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Rehabilitation of Former Nickel Mine Soil through Humate and Compost Application for Revegetation Plant Growth Media

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Abstract: Former nickel mine lands often have low soil quality and do not support the growth of revegetation plants. This study aims to evaluate the effect of humic substances and compost on improving the quality of post-nickel mine soil and plant growth media. The experiment was conducted using a completely randomized design in a factorial pattern with three levels of humic and compost treatments, as well as a combination of both, applied to nickel post-mining soil. The results showed that the addition of compost significantly increased the cation exchange capacity (CEC) and availability of nutrients (Ca, Mg, K, Na) in the soil. The addition of humic materials had relatively no significant impact on increasing CEC, but could increase phosphorus levels in the soil. In addition, compost and the combination of compost with humic materials can reduce available heavy metal Cr, although it causes an increase in Ni heavy metal levels in the soil. The results of this study make a significant contribution to the rehabilitation of ex-mining land in a sustainable manner, especially the use of humic materials and compost as a strategy to improve soil quality and increase agricultural productivity. The use of these organic materials is proven to be effective in improving the physical, chemical and biological properties of degraded soils, so it can be a more environmentally friendly approach compared to the use of synthetic chemicals.

Keywords: Compost; Heavy metals; Humic materials; Nickel mine waste soil; Revegetation; Soil quality

Introduction

Nickel mining activities, while contributing significantly to economic growth, often leave behind serious environmental impacts, particularly soil degradation at former mine sites (Vischetti et al., 2022). Nickel post-mining lands tend to suffer severe damage, including loss of essential nutrients, changes in soil structure, as well as contamination by heavy metals, which significantly hampers their ability to support plant growth (Romele, 2022). This soil degradation not only reduces land productivity, but also hinders sustainable revegetation and ecosystem restoration efforts (Edrisi et al., 2022). Therefore, rehabilitation of mined lands is a top priority in environmental restoration strategies, especially in areas affected by mineral resource extraction activities (Raizada & Dhyani, 2020).

One promising approach to improve soil quality is through the utilization of organic materials such as humates and composts (Mahmoud et al., 2022 ; (Wandansari et al., 2023). These materials are known to increase soil fertility and improve its physical and chemical characteristics, thus supporting the recovery of post-mining land productivity (Jin et al., 2019; Terrones-Saeta et al., 2021).

While there is a wide range of research on the rehabilitation of mined land, studies that specifically explore the use of a combination of humic and compost materials to improve the quality of nickel mined soils are

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limited. Most previous studies have focused on conventional methods such as the use of chemicals for soil restoration, which often only provide short-term results and potentially have negative environmental impacts (Miu et al., 2022; (Castellanos-Barliza & León-Peláez, 2023). Existing literature also tends to discuss the use of either organic matter in isolation, without examining the potential synergies between humates and compost in improving soil structure, increasing organic matter levels and reducing heavy metal toxicity (Maftu'Ah et al., 2023; Piccolo et al., 2019).

In addition, the lack of comprehensive empirical data on the effectiveness of these techniques on nickel mine land raises the need for more focused research (Iwatsuki et al., 2018; Zeqiri, 2020). This research aims to evaluate the effectiveness of humic and compost application in improving the physical, chemical and biological characteristics of nickel mine waste soil. The main focus of the research is to increase soil fertility, improve soil structure, increase nutrient availability, and support sustainable plant growth and productivity. This research offers an innovative approach in the rehabilitation of former nickel mine lands through the utilization of a combination of humic and compost materials, which have not been studied in depth in the context of revegetation of degraded soils. This approach not only provides a more sustainable solution compared to conventional methods, but also offers long-term environmental benefits by reducing reliance on synthetic chemicals.

Method

This research was conducted in the greenhouse area of the nursery using a randomized complete block design (RAL) factorial pattern. Soil samples were taken from the nickel post-mining area of PT Vale International (Persero) Tbk. in a composite manner from 21 points at a depth of about 10-20 cm, which were selected to represent the general condition of the post-mining land. The soil obtained was then dried and sieved using a 5 x 5 mm wire sieve. Next, the soil was weighed as 10 kg air-dry weight and placed in appropriate polybags. Each polybag was given 10 g of NPK base fertilizer and the soil was incubated for 14 days.

For plant preparation, sengon (Paraserianthes falcataria) seeds were germinated on 30 x 30 cm² mica for one week. During the germination process, the seeds were covered to reduce evapotranspiration and maintain media moisture. The dose of humic material used referred to a previous study, where the dose of humate for 1 hectare of land was 15 liters. In this study, the dose was increased to 100 liters/ha. Based on the weight of soil in the polybag (10 kg or equivalent to 0.01 ton), the humic dose was calculated at 0.5 ml/polybag. The three levels of humate dosage used were 0.0 ml, 0.5 ml, and 1.0 ml/polybag. In addition, the compost used consisted of a mixture of chicken manure, cow dung, and rice husk in a ratio of 1:1:1. The compost dose consisted of 3 levels, namely 0.0 kg, 1.0 kg, and 2.5 kg/polybag.

The treatment combinations obtained from these two materials were 9 combinations that were repeated 3 times, so there were a total of 27 polybags for all treatments. Humic materials were applied by pouring a diluted solution of 100 ml into each polybag. Compost was applied by mixing the materials homogeneously into the soil in the polybags according to the predetermined dose.

Result and Discussion

The results of soil analysis showed that the pH of the soil in all treatments did not change significantly and remained acidic. The pH of the KCl extract was slightly lower than the pH of the H_2O extract, indicating the low negative charge of the soil in all treatments. The application of humic and compost materials and the combination of both was able to increase phosphorus (P) levels in the soil, although in the H1P0 and H2P1 treatments no significant increase in P levels was observed. This increase in P levels indicates that organic matter, especially compost, has an important role in improving soil phosphorus availability, which supports plant growth.

Tabel 1. Results of analysis of soil chemical properties in the greenhouse experiment

Treatment	pH		C-organic	N-total	P	KTK	Ca-dd	Mg-dd	K-dd	N-dd	KB
	H_2O	KCl	---------%---------		ppm	----------------cmol$_c$/kg----------------					%
H0P0	5.4	5.3	1..44	0.11	6	10;01	1.18	7.33	1.04	0.16	97
H0P1	5.5	5.3	3.10	0.20	47	16.47	8.73	8.50	3.31	0.87	> 100
H0P2	5.5	5.3	3.82	0.23	111	14.49	13.17	9.42	5.23	1.31	> 100
H1P0	5.5	5.3	1.03	0.13	5	9.75	0.88	7.18	0.91	0.16	94
H1P1	5.7	5.6	2.86	0.23	159	12.67	8.40	7.83	2.49	0.62	> 100
H1P2	5.5	5.4	3.90	0.20	239	14.44	10.50	8.16	3.70	0.86	> 100
H2P0	5.6	5.4	1.64	0.12	46	8.89	1.01	6.33	0.89	0.10	94
H2P1	5.4	5.3	2.29	0.16	14	11.91	5.71	9.08	2.42	0.62	> 100
H2P2	5.2	5.1	2.95	0.28	56	12.92	11.13	8.33	4.33	1.24	> 100

Cation exchange capacity (CEC) in the soil increased significantly in the compost treatment compared to the control. In contrast, the application of humic materials did not show a significant effect on the increase in CEC when compared to the control. This indicates that the effect of humic materials was relatively covered by the effect of compost on CEC. The compost treatment also contributed to an increase in the levels of base cations in the soil, such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), indicating an improvement in soil chemistry. Overall, compost application, either alone or in combination with humic materials, was more effective in increasing base cation levels compared to humic materials alone. The application of compost and humic materials can effectively increase soil pH through the mechanisms of H^+ ion neutralization, toxic metal chelation, CEC increase, and base cation release. This makes them a sustainable solution in the rehabilitation of former nickel mine soils that are generally acidic and nutrient-poor.

Table 2. Available heavy metal content in soil in greenhouse experiments

Treatment	Cr	Ni
	----------------ppm--------------	
H0P0	1.50	92.69
H0P1	0.38	160.36
H0P2	0.39	210.67
H1P0	2.10	94.71
H1P1	0.44	160.70
H1P2	0.51	195.96
H2P0	2.81	75.75
H2P1	0.47	124.62
H2P2	0.54	179.91

The results of the analysis also showed that the application of compost and the combination of humic materials and compost could reduce the levels of heavy metal chromium (Cr) available in the soil. In contrast, there was an increase in the levels of nickel (Ni) available in the soil in this treatment. This increase was probably due to the higher nickel content in the compost compared to the humic material. The increase in Ni levels in the soil needs further attention, although the decrease in Cr levels recorded may indicate the role of compost in reducing the negative impact of heavy metals on soil quality and plant health.

Table 3. Effect of humic materials and compost on the height of sengon plants at 9 weeks of age in the greenhouse experiment

Hum Ingredients	Compost		
	P0	P1	P2
		-------------------cm---------------	
H0	7.40 ± 0.98^a	11.77 ± 1.60^{bc}	12.87 ± 2.67^c
H1	7.72 ± 0.54^a	14.00 ± 3.06^{bc}	21.57 ± 1.72^e
H2	8.83 ± 0.58^a	11.60 ± 3.35^{bc}	16.53 ± 1.53^d

The results showed that the application of humic materials and compost did not change the pH of the soil, which remained acidic, with the pH of the KCl extract being lower than the pH of the H_2O extract (Aylaj et al., 2023). This indicates that former nickel mine soils have low pH buffering capacity, leading to acidic soil properties (Tabañag & Taboada, 2023). This finding is consistent with previous findings showing that ex-mining soils, particularly those from nickel mining activities, generally have acidic pH and low cation exchange capacity (CEC), thus affecting nutrient availability in the soil (Nadalia & Pulunggono, 2018). However, although soil pH did not change, improvements in soil chemical properties can be seen in other parameters, such as phosphorus (P) levels, CEC, and base levels in the soil (Nyamaizi et al., 2022). Higher phosphorus levels in treatments with compost and a combination of humic materials indicate that these two organic materials are able to increase the availability of phosphorus, which is important for plant growth, through a more effective phosphorus solubilization process (Haouas et al., 2021). This supports previous research which states that compost can increase nutrient availability through improved soil structure and increased soil microbial activity (Roy et al., 2022).

These results provide strong empirical evidence of the importance of organic matter, particularly compost, in improving the quality of mined soils (Munawar et al., 2023). Compost not only increases CEC, but also increases the levels of base cations in the soil, which contributes to the overall improvement of soil chemical properties (Tong et al., 2021). The increased levels of Ca, Mg, K and Na indicate that compost has great potential in improving soil conditions, making it more fertile and more supportive of plant growth (Niamat et al., 2019).

These results provide support for the theory that organic matter plays an important role in the rehabilitation of mined soils (Proto & Courtney, 2023). From a practical perspective, the use of compost as a soil conditioner is highly relevant for revegetation applications on post-mining land, especially to increase the planting efficiency of revegetation crops that can restore soil function (Myszura-Dymek & Żukowska, 2023). In addition, the use of lower humic materials in this study suggests that compost has a greater potential to affect soil quality when compared to humic materials, which is in line with previous research findings emphasizing that compost is more effective in improving soil physical and chemical properties (Lanno et al., 2022).

Previous research has shown that higher doses can provide more optimal results, and therefore, further research needs to be carried out with higher variations in humic material doses (Borzyh et al., 2022). In addition, this study was conducted in a greenhouse under controlled conditions, so the results may not fully reflect more dynamic field conditions (Zhang et al., 2020). Other factors, such as weather and the diversity of soil microorganisms in the field, may affect the results obtained under natural conditions (Guo et al., 2022). The use of compost and humic materials in the rehabilitation of mined soils can not only improve soil quality, but can also reduce the risk of heavy metal pollution that is detrimental to ecosystems and human health (Raghunathan et al., 2021; Zhao & Naeth, 2022). The reduced levels of heavy metal Cr found in this study indicate the role of compost in stabilizing heavy metals, thereby improving soil quality for safer agriculture and plant habitat (Bhardwaj et al., 2023).

Conclusion

The application of organic materials in the form of compost and humic materials has a significant effect on improving the quality of ex-nickel mine soil. Although the soil pH remains acidic, both compost and the combination of compost and humic materials can increase phosphorus (P) levels, cation exchange capacity (CEC), and basic cations in the soil such as Ca, Mg, K, and Na. Compost was more effective in increasing CEC and nutrient availability than humic materials, indicating the potential of compost as a key ingredient in the rehabilitation of mined soils. In addition, compost and the combination of humic materials with compost succeeded in reducing the levels of heavy metal Cr available in the soil, despite an increase in the levels of heavy metal Ni. The decrease in available Cr in the soil can be interpreted as a result of the role of compost in stabilizing heavy metals, while the increase in available Ni is likely due to the Ni content in the compost itself.

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S.S.: Developing ideas, analyzing, writing, reviewing, responding to reviewers' comments; T.S.A.; A.B.: supervising data collection; A.K., R.N.: Analyzing data; P.I.M., S.T.: reviewing data and writing

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Conflicts of Interest
The authors declare no conflict of interest.

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