Kacar (1995). Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucus, 1952). pH was measured using the $CaCl_2$ method. $CaCO_3$ content was determined using the volumetric method described by Loeppert et al. (1996). Organic matter content was determined as reported by Kacar (1995).

### 2.3. Soil parameters used in the study

Some physical and chemical analysis results of the soil used in the experiment are presented in Table 1. As seen in the table, the soil used in the study has a clay-loam texture. The lime content of the experimental soil is approximately 12.3 %, indicating moderately calcareous soil, with a pH of 7.48, indicating slightly alkaline conditions. There are no issues regarding salinity.

**Table 1.** Some chemical and physical parameters of the experimental soil

| Parameters | Soil |
|---|---|
| Texture | Clay-Loam |
| pH | 7.48 |
| Salinity (%) | 0.15 |
| Lime (%) | 12.3 |
| O. M. (%) | 1.47 |
| N (%) | 0.21 |
| P (kg $P_2O_5$ $da^{-1}$) | 8.13 |
| K (kg $K_2O$ $da^{-1}$) | 56.8 |
| Fe (mg $kg^{-1}$) | 34.8 |
| Cu (mg $kg^{-1}$) | 2.05 |
| Mn (mg $kg^{-1}$) | 38.6 |
| Zn (mg $kg^{-1}$) | 1.48 |
| Ni (mg $kg^{-1}$) | 0.13 |

### 2.4. Artificial soil contamination process

To ensure homogeneous distribution of Ni in the soil, a solution of $NiSO_4.6H_2O$ was used to prepare different Ni doses. These doses were prepared in increasing doses of Ni, namely control (0 mg $kg^{-1}$), 200 mg $kg^{-1}$, 400 mg $kg^{-1}$, 600 mg $kg^{-1}$, and 800 mg $kg^{-1}$. The solution of the determined Ni doses was applied to the soil of each pot. This application aims to ensure homogeneous enrichment of the soil with Ni. The amount of applied solution was adjusted to 60-65 % of the soil's water holding capacity. This is important to regulate the soil moisture level and provide a suitable incubation environment. After the process was completed, the pots were left for incubation under controlled conditions for one week. During this time, the soil interacts homogeneously with Ni, ensuring distribution.

### 2.5. Setting up the pot experiment

Throughout the experiment, 3-liter pots were prepared using clean and artificially contaminated air-dried soil samples. Each pot was filled with 3 kg of air-dried soil. Lavender plant seedlings were prepared in advance in peat medium for cultivation. These seedlings were transferred to the pots and grown under controlled conditions (16 hours of light:8 hours of dark) for approximately 6 weeks. The experiment was set up in triplicate. Each pot was considered an independent trial. The watering process aimed to reach 60-65 % of the soil's water holding capacity.

### 2.6. Preparation and analysis of plant samples

Plant samples obtained from the pot experiments were harvested along with their green parts. The plant samples were washed with distilled water. This step ensures the removal of any dust, dirt, or other contaminants present on the plants. Washed plant samples were dried in a drying cabinet at 65 °C until a constant weight was reached. This process removes the water content of the plants and allows for the determination of their dry weights. The dry weights of the dried plant samples were measured. This weight represents the remaining weight of the plant after the water content is removed. Plant samples were ground into a fine powder using a plant grinding mill. This step ensures that the plants are ground into a fine powder for later analysis. The ground plant samples can be used for various analyses, such as determining the content of nutrients, toxins, or other components. The nitrogen (N) content in the plant samples was analyzed using the Kjeldahl method (Bremner, 1965). Additionally, the total element concentrations (Ni, P, K, Cu, Fe, Mn, and Zn) in the ground plant samples were determined by digesting them with nitric acid ($HNO_3$) in a microwave oven (MarsXpress CEM) and then analyzed using ICP-AES.

### 2.7. Statistical analysis

The SPSS statistical package program was used to determine the significance of differences between means using analysis of variance (ANOVA). The Walker-Duncan test is a method used in post-hoc analysis of ANOVA results. This test makes pairwise comparisons between groups to determine differences and statistically separates groups into significant subgroups. In this way, it can be determined which groups are statistically different from each other. The SPSS statistical package is a commonly used software that allows for statistical analysis, including ANOVA analysis and post-hoc tests. This program is frequently used in research for the statistical analysis of data and evaluation of results. The Walker-Duncan test, based on ANOVA results, statistically separates groups into significant subgroups and uses P-values. The P-value is a measure used to determine the significance of the statistical difference between two groups. $P \leq 0.01$ and $P \leq 0.05$ are commonly accepted threshold values for statistical significance.

## 3. Results and Discussion

### 3.1. The effect of different doses of Ni applications on fresh and dry weights, as well as plant heights of *Lavandula latifolia* plants

According to the variance analysis results for the fresh and dry weights (g per plant) and plant heights (cm) of *Lavandula latifolia* plants, it was statistically significant at the level of $P \leq 0.01$ for the weight amounts and at the level of $P \leq 0.05$ for the height amounts (Table 2). These results indicate that the different doses of Ni applications have a significant effect on the growth and weight development of the plant.

It was determined that Ni applications resulted in variations in the fresh weights of plants ranging from 10.5 to 16.7 g per plant, with the lowest being in the application of 800 mg Ni $kg^{-1}$ and the highest in the application of 200 mg Ni $kg^{-1}$ (Table 2). Heavy metal (Cd, Pb, and Ni) contamination significantly reduces plant height, fresh and dry weight per plant, flower and fruit numbers per plant, and fruit yield compared to non-contaminated soil (Zeeshan et al., 2020). Decreases in fresh and dry weights were reported in chickpea plants with Ni applications (10, 50, 100, 200, and 400 mg $kg^{-1}$) (Khan and Khan, 2010). It was determined that the dry weights of plants varied from 2.36 to 3.97 g per plant, with the lowest being in the application of 800 mg Ni $kg^{-1}$ and the highest in the application of 200 mg Ni $kg^{-1}$. The different doses of Ni applications resulted in variations in plant height ranging from 26.0 to 29.7 cm, with the lowest being in the application of 600 mg Ni $kg^{-1}$ and the highest in the application of 200 mg Ni $kg^{-1}$ (Table 2). It was found that the fresh and dry weights and plant heights increased with 200 and 400 mg Ni $kg^{-1}$ applications compared to the control groups, while a decrease was observed in plants with 600 and 800 mg Ni $kg^{-1}$ applications.

Nickel toxicity reduces the green biomass, dry matter accumulation, and height of the stems in many plant species. Additionally, Ni toxicity has been reported to decrease flower and fruit numbers in various plant species (Balaguer et al., 1993; Singh and Nayyar, 2001; Mizuno et al., 2003; Doğru et al., 2021). These effects indicate that high Ni concentrations have a negative impact on plant growth, development, and reproductive abilities. Nickel toxicity can disrupt normal physiological processes in plants, negatively affecting plant health and yield.

The results obtained demonstrate that different doses of Ni applications have dose-dependent effects on the fresh and dry weights and plant heights of plants, leading to an increase at lower doses and a decrease at higher doses.

**Table 2.** The effect of different doses of ni applications on fresh weight, dry weight, and height of Lavender plants.

| **Doses (mg Ni kg$^{-1}$)** | **Fresh Weight (g bitki$^{-1}$)** | **Dry Weight (g bitki$^{-1}$)** | **Height (cm)** |
|---|---|---|---|
| **0** | 14.7 a | 3.52 bc | 28.3 a |
| **200** | 16.7 a | 3.97 a | 29.7 a |
| **400** | 16.3 a | 3.84 a | 28.7 a |
| **600** | 13.7 ab | 3.23 b | 26.0 b |
| **800** | 10.5 b | 2.36 c | 27.7 ab |
| **F** | 6.41** | 15.3** | 4.39* |

(**) Statistically significant at the level of $P \leq 0.01$, (*) Statistically significant at the level of $P \leq 0.05$

### 3.2. The effect of different doses of Ni applications on N, P, and K concentrations in *Lavandula latifolia* plants

According to the variance analysis results for N and P concentrations in Lavandula latifolia plants, it was found to be statistically significant at the level of $P \leq 0.01$, while the K concentration was determined to be not statistically significant (Table 3). The analysis indicates that Ni applications have a significant effect on N and P concentrations in the plant, but do not affect K concentration.

**Table 3.** The effect of different doses of Ni applications on N, P, and K concentrations in Lavender plants

| **Doses (mg Ni kg$^{-1}$)** | **N (%)** | **P (mg kg$^{-1}$)** | **K (mg kg$^{-1}$)** |
|---|---|---|---|
| **0** | 2.87 b | 2.76 a | 4,14 |
| **200** | 3.38 a | 2.71 a | 4,01 |
| **400** | 2.82 b | 1.96 c | 3,81 |
| **600** | 2.72 cb | 2.37 b | 3,83 |
| **800** | 2.59 c | 1.82 d | 3,69 |
| **F** | 29.9** | 168** | 2.42$^{N.S.}$ |

(**) Statistically significant at the level of $P \leq 0.01$, (N.S.) Not statistically significant

The application of Ni resulted in variations in % N concentrations in plants ranging from 2.59 to 3.38 %, with the lowest concentration observed in the application of 800 mg Ni kg$^{-1}$ and the highest in the application of 200 mg Ni kg$^{-1}$. The concentrations of P in plants varied from 1.82 to 2.76 mg kg$^{-1}$, with the lowest concentration observed in the application of 800 mg Ni kg$^{-1}$ and the highest in the control group with no application. Different doses of Ni applications resulted in variations in K concentrations in plants ranging from 3.69 to 4.14 mg K kg$^{-1}$, with the lowest concentration observed in the application of 800 mg Ni kg$^{-1}$ and the highest in the control group with no application (Table 3). It has been reported that different doses of Ni applications in *Xanthium strumarium* L. plants (50, 100, 200, and 400) led to a decrease in N, P, and K concentrations in the plants depending on the doses (Eren, 2019). Dağhan et al. (2013) indicated that the effect of heavy metal applications on N, P, and K in transgenic and non-transgenic tobacco plants decreased depending on Ni applications.

It is concluded that Ni applications can affect the N, P, and K concentrations in plants and these elements can accumulate in plant tissues at different concentrations.

### 3.3. The effect of different doses of Ni applications on Cu, Fe, Mn, and Zn concentrations in *Lavandula latifolia* plants

According to the variance analysis results, it has been determined that different doses of Ni applications have a statistically significant effect on Cu and Zn concentrations in *Lavandula latifolia* plants. This indicates that it is statistically significant at the level of $P \leq 0.01$ (Table 4).

**Çizelge 4.** The effect of different doses of Ni applications on Cu, Fe, Mn, and Zn concentrations in Lavender plants

| Doses (mg Ni kg$^{-1}$) | (Cu) | (Fe) | (Mn) | (Zn) |
|---|---|---|---|---|
| | (mg kg$^{-1}$) | | | |
| **0** | 13.4 c | 1368 | 173 | 40.3 cb |
| **200** | 24.2 ba | 1497 | 158 | 46.5 ba |
| **400** | 27.6 a | 1703 | 195 | 52.4 a |
| **600** | 9.73 c | 1484 | 134 | 31.0 dc |
| **800** | 16.0 cb | 1228 | 84,5 | 28.2 d |
| **F** | 8.72** | 0.93 $^{N.S.}$ | 1.49 $^{N.S.}$ | 13.9** |

(**) Statistically significant at the level of $P \leq 0.01$, (N.S.) Not statistically significant.

The application of Ni resulted in variations in Cu concentrations in plants ranging from 9.73 to 27.6 mg kg$^{-1}$, with the lowest concentration observed in the application of 600 mg Ni kg$^{-1}$ and the highest in the application of 400 mg Ni kg$^{-1}$. The concentrations of Fe in plants varied from 1228 to 1703 mg kg$^{-1}$, with the lowest concentration observed in the application of 800 mg Ni kg$^{-1}$ and the highest in the application of 400 mg Ni kg$^{-1}$. Different doses of Ni applications resulted in variations in Mn concentrations in plants ranging from 84.5 to 195 mg kg$^{-1}$, with the lowest concentration observed in the application of 800 mg Ni kg$^{-1}$ and the highest in the application of 400 mg Ni kg$^{-1}$. The effect of Ni doses on Zn concentration in plants ranged from 28.2 to 52.4 mg kg$^{-1}$, with the lowest concentration observed in the application of 800 mg Ni kg$^{-1}$ and the highest in the application of 400 mg Ni kg$^{-1}$ (Table 4). Different levels of Ni applications (10, 20, 30, and 40 mg L$^{-1}$) were reported to significantly decrease the concentrations of micronutrients (Zn, Mn, Fe, and Cu) in both leaves and stems of *Helianthus annuus* L. plants by Ahmad et al. (2011). Other researchers have also reported that Ni applications lead to a decrease in micronutrients in plants (Turgut et al., 2004; Ali et al., 2009).

### 3.4. The effect of Ni applications at different doses on Ni concentration (mg kg$^{-1}$) and Ni content (µg plant$^{-1}$) in plants

According to the variance analysis results for Ni concentration (mg kg$^{-1}$) and Ni content (µg plant$^{-1}$) in *Lavandula latifolia* plants at different doses of Ni applications, it was statistically significant at the level of $P \leq 0.01$ (Table 5). These results indicate that different doses of Ni applications have a significant effect on both Ni concentration and Ni content in the plant.

Nickel applications resulted in variations in Ni concentrations in plants ranging from 2.58 to 63.6 mg Ni kg$^{-1}$, with the lowest application in the control group without any treatment and the highest at 800 mg Ni kg$^{-1}$ application (Table 5). Kaviani et al. (2017) reported in their research using Salicornia iranica plants that Ni doses in soil (0, 50, 250, and 500 mg Ni kg$^{-1}$) led to an increase in Ni concentration in plants. Dağhan et al. (2013) reported an increase in Ni concentration in tobacco plants, both transgenic and non-transgenic, in response to Ni applications of heavy metals.

Different doses of Ni applications resulted in variations in Ni content in plants ranging from 9.04 to 150 µg plant$^{-1}$, with the lowest value in the control group without any treatment and the highest value at 800 mg Ni kg$^{-1}$ application (Table 5).

**Table 5.** The effect of different doses of Ni applications on Ni concentration and Ni content in Lavender plants

| Doses (mg Ni kg$^{-1}$) | Ni concentration (mg kg$^{-1}$) | Ni Content (µg bitki$^{-1}$) |
|---|---|---|
| **0** | 2.58 e | 9.04 c |
| **200** | 17.6 d | 69.6 b |
| **400** | 32.2 c | 124 a |
| **600** | 42.3 d | 137 a |
| **800** | 63.6 a | 150 a |
| **F** | 294** | 50.02** |

(**) Statistically significant at the level of $P \leq 0.01$

Khan and Khan (2010), investigating the effects of increased Ni applications (0, 10, 50, 100, 200, and 400 mg kg$^{-1}$) on chickpea plant growth and yield, reported an increase in Ni content in roots, stems, and leaves of plants with Ni applications. The critical toxic level of Ni in soil is 100 mg kg$^{-1}$, > 10 µg g$^{-1}$ dry matter in sensitive plants, and > 50 µg g$^{-1}$ dry matter in moderately sensitive plants (Özbek et al., 1995). The effect of different doses of Ni applications on Ni concentration and Ni content in Lavender plants is presented in Figure 2.

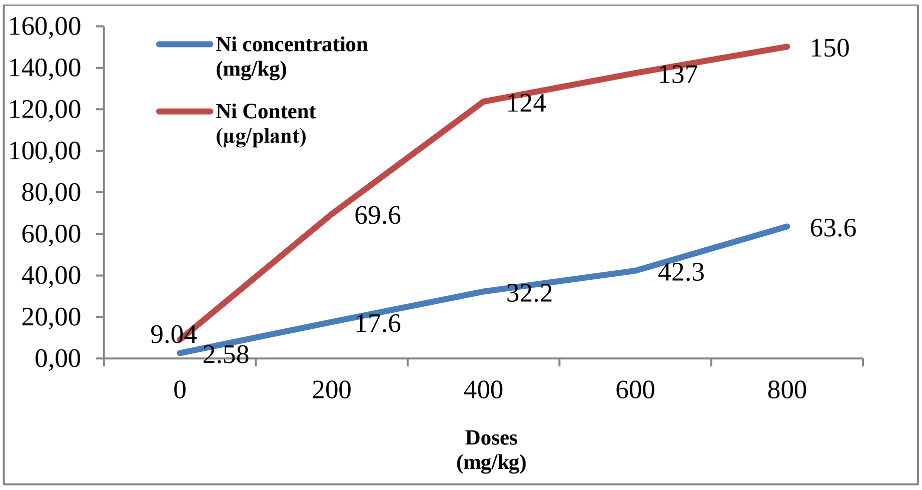


**Figure 2.** The effect of different doses of Ni applications on Ni concentration and Ni content in Lavender plants

## 4. Conclusion and Recommendations

The increasing presence and usage of Ni in the environment raise concerns for both environmental and health reasons. Research is being conducted to better understand the environmental effects of Ni and its potential impacts on human health. Topics such as Ni sources, dispersion, effects, and control methods form an important area of research for environmental protection and human health. Nickel is one of the heavy metals that can affect the development of living organisms at high concentrations. Nickel naturally occurs in soil and water sources, but human activities lead to an increasing amount of Ni in the environment over time.

In the study of plants, it was observed that the age, dry weight, and height of the plants increased with the application of 200 and 400 mg Ni $kg^{-1}$ compared to the control groups, while a decrease was observed in plants treated with 600 and 800 mg Ni $kg^{-1}$.

In the research conducted with Lavender plants, it was found that increasing doses of Ni applications resulted in variations in the N % concentrations ranging from 2.59 % to 3.38 %, P concentrations ranging from 1.82 to 2.76 mg $kg^{-1}$, and K concentrations ranging from 3.69 to 4.14 mg $kg^{-1}$. The lowest concentrations were observed in the 800 mg Ni $kg^{-1}$ applications, while the highest values were found in the untreated control group. The effect of Ni applications on %N concentrations in plants increased with the application of 200 mg $kg^{-1}$ compared to the control group, and the lowest content of N, P, and K concentrations was observed in the 800 mg $kg^{-1}$ Ni applications.

The effect of Ni applications on microelement concentrations in plants was observed as follows: Fe: ranging from 1228 to 1703 mg $kg^{-1}$, Mn: ranging from 84.5 to 195 mg $kg^{-1}$, and Zn concentration ranging from 28.2 to 52.4 mg $kg^{-1}$. The lowest concentrations were observed in the 800 mg Ni $kg^{-1}$ applications, while the highest concentrations were found in the 400 mg Ni $kg^{-1}$ applications. Nickel applications also affected Cu concentrations in plants, which ranged from 9.73 to 27.6 mg Cu $kg^{-1}$, with the lowest concentration observed in the 600 mg Ni $kg^{-1}$ application and the highest in the 400 mg Ni $kg^{-1}$ application.

In addition, Ni applications resulted in variations in Ni concentrations in plants, ranging from 2.58 to 63.6 mg Ni $kg^{-1}$, with the lowest concentration observed in the control group without Ni application and the highest in the 800 mg Ni $kg^{-1}$ application. Different doses of Ni applications also affected Ni content in plants, with the lowest value of 9.04 µg $plant^{-1}$ observed in the control group without any Ni application and the highest value of 150 µg $plant^{-1}$ observed in the 800 mg Ni $kg^{-1}$ application.

Further research is needed to evaluate the phytoremediation potential of Lavender plants, particularly to determine their Ni uptake and removal capacities. Such studies are important for understanding and harnessing the phytoremediation abilities of plants in combating heavy metal pollution. Plants like Lavender hold potential as natural and sustainable methods for reducing soil pollution.

## Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

## Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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