Clay Application in the Improvement of Nickel Rich Soil

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Abstract

The objective of this study was to evaluate the effectiveness of clay in improving natural nickel-rich soils using the nickel-hyperaccumulating plant *Odontarrhena chalcidica* (Janka) Španiel et al. The experiment was conducted in a greenhouse using a completely randomized design with three replications. Smectite:illite:chlorite composition Clay soil from Durrës (central Albania) served as the clay source, while the nickel-rich soil was collected from Rajce, an ultramafic region in eastern Albania. The experiment was carried out in 2 kg plastic pots, with four clay application rates corresponding to 0, 30, 60, and 90 t ha^{-1}. The seeds of *Odontarrhena chalcidica* were sown with three replicates for each treatment. Plants were regularly irrigated, and NPK fertilization was applied. After 60 days, total nickel content was analyzed using X-ray fluorescence (XRF), while soluble nickel was determined through water extraction and atomic absorption spectroscopy (AAS). The concentrtion of nickel in the dry biomass of the aerial parts and roots of *O. chalcidica*, as well as the transfer factor (TF = Ni_shoot / Ni_root), were evaluated. Statistical analysis using ANOVA one way revealed that increasing clay application rates significantly reduced both the concentration of nickel in the plant and in the roots. These findings suggest that clay application enhances nickel adsorption in the soil, thereby reducing its bioavailability and subsequent uptake by the plant.

Keywords: Clay minerals, *Odontarrhena chalcidica*, soil improvement, nickel in solution.

1. Introduction

Utramafic soils, which are rich in heavy metals, pose a potential risk to food crops cultivated in such environments (Galey et al., 2017). This study aimed to evaluate the potential of a natural clay—extracted from a clay-rich soil—as an adsorbent for remediating nickel-contaminated soils, using the nickel hyperaccumulator *Odontarrhena chalcidica* as a test plant (Tognacchini et al., 2020). The unique geochemical conditions of ultramafic soils create a hostile environment for most plant species, leading to specialized adaptations in the flora that are able to colonize them successfully (Rawat et al., 2020). Hyperaccumulator plants adapted to ultramafic regions have the potential to extract metals from the soil and have proven effective in improving the quality of agricultural soils (Bani et al., 2015; 2019).

Ultramafic soils are characterized by high concentrations of heavy metals, particularly nickel. The elevated levels of bioavailable nickel in these soils render them potentially toxic to cultivated crops and hazardous to the food chain (Bani et al., 2014; Halilaj et al., 2025).

Odontarrhena chalcidica, a well-known nickel hyperaccumulator, has been extensively studied for its capacity to extract and store nickel in its aerial tissues at concentrations exceeding 1,000 mg kg^{-1} (Bani et al., 2015). This characteristic makes it a promising candidate for agromining on metal-rich soils, enabling the extraction and recovery of economically valuable nickel (Bani, 2024). The efficiency of nickel uptake is influenced by various soil properties, particularly the bioavailability of the metal, which can be modified through the use of soil amendments (Uddin, 2017).

Clay minerals, due to their high cation exchange capacity (CEC) and large surface area, have been proposed as effective soil amendments for immobilizing metals and reducing their bioavailability (Uddin, 2017). When applied to contaminated or naturally metal-rich soils, clays can absorb metals, thereby limiting their uptake by plants—a process that is beneficial for reducing phytotoxicity in crops (Moreira et al., 2021). Despite this, the interactions between clay amendments and hyperaccumulator plants growing in ultramafic soils remain poorly understood, particularly in Mediterranean regions such as Albania, where ultramafic outcrops are widespread (Bani et al., 2021).

The Rrajce region of Albania hosts extensive ultramafic soils rich in nickel (Ni) and the native *Odontarrhena chalcidica* plant (Bani et al., 2024; Xhaferri et al., 2018). However, no studies have examined how locally sourced clays, such as Durres clay, influence nickel dynamics in these systems. This research addresses this gap by elucidating the trade-offs between clay-assisted metal immobilization and hyperaccumulator-based remediation strategies.

2. Materials and Methods

The experiment was conducted in a greenhouse at the Agricultural University of Tirana under controlled conditions, using a completely randomized design with three replicates (Kumar et al., 2020). The nickel hyperaccumulator *Odontarrhena chalcidica*, native to serpentine soils in the Rrajce region of southeastern Albania (Xhaferri et al., 2018), was used in the study. The experiment took place in 2 kg plastic pots, with four different clay application rates: 0, 21.4, 44.3, and 64 gkg^{-1} (equivalent to 0, 30, 60, and 90 t ha^{-1}). Three replicates were used for each application, and the clay was extracted from clayey soil of Durrës (central Albania).

Clay characterization with XRD was performed in University of Natural Resources and Life Sciences, Vienna and confirmed that the clay extracted from clayey soil from Durres region was composed of smectite, illite, and chlorite. The soil was incubated for 20 days after added doses of clay, before sowing (Li et al., 2021). The seeds of *Odontarrhena chalcidica* were sown with three replicates for each treatment. Plants were irrigated to field capacity and fertilized with NPK. Harvesting occurred after 60 days.

2.1 Plant and Soil Nickel Analysis

Total nickel concentrations in plant shoots, roots, and soil were quantified. Soil and plant tissues were first oven-dried at 70°C to a constant weight, homogenized, and then analyzed for nickel content using X-ray fluorescence spectroscopy (XRF) at the Laboratory of the Department of Biology, University of Florence, Italy. This non-destructive technique provided rapid and accurate measurements of total nickel without the need for acid digestion.

The water-extractable nickel fraction (total soluble nickel) was determined at the Department of Environment and Natural Resources, Agricultural University of Tirana, using the following protocol: 5 g of dry weight soil was equilibrated with distilled water at a soil-to-solution ratio of 1:10 and mechanically shaken for 24 hours at 25°C. The suspensions were then centrifuged at 3,000 × g for 15 minutes and filtered through a 0.45 µm membrane to remove particulate matter. The filtrates were analyzed for nickel concentration by flame atomic absorption spectroscopy (AAS). The translocation factor (TF) indicates the concentration of nickel in the aerial parts of the plant (shoot) relative to the concentration in the roots, reflecting the plant's ability to translocate nickel from the roots to the shoots at different concentrations. This index was calculated using the following formula: TF = Nickel concentration in the aerial part of the plant ($mgkg^{-1}$) / Nickel concentration in the root (mg/kg) (Bani et al., 2024).

2.2 Soil Properties

The pH of the experimental soil was neutral (7.0), which is within the optimal range for this hyperaccumulating species (Bani et al., 2014). The ultramafic soil from Rajce had a cation exchange capacity (CEC) of 27.1 cmol kg^{-1}, which is attributed to its considerable clay content. The organic matter content was 4.5%, which is considered satisfactory for agronomic purposes (Brady & Weil, 2016).

2.3 Statistical Analysis

Data were analyzed using ANOVA to assess significant differences between treatments (Sokal & Rohlf, 2012). Regression analysis was conducted to examine the relationship between clay doses and nickel concentrations in both plants and soil (Zar, 2010).

3 Result

The addition of clay to nickel (Ni)-rich soil significantly influenced Ni uptake and translocation in *Odontarrhena chalcidica*. The study found that clay application notably reduced Ni translocation to the shoots. Shoot Ni concentration decreased by 2.7% (from 9,311 to 9,063 $mgkg^{-1}$), while root Ni concentration increased by 12.3% (from 2,210.78 to 2,483.52 $mgkg^{-1}$), suggesting enhanced Ni immobilization in the rhizospheric soil as a result of clay-mediated adsorption.

Table 1: Transfer Factor (TF) for Nickel (Ni) in Odontarrhena chalcidica

Clay Treatment (g Ni/kg soil)	Ni Shoot (mg/kg)	Ni Root (mg/kg)	TF (Shoot/Root)
0 (Control)	9311	2253	4.1
21.4	9280	2199	4.2
43.4	9132	2157	4.2
64	9063	2042	4.4

The transfer factor (TF) did not show significant differences for different doses of clay, as this plant is a known nickel hyperaccumulator with a high capacity to extract nickel from various soil pools (Bani et al., 2024).

Table 2. Clay doses effects on Ni Shoot, Ni root and TF(Shoot/Root) tested one-way ANOVA.

Variable	F-value	P-value	F-critical
Clay Treatment vs. Ni Shoot	22721.43	5.75×10^{-12} ***	5.987
Clay Treatment vs. Ni Root	2066.2	7.59×10^{-9} ***	5.987
Clay Treatment vs. TF (Shoot/Root)	4.1	0.089 (ns)	5.987

*** *** = Extremely significant (P < 0.001)

Nickel in shoots and roots are significantly different for different doses of the clay treatment.

Table 3. Total and Water-extractable Ni in Soil (mgkg^{-1}) of Rajca

Clay Dose *mgkg^{-1}* soil	Total Ni *mgkg^{-1}*	Ni in soil solution *mgkg^{-1}*
0	2534. 98	15.66
21.4	2585. 2	7.13
43.4	2557.1	3.33
64	2521.3	2.59

The addition of clay to the ultramafic soil of Rajce progressively reduced the concentration of soluble nickel. While the total nickel content remained relatively stable (2534–2585 mgkg^{-1}), the water-extractable Ni—representing the most readily available fraction—decreased sharply.

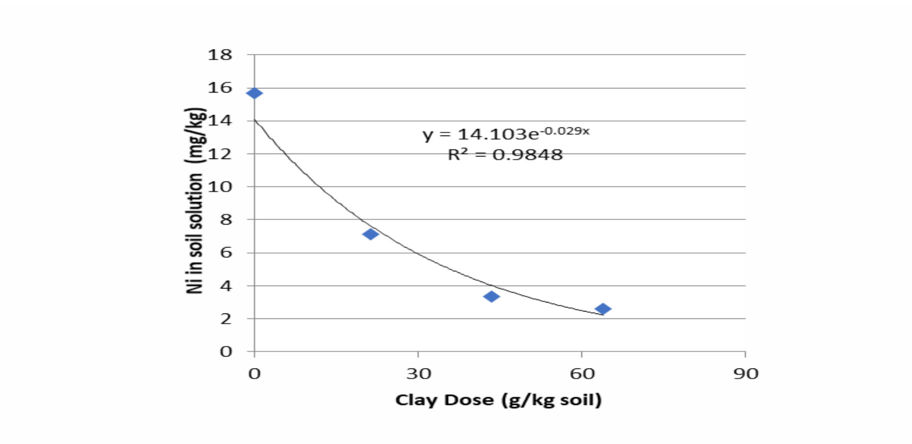

Figure 1. The relationship between clay doses and available nickel in soil solution.

The concentration of available Ni in the soil solution decreased significantly from 15.66 mg/kg in the control to 2.59 mgkg^{-1} with increasing clay additions ranging from 0 to 64 gkg^{-1} soil, representing a reduction of approximately 83.5% ($p < 0.001$, exponential trend). Intermediate clay doses (21.4 and 43.4 g/kg) reduced water-extractable Ni by 54.5% and 78.7%, respectively, highlighting the strong adsorption capacity of smectite-rich clay. This is consistent with the findings of Li et al. (2021), who reported that the water-extractable metal fraction decreases more significantly than the DTPA-extractable fraction in clay-amended soils. Nickel concentration in plants was also affected by increasing clay doses, showing a reduction of 2.7% (from

9,311 to 9,063 mg/kg). The analysis revealed a significant dose-dependent effect of clay on plant Ni uptake ($p < 0.001$).

4 Conclusions

The 83.5% reduction in water-extractable Ni achieved with a clay dose of 64 gkg^{-1} highlights the exceptional ability of smectite-rich clay to immobilize the most labile fraction of nickel in the soil. These results are consistent with the well-known adsorption capacity of smectite, while also providing new insights within the context of ultramafic soils.

The use of clay significantly reduced water-extractable Ni, offering a cost-effective and efficient strategy for improving ultramafic soils. *Odontarrhena chalcidica* maintained high nickel concentrations in its shoots (> 9000 mg/kg) despite the immobilization of Ni in the soil, emphasizing its strong potential to accumulate nickel and contribute to the rehabilitation of Ni-contaminated soils, particularly those impacted by industrial activities. These findings support the application of clay as a low-cost amendment for Ni immobilization in agricultural Albania's ultramafic soils.

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