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# Using of Oil Palm Empty Fruit Bunch Compost and Mycorrhizae Arbuscular for Improving the Fertility of Nickel Post-Mining Soil

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**ABSTRACT**
The nickel post-mining soil with an open-pit mining system has poor soil chemical and physical properties. Thus, it requires appropriate site-specific management so that it can be optimized as a plant cultivation area. This study aimed to analyze the effectiveness of compost from oil palm empty fruit bunches (OPEFB) and mycorrhizal vesicular-arbuscular (MVA) in improving soil fertility of nickel post-mining soil. This study was conducted using a randomized block trial design with 2 factors. The first factor is compost with 3 treatments, consisting of 5 $t \cdot ha^{-1}$ (K1), 7.5 $t \cdot ha^{-1}$ (K2), 10 $t \cdot ha^{-1}$ (K3) and the second factor was mycorrhiza (M) in the fine-crushed brick carrier media with as many as 3 treatments consisting of 2 $t \cdot ha^{-1}$ (M1), 4 $t \cdot ha^{-1}$ (M2), 6 $t \cdot ha^{-1}$ (M3). A total of 9 treatment combinations were repeated 3 times, arranged in experimental pots at the Experimental Farm of Hasanuddin University, South Sulawesi, Indonesia. The results showed that the compost and MVA treatments had a significant effect on increasing the average values of cation exchange capacity, organic carbon, available $P_2O_5$, calcium and magnesium exchangeable,as well as decreasing exchangeable aluminum and iron. The highest soil properties values were found in the combination of compost 10 $t \cdot ha^{-1}$ (K3) and MVA 6 $t \cdot ha^{-1}$ (M3). The application of compost from OPEFB combined with MVA significantly improved soil fertility, which was indicated by improving soil chemical and biological properties. The application of MVA at various doses had a significant effect on the dry weight, root length of *Calopogonium mucunoides* and increase the number of MVA spores in the soil.

**Keywords:** post nickel mining soil, oil palm empty fruit bunches, mycorrhizae, compost, cover crop.

## INTRODUCTION

Mining activities affect the ecosystem and have an impact on decreasing land function and productivity as well as life associations that will be lost and difficult to replace. This is of course caused by mining activities starting from land clearing and then dredging (open cast) which can have a negative impact on the ecosystem (Kumar, 2013; Chen et al., 2011)) so that land rehabilitation must be carried out immediately. Many cases of mining around the world cause soil to be contaminated with metallic materials (Navarro et al., 2008; Nakajima et al., 2017) and suffer physical damage and a decrease in soil fertility quality (Ghose, 2004; Adetunji et al., 2020; Kumar, 2013; Sembiring, 2008), including nickel post mining soil located in South Sulawesi Province, Indonesia. The nickel post mining soils formed from ultra-mafic nickel have lower potential compared to other developing soils, because the pH of these ranges from acidic to very acidic; moreover, they have low cation exchange capacity (Allo, 2016). One of the efforts to manage the soil damage caused by mining is the planting of legume cover crop (LCC) (Prayogo, 2018), the use of compost (Mahyudin et al., 2020; Zaeni et al., 2021) and application of arbuscular vascular mycorrhizae (MVA) (Ghaida, 2020). LCC plants are able to live on damaged soil and are able to improve the physical and chemical properties of the soil (Prayogo, 2018) including nickel post mining soil (Sarrantonio & Gallandt, 2003; Nakhone & Tabatabai, 2008). The types of LCC that are widely planted in post-mining areas include *Calopogonium mucunoides, Mucuna sp,* *Sesbania sp, Flemingia sp, Tephrosia sp*, which are useful for protecting the soil from erosion damage. In addition to LCC planting, application of organic fertilizers such as compost that comes from agricultural waste such as oil palm empty fruit bunches (OPEFB) can improve soil fertility (Hastuti & Rohmiyati, 2020; Gandahi & Hanafi, 2014). The OPEFB compost contains many types of nutrients, such as carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) and can be used as a potential source of organic matter (Soil Research Institute, 2010; Hastuti & Rohmiyati, 2020).

Mycorrhizae Vesicular Arbuscular (MVA) plays a role in improving the physical properties of the soil. According to Wright & Uphadhyaya (1998) *in* Musfal (2010), MVA through its external roots produces glomalin glycoprotein compounds and organic acids that will bind soil grains into micro aggregates. The use of arbuscular mycorrhizal fungi as biological agents is an environmentally friendly biological approach and has been widely developed in the fields of forestry, agriculture and plantations (Husna et al., 2021; Ghaida et al., 2020). The advantages obtained by the use of MVA are that they do not cause environmental pollution, and also play an active role in the nutrient cycle (Herawati et al., 2021). The plants that have been infected with MVA will benefit for the life of the plant.

## METHODOLOGY

The study was conducted using a randomized block design experimental method with 2 factors, namely OPEBF compost factor with 3 levels K1 (5 t·ha$^{-1}$), K2 (7.5 t·ha$^{-1}$) and K3 (10 t·ha$^{-1}$) and mycorrhizal factors in the carrier media (fine-crushed bricks) as much as 3 levels, namely M1 (2 t·ha$^{-1}$), M2 (4 t·ha$^{-1}$) and M3 (6 t·ha$^{-1}$), there were 9 treatment combinations which were repeated 3 times to obtain 27 experimental units. The soil samples were obtained from the nickel mine of PT Vale Indonesia (PTVI) located in the Sorowako Village, Nuha District, East Luwu Regency at coordinates 121º21′11.838″ E and 02º33′0.965″ S, as shown in Figure 1. The number of spores in the carrier media of fine-crushed bricks is 241 per 100 g of soil. The study was conducted in the Experimental Farm of Hasanuddin University, Indonesia. The OPEFB compost is made using the Berkeley method, which is to pile compost materials on top of the soil with effective microorganisms added. Then, the pile is closed to speed up the composting process with increasing temperature, so it is called hot composting. Ripe compost is obtained after 1 month of stacking and stirring periodically. The soil sample was analyzed at the Laboratory of Chemistry and Soil Fertility, Department of Soil Science, Hasanuddin University. The methods used in the analysis of soil properties include: soil pH (pH meter), C-organic (Walkley & Black), CEC and the amount of exchangeable bases (Ca, Mg, K and Na) (titration of $NH_4OAc$ pH 7.0), P-available (Bray 1), Fe and Al-exchangeable (Atomic Absorption Spectrophotometer). The spore density was analyzed using the wet sieved method. The measured parameters of the *Calapogonium mucunoides* plants were: dry weight of plants, root length and root volume at 49 day after planting (DAP). The data obtained were analyzed by using analysis of variance with a confidence level of 95%; Tukey HSD was conducted with a confidence level of 95%.

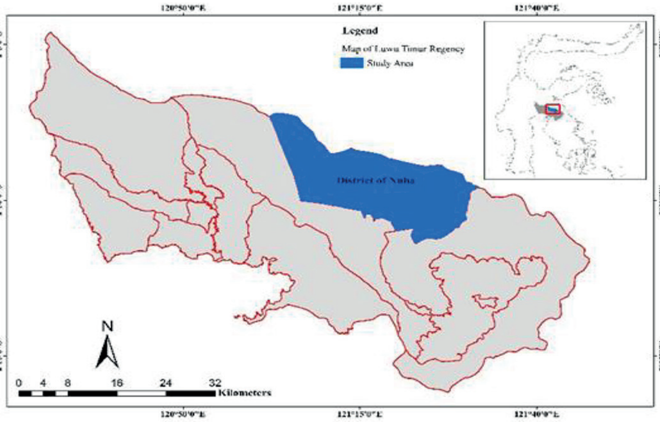


**Fig. 1.** Soil sampling location

## RESULTS & DISCUSSION

This study used the post-nickel topsoil from the reclamation area obtained from the post-mining area of a nickel mining company in South Sulawesi, Indonesia. The results of soil properties analysis of the post-nickel soil sample are shown in Table 1.

The results of the initial soil analysis before treatment showed that the post nickel mining soil had low soil fertility, as shown by the value of soil fertility parameters such as pH which was classified as slightly acidic, C-organic was very low, CEC and P available were low, the number of cations Mg>Ca and very high levels of Fe-exch and Al-exch. According to Umarternate et al. (2014), the acid soils with pH < 5.5 are dominated by $Fe^{3+}$ and $Al^{3+}$ cations which will affect the availability of P. In acid soils, the availability of P in rare earths exceeds 0.01% of the total P. Most of the P forms are bound by soil colloids so that they are not available to plants (Umaternate et al., 2014). The analysis results of the nickel post-mining soil showed that the CEC value of the soil was low (< 16 cmol·kg$^{-1}$). This is closely related to the dominant soil-forming factors in this region, which are ultramafic parent materials and the high rainfall and temperature factors that result in intensive weathering and leaching processes in this region. As a result, the organic matter content becomes low (<1%) and the soil pH is acidic.

### Effect of treatments on soil chemical properties

The compost treatment had a significant effect on the average increase of SOC (Fig. 2) and the highest was found in the compost treatment (K3), reaching 1.41% which was significantly different from K1 (1.15%) and K2 (1.22%). The percentage of SOC obtained is still relatively low, according to the criteria of the Balai Penelitian Tanah (2009). However, when compared with the results of the initial soil analysis before being treated, which was 0.63%, the average C-organic data after treatment which had increased >1% already showed a good effect from the addition of organic matter (compost). According to Hakim (2006); Riniarti et al. (2012), the application of organic matter into the soil, in addition to increasing organic matter in the soil, can also maintain the organic matter already contained in the soil. The compost treatment also increases SOC in the soil because the OPEFB compost also contains C, K, N, P, and Mg nutrients, which can help improve SOC in post-mining soil. The result study of Susanto et al. (2005) showed that the nutrients contained in the OPEFB compost are 42.8% C; 0.80% $K_2O$; 2.90% N; 0.22% $P_2O_5$ ; 0.30% Mg; 100 ppm B; 23 ppm Cu; and 51 ppm Zn.

The effect of adding the OPEFB compost was also significant for the increase in the soil cation exchange capacity (CEC) parameters and the highest average soil CEC was found in treatment (K3) 10 t·ha$^{-1}$ of 19.67 cmol·kg$^{-1}$ which was significantly different from K1 and K2 treatments, as shown in Figure 3. If it is adjusted to the criteria of the Soil Research Institute (2009), the CEC value of this land is classified as moderate. These results indicate that the K3 treatment (10 t·ha$^{-1}$) significantly affected the increase in the CEC value of the soil, which was initially 14.51 cmol·kg$^{-1}$. This indicates that the increase in soil CEC value is strongly influenced by the addition of the OPEFB compost. This is in accordance with the opinion of Widijanto et al. (2007) which states that organic fertilizer can increase soil CEC. The increase in soil CEC is correlated with the increase in SOC; the higher SOC, the higher the CEC (Hakim et al., 1986).

The results of this study also showed that the effect of compost and MVA treatment was very significant on increasing the available P value of the soil, including the interaction effect of compost and MVA as shown in Figure 4. The results of the 95% HSD Tukey test as shown in

**Table 1.** The post-nickel mining soil characteristics analysis results

| Soil characteristics | Value | Criteria* |
|---|---|---|
| pH ($H_2O$) | 5.47 | Slightly acid |
| pH (KCl) | 5.79 | Slightly acid |
| C-Organic (SOC) | 0.63% | Very low |
| Cation exchange capacity (CEC) | 14.51 cmol kg$^{-1}$ | Low |
| Ca | 3.83 cmol kg$^{-1}$ | Low |
| Mg | 6.67 cmol kg$^{-1}$ | High |
| K | 0.22 cmol kg$^{-1}$ | Low |
| Na | 0.21 cmol kg$^{-1}$ | Low |
| Available P | 6.60 ppm | Low |
| Al-exch. | 3.80 cmol kg$^{-1}$ | Very high |
| Fe-exch. | 51.23 ppm | Very high |

*Criteria according to the Balai Penelitian Tanah (2009)

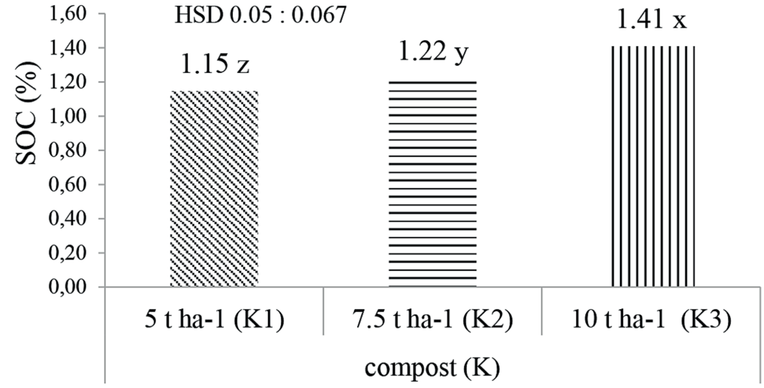


**Fig. 2.** Effect of the OPEFB compost on SOC

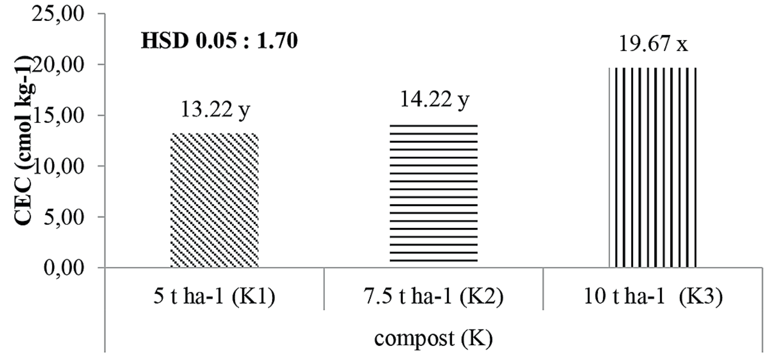


**Fig. 3.** Effect of OPEFB compost on soil CEC

Figure 4 indicate that the K3M3 treatment produced the highest average available P, which was 17.49 ppm and was significantly different from other treatments. The increase in available P is certainly influenced by the P nutrient content in the OPEFB compost. According to Ningtyas & Lia (2010), the OPEFB compost contains macro nutrients, namely 2.15% for N-Total; 1.54% for $P_2O_5$; 0.15% for $K_2O$; and contains a small amount of micro elements, such as Cu, Zn, Mn, Fe, Bo and Mo. Gandahi and Hanafi (2014) stated that the availability of P increases in the soil due to the direct addition of organic matter and the result of the mineralization process of organic matter so that it can release fixed P.

Furthermore, the results of the analysis of variance showed that there was a very significant interaction between compost and MVA treatments on the average Ca-Exch, as shown in Figure 5. The results of the 95% HSD Tukey test showed that the compost treatment was 10 t·ha $^{-1}$ and mycorrhizal 6 t·ha$^{-1}$ (K3M3) resulted in the highest Ca-exch average of 3.33 cmol·kg$^{-1}$, and was significantly different from other treatments. The Ca-exch data after treatment showed a lower value than the results of soil analysis before treatment, namely 3.83 cmol·kg$^{-1}$. The decrease in the value of Ca can be caused by Ca being exchanged or absorbed by plant roots either through root interception or mass flow, and can be caused by the acidity of the post-nickel mining soil, which is classified as slightly acidic.

In addition, the effect of compost treatment also significantly affected the Mg-exch levels, as shown in Figure 6. The results of the 95% HSD Tukey test showed that the compost treatment of the OPEFB 10 t·ha$^{-1}$ (K3) produced the highest Mg-exch average of 4.88 cmol·kg$^{-1}$ and significantly different from other treatments. The results obtained showed a decrease in the value of Mg with increasing compost dose. The results of soil analysis at the beginning of the research showed that the Mg value of 6.67 cmol·kg$^{-1}$, which was classified as low, had decreased to 4.88 cmol·kg$^{-1}$. The decrease in Mg-exch levels in the soil can be caused by magnesium being lost with percolation water, magnesium being absorbed by plants or other living organisms, being adsorbed by clay particles and deposited into secondary minerals. Hakim et al. (1986) stated that the availability of magnesium for plants will be reduced in the soils that have high acidity.

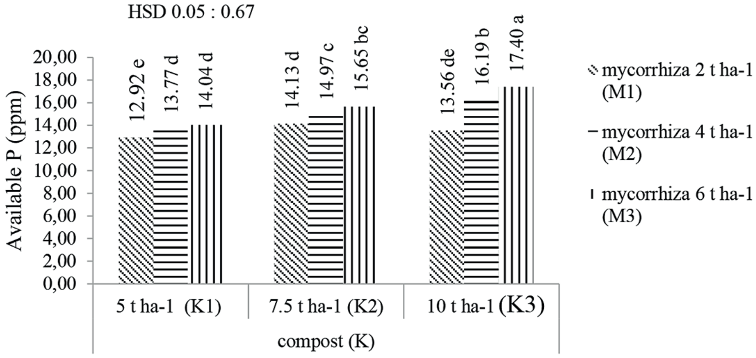


**Fig. 4.** Effect of the OPEFB and MVA compost on the soil available-P

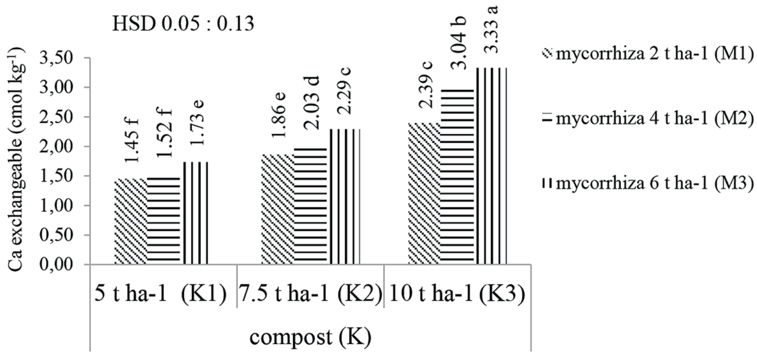


**Fig. 5.** Effect of the OPEFB and MVA compost treatment on soil Ca- exchangeable

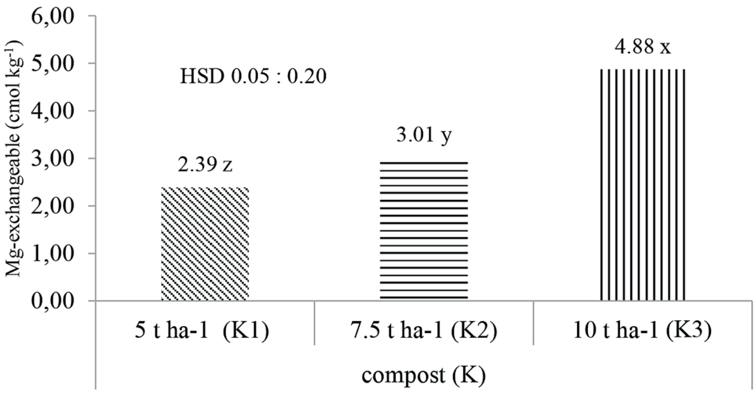


**Fig. 6.** Effect of the OPEFB compost on soil Mg-exchangeable

The results of the analysis showed that there was a very significant interaction between the OPEFB and MVA compost treatment on the K-exch. The results of the 95% HSD Tukey test showed that the compost treatment of 5 t·ha $^{-1}$ and MVA 2 t·ha $^{-1}$ (K1M1) produced the highest K average of 0.33 cmol·kg $^{-1}$ and was significantly different from other treatments (Figure 7). The results of the initial analysis of the soil samples showed that the K content of the soil was 0.22 cmol·kg$^{-1}$ (which was low) and increased to 0.33 cmol·kg$^{-1}$. This increase in K value can be influenced by the addition of the OPEFB compost. This is in line with the opinion of Suherman (2007) that the OPEFB compost is an organic material that contains the main nutrients N, P, K and Mg as well as micro nutrients. This statement is reinforced by the opinion of Rosmimi (2000) that compost given to the soil will decompose to produce the compounds and nutrients that are available to plants. The nutrient content of the OPEFB compost also helps provide nutrients to post-mining soil, which is classified as nutrient-poor. The K value of the soil also depends on the CEC value of the soil.

The effect of compost treatment and MVA was significant to increase the average Na-Exch of the soil. The results of the 95% HSD Tukey test showed that the compost treatment 10 t·ha$^{-1}$ and mycorrhizal 6 t·ha $^{-1}$ (K3M3) produced the highest average Na-Exch (0.30 cmol·kg$^{-1}$) and was significantly different from other treatments (Figure 8). On the basis of Table 5, it is known that the best average value for exchangeable sodium is the K3M3 treatment with a value of 0.30 cmol·kg$^{-1}$ and is significantly different from the other treatments. This value also shows that there is an increase in the initial value of Na-exch before being treated, which is relatively low.

Compost and MVA treatment had a significant effect on the decrease in the Al-exch value. Analysis of variance showed that there was a very significant interaction between compost and MVA treatment on the average Al-exch. The results of the 95% HSD Tukey test showed that the compost treatment of 10 t·ha $^{-1}$ and MVA 6 t·ha $^{-1}$ (K3M3) resulted in the lowest Al-exch average of 0.80 cmol·kg$^{-1}$ (Figure 9). The lowest Al-exch value was shown in the K3M3 treatment with a value of 0.8 cmol·kg$^{-1}$ which was significantly different from the other treatments. This value indicates that there is a decrease in the value of Al-exch, compared to the value before being treated with 3.80 cmol·kg$^{-1}$. This shows that the addition of the OPEFB compost and MVA can reduce the aluminum content in the soil. This correlates with the opinion of Tan (2010) who states that compost can reduce exchangeable Al because composting into the soil will produce organic acids that form chelating compounds with free Al in the soil so that the exchanged Al can decrease. The amount of aluminum that can be tolerated by most plants is <1 cmol·kg $^{-1}$. Aluminum is one of the supporting nutrients that can cause soil poisoning around plant roots, so that it can inhibit plant growth and development. According to Foy in Rout et al. (2001), Al causes disruption of cell division in the root cap and lateral roots and causes an increase in cell rigidity through the formation of pectin cross-links in the cell wall, and reduces DNA replication through increased double chain rigidity. Al cations occupy the mineral soils that have a pH <5.0, most colloidal complexes of which are negatively charged (Hanafiah, 2010).

In addition to the significantly decreased Al-exchangeable content, the chemical parameter of the soil that decreased with the compost treatment was Fe-exch. Analysis of variance showed that the treatment of the OPEFB compost had a significant

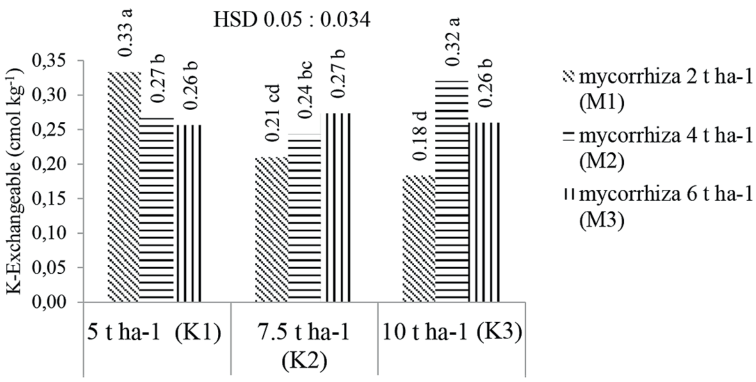


**Fig. 7.** Effect of the OPEFB compost on soil K-Exchangeable

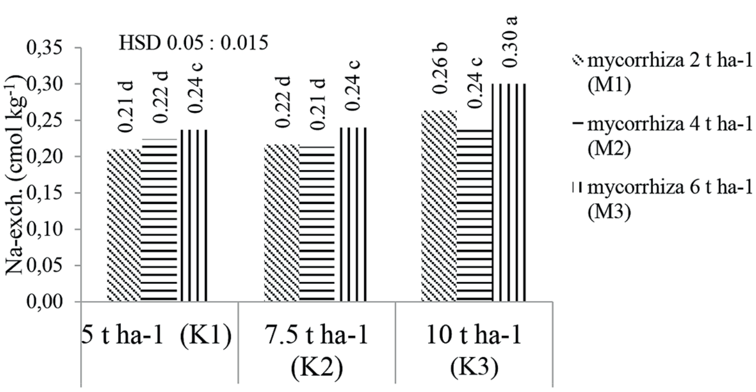


**Fig. 8.** Effect of the OPEFB compost and MVA on soil Na-Exchangeable

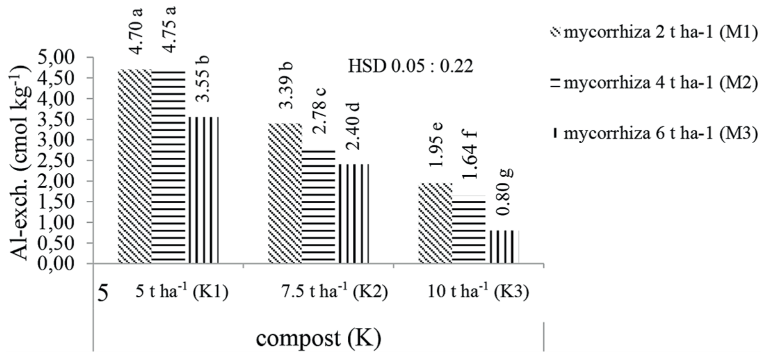


**Fig. 9.** Effect of the OPEFB compost and MVA on soil Al-exchangeable

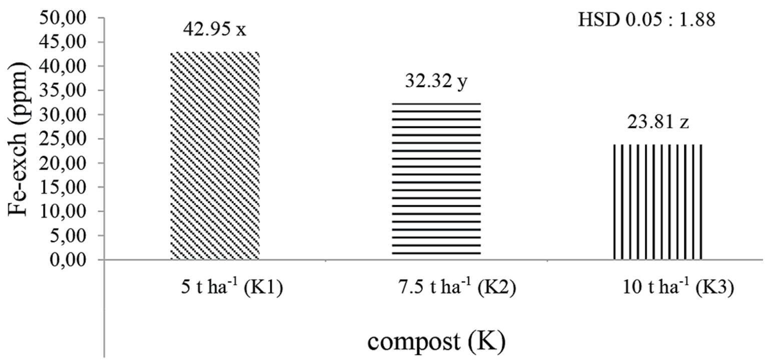


**Fig. 10.** Effect of the OPEFB compost on soil Fe-exchangeable

effect on reducing the soil Fe- exchangeable levels (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 $t{\cdot}ha^{-1}$ (K3) produced the lowest average Fe-exch of 23.81 ppm. When compared with the value of Fe-dd before treatment, which was 51.23 ppm i.e. was classified as very high, all compost and MVA treatments had a significant effect on the decrease in Fe-exchangeable.

## Effect of treatments on the plant growth of *Calopogonium mucunoides*

The results showed that the MVA treatment had a significant effect, while the OPEFB compost treatment and its interactions had no significant effect on the average dry weight of *Calopogonium mucunoides*. The results of the 95% Tukey test showed that the MVA treatment of 6 $t{\cdot}ha^{-1}$ (M3) produced the highest average dry weight of the plant, which was 0.97 g and was significantly different from other treatments. Mycorrhizae are structures formed due to mutualistic symbiotic associations between soil fungi and roots of higher plants, and there are five benefits of mycorrhizae for the development of the plants they host, namely increasing nutrient absorption from the soil, serving as a biological barrier against root pathogen infection, increasing host resistance to drought, increase growth-promoting hormones, and ensure the implementation of biogeochemical cycles. In this symbiotic relationship, the fungus obtains nutritional benefits (carbohydrates and other growth substances) for its life needs from plant roots (Noli et al., 2011). The use of OPEFB compost and MVA can increase plant growth and improve the availability of nutrients in the soil. *Calopogonium mucunoides* is better able to grow and live in dry stress so that mycorrhizae can increase the ability of plants to grow and survive under the conditions that lack water because of decreased osmotic potential and increased osmotic pressure which can interfere with mycorrhizal activities. Mycorrhizae then enter and live in or between the cortex of secondary roots (Begum et al., 2019).

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 $t{\cdot}ha^{-1}$ (M3) produced the highest average plant root length of 10.19 cm and was significantly different from other treatments. Analysis of variance showed that compost and MVA treatments and their interactions had no significant effect on the average root volume of plants (Figure 13). Figure 13

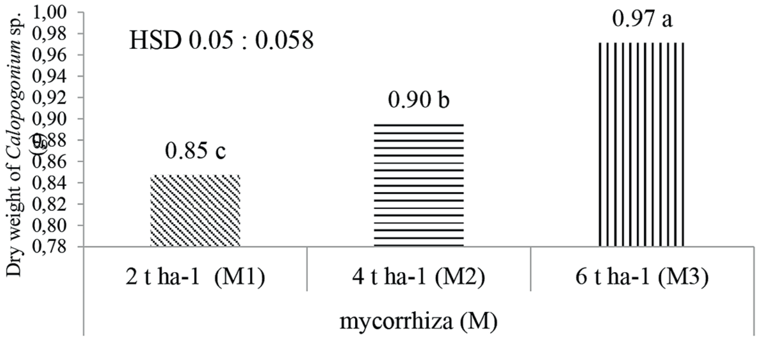


**Fig. 11.** Effect of MVA on plant dry weight of *Calopogonium mucunoides*

shows that the compost treatment of 10 t·ha $^{-1}$ and MVA 6 t·ha $^{-1}$ (K3M3) resulted in the highest average root volume of 2.50 cm $^{3}$. The results of this study are in line with the opinion of Charisma et al. (2012) that mycorrhizae can stimulate root formation which has the ability to increase the speed of plant growth which causes healthy roots. Mycorrhizae can also increase the suction surface area of the root system. The increase in root volume was thought to be due to VMA being able to absorb available nutrients in the soil. This is in line with the opinion of Goltapeth et al. (2013) who said that MVA is one of the soil microorganisms that can assist in the nutrient cycle. The long and fine hyphae structure can penetrate into the soil to absorb water, macro and micro nutrients that cannot be reached by plant roots. The use of mycorrhizae in combination treatment not only helps plant roots in nutrient absorption, but can also improve the post-mining soil properties. Suharno & Suncayaningsih dan Suharno (2013) also found that MVA can also assist in the photo-remediation process on the soil contaminated with heavy metals.

## Infection and spores observation of MVA

The results of the observation of the percentage of MVA infection on the roots of the *Calopogonium mucunoides* plant showed that the treatment with the highest average percentage of mycorrhizal infections was the M3 treatment with a value of 33.33%, followed by M2 13.33% and M1 3.33%. These results were in line with the length of the plant roots, which increased along with the dose of MVA, where the highest was found in the M3 treatment. Dewi (2007) said that the high percentage of mycorrhizal infection will extend and also expand the roots in the soil so that the root range to absorb nutrients will increase.

The results of observations on the number spores of *Acalauspora* sp. per 100 g of soil (Table 2) showed that each soil sample has a different number and morphotype. The dominant morphotype of *Acalauspora* sp. which was found in the soil after treatments is shown in Figure 13. The difference in the number of MVA spores is thought to be due to the different combinations of treatment doses given that affect the chemical and physical properties of the soil. Samsi et al. (2017) stated that the distribution of mycorrhizae

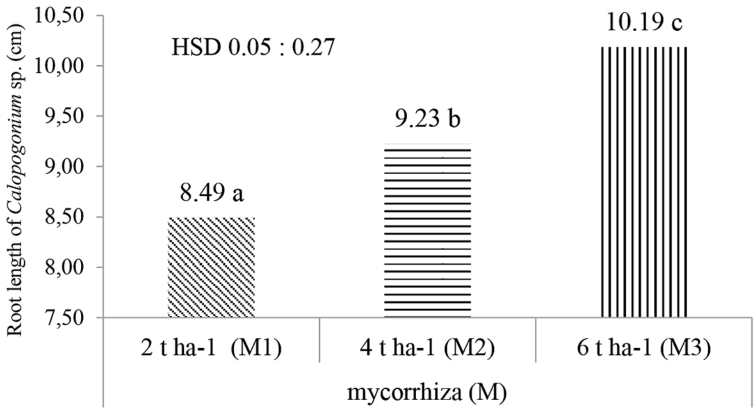


**Fig. 12.** Effect of MVA on root length of *Calapogonium mucunoides*

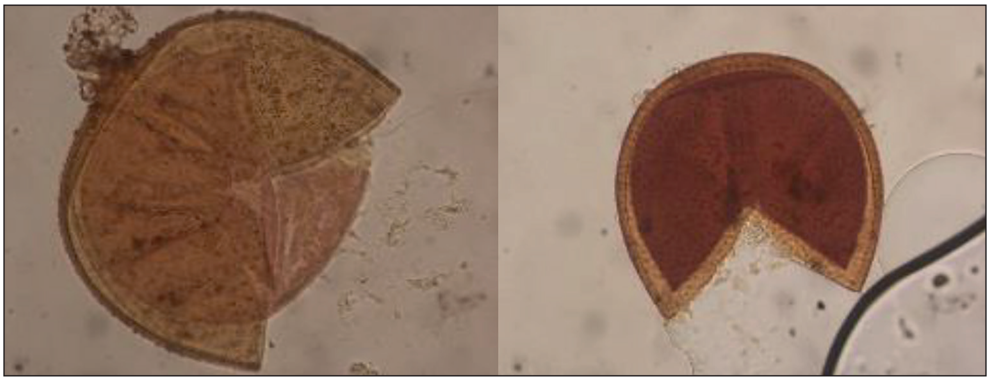

**Fig. 13.** Morphotype *Acalauspora sp.* dominantly found in the soil

**Table 2.** Density of VMA spores per 100 g of soil

| Treatment | Morphotype | Spore count | Total |
|---|---|---|---|
| K1M1 | Small Yellow Round | 5 | 5 |
| K1M2 | Small Yellow Round | 6 | 6 |
| K1M3 | Small Yellow Round | 9 | 9 |
| K2M1 | Small Yellow Round | 4 | 4 |
| K2M2 | Small Yellow Round | 23 | 23 |
| K2M3 | Small Yellow Round | 25 | 25 |
| K3M1 | Small Yellow Round | 16 | 16 |
| K3M2 | Small Yellow Round | 7 | 9 |
| | Small Clear Round | 2 | |
| K3M3 | Small Yellow Round | 99 | 99 |

was influenced by several factors, including the physical and chemical properties of the soil.

On the basis of the data in Table 2, it can be seen that the highest VMA spore density was in the K3M3 treatment, namely the dose of OPEFB compost 10 $t\cdot ha^{-1}$ and MVA 6 $t\cdot ha^{-1}$ found 99 spores per 100 g of soil. The high number of spores in the K3M3 soil sample was thought to be due to more suitable environmental conditions, such as the P content in the soil that supported the development of mycorrhizae. The high spore population is thought to be due to more suitable, optimal and compatible environmental conditions in supporting the growth and development of spores (Puspitasari et al., 2012). Furthermore, the distribution of mycorrhizae was influenced by many factors such as, soil type, P and N nutrients, water, pH, and soil temperature (Nurhalimah et al, 2013; Abdullah et al., 2020).

## CONCLUSIONS

The results of this study can be concluded that the use of the OPEFB compost 10 $t\cdot ha^{-1}$ and MVA 6 $t\cdot ha^{-1}$ (K3M3) is significant in improving the chemical properties of soil fertility after nickel mining, which is characterized by an increase in C-organic, CEC, P-available and exchangeable bases (Ca, Mg, K, Na) and reduce the Al-dd and Fe-dd content in the soil. The use of a combination of OPEFB and mycorrhizal (MVA) compost in various doses gave a significant effect on plant dry weight and root length of the ground cover plant *Calopogonium mucunoides.*

### Acknowledgments

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