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Use of compost from empty fruit bundles of oil palm and the arbuscular mycorrhizae to improve post-mining nickel soil fertility

ABSTRACT

The nickel mining soil of an open pit system exhibits poor soil chemistry and physical characteristics that require appropriate site-specific management to optimize it as a growing area. This study aims to analyze the efficacy of compost from oil palm empty fruit tufts (OPEFB) and vesicular-arbuscular mycorrhiza (MVA) in improving soil fertility of nickel post-mining soil. This study was conducted using a 2-factor randomized block study design. The first factor is compost with 3 treatments consisting of 5 t ha-1 (K1), 7.5 t ha-1 (K2), 10 t ha-1 (K3) and the second factor was mycorrhiza (M) in the fine crushed brick substrate up to 3 treatments consisting of 2t ha-1 (M1), 4t ha-1 (M2), 6t ha-1 (M3). A total of 9 treatment combinations were repeated three 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 P2O5, exchangeable calcium and magnesium exchangeable, and decreasand reducing exchangeable aluminium and iron. The highest soil properties values were found in the combination of compost 10 t ha-1 (K3) and MVA 6 t 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. Application of MVA at different doses had a significant effect on dry weight, root length of Calopogonium mucunoides and increased number of MVA spores in soil.

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

Introduction

Mining activities degrade the ecosystem and impact declining 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 instances of mining around the world result in soil being contaminated with metallic materials (Navarro et al., 2008; Nakajima et al., 2017) and suffering physical damage and a decrease in soil fertility quality (Ghose, 2004; Adetunji et al . , 2020; Kumar, 2013; Sembiring, 2008), including post-mining nickel earth in South Sulawesi Province, Indonesia. Nickel post mining soils made formed from ultra-mafic nickel have lower potential compared to other developing soils, because these soil reaction acidic to very acidic, and have low cation exchange capacity (Allo, 2016). One of the efforts to combat soil damage from mining is planting of legumes (LCC) (Prayogo, 2018), 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). Species of LCC widely distributed in post-mining areas include Calopogonium mucunoides, Mucuna sp, Sesbania sp, Flemingia sp, Tephrosia sp, which are useful in protecting 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 soil physical properties. According to Wright & Uphadhyaya (1998) in Musfal (2010), through its outer roots, MVA produces glomalin glycoprotein compounds and organic acids that bind soil grains into microaggregates. The use of arbuscular mycorrhizal fungi as biological agents is an environmentally friendly biological approach and has been widely developed in forestry, agriculture and plantation sectors (Husna et al., 2021; Ghaida et al., 2020). The benefits obtained by using WIP are that they do not cause pollution and also play an active role in nutrient cycling (Herawati et al., 2021). Plants infected with MVA benefit for life.

Methodology

The study was conducted using an experimental method with randomized block design 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 (stones finely broken) up to 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. Soil samples were obtaincollected from the nickel mine of PT Vale Indonesia (PTVI) located inNickel Mine at Sorowako Village, Nuha District, East Luwu Regency at coordinates 1212111.838 E and 02330.965 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. 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. Soil sample 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). Spore density analysis using the wet sieve method. Parameters of Calapogonium mucunoides plants that were measured were: plant dry weight, root length and root volume 49 days 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%.

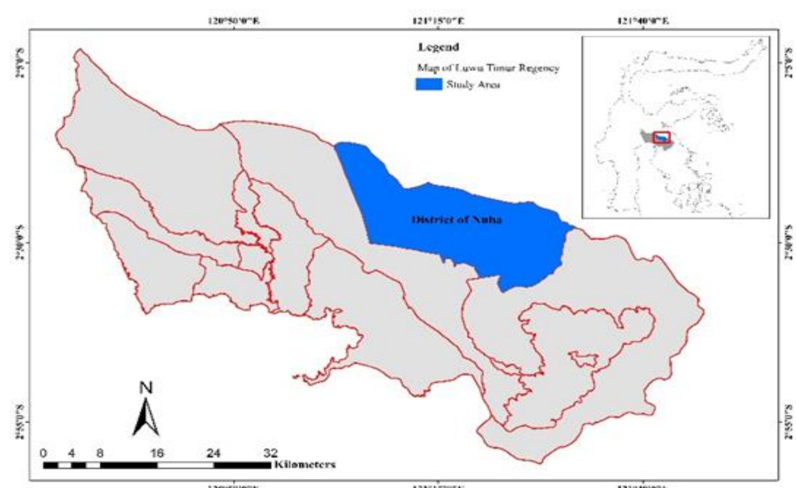

Fig 1. Soil Sampling Location

Results & Discussion

This study uses post-nickel topsoil from the reclamation area originating from the post-mining area of a nickel mining company in South Sulawesi, Indonesia. The results of the soil property analysis of the post-nickel soil sample are presented in Table 1.

Table 1. The results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil Characteristics	Value	Criteria*
pH (soil reaction)		
• H_2O	5.47	Slightly acid
• KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 cmol kg^{-1}	Low
Exchangeable basic cations		
• 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)

The results of the initial soil analysis before treatment showed that the post nickel mining soil had low soil fertility as shown by soil fertility parameters such as pH, which was classified as slightly acidic, C-organic, CEC, and P available were all very low, as were the number of cations Mg>Ca and very high levels of Fe-exch and Al-exch. According to Umarternate et al. (2014), acidic soils with pH < 5.5 are dominated by Fe3+ and Al3+ cations, which affect P availability. In acidic soils, the availability of P in rare earths exceeds 0.01% of total P. Most P forms are bound by soil colloids, making them unavailable to plants (Umaternate et al., 2014). Post-mining nickel soil analysis results showed that the CEC of the soil was low (<16 cmol kg-1). This is closely related to the dominant soil-forming factors in this region, namely ultramafic parent materials and the high precipitation and temperature factors that lead to intensive weathering and leaching processes in this region, as the organic matter content becomes low (<1%) and the pH -Value of soil is acidic.

Effect of treatments on soil chemical properties

Compost treatment had a significant effect on the average increase of SOC (Fig. 2) and the highest was found in the compost treatment (K3) worth 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 in the soil. Compost treatment also increases SOC in the soil because 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 OPEFB compost are 42.8% C; 0.80% K2O; 2.90% N; 0.22% P2 O5 ; 0.30% Mg; 100 ppm B; 23 ppm Cu; and 51 ppm Zn.

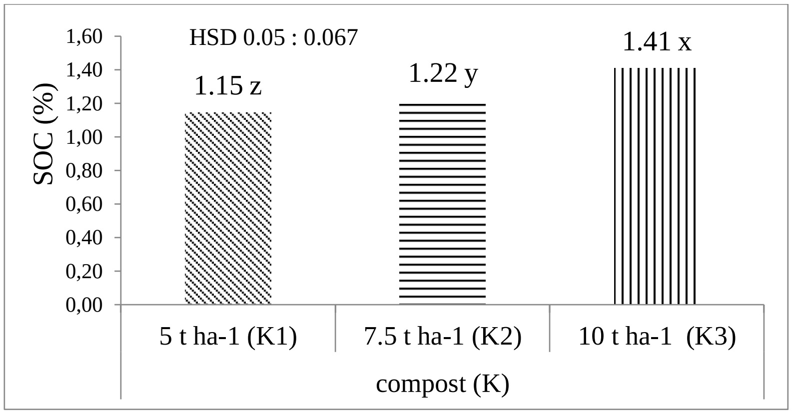

Fig 2. Effect of OPEFB compost on SOC

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

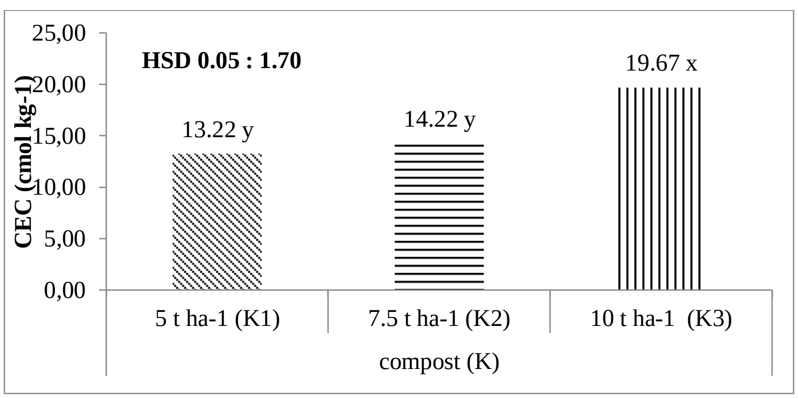

Fig. 3. Effect of TKSS compost on soil CEC

The results of this study also showed that the effect of compost and incinerator treatment in increasing the available soil P-value was very significant on increasing the available P value of the soil including the interaction effect of compost and incinerator as shown in Fig. 4. The results of the 95% HSD Tukey test as shown in 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 OPEFB compost. According to Ningtyas & Lia (2010), OPEFB compost contains macro nutrients, namely 2.15% for N-Total; 1.54% for P2 O5 ; 0:15% for K2O; and contains a small amount of micro elements such as Cu, Zn, Mn, Fe, Bo and Mo. Gandahi &Hanafi (2014) stated that the availability of P in soil is due to the direct addition of organic matter and the result of the mineralization process of organic Material increases so that it can release fixed P.

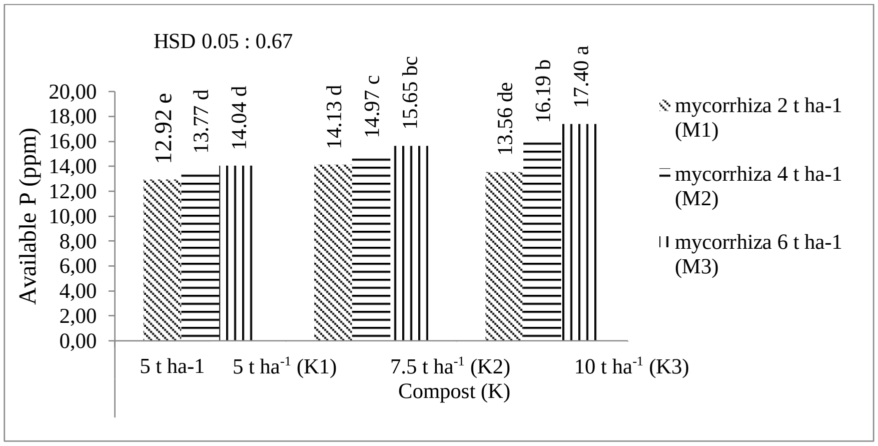

Fig. 4. Effect of OPEFB and MVA compost on the soil available-P

Furthermore, the results of the analysis of variance showed that there was a very significant interaction between compost and incinerator treatments in mean Ca exchange, as shown in Figure 5. The results of the 95% HSD Tukey test showed that the compost treatment was 10 t ha-1 and mycorrhiza 6 t ha-1 (K3M3) gave the highest Ca-exchange average of 3.33 cmol kg-1 and distinguished differ significantly from other treatments. The Ca exchange data after treatment showed a lower value than the soil analysis results before treatment, namely 3.83 cmol kg-1. The decrease in Ca can be caused by the exchange or uptake of Ca by plant roots either by root scavenging or by mass flow and can be caused by the acidity of the post-nickel mining soil, which is classified as slightly acidic.

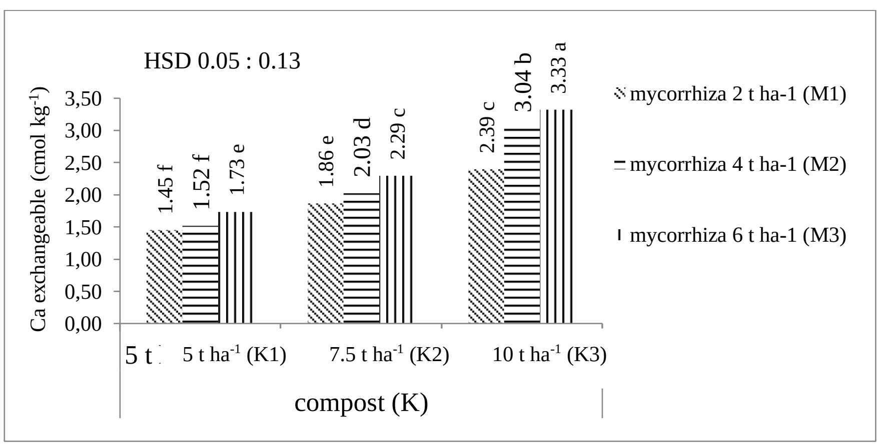

Fig. 5. Effect of OPEFB and MVA compost treatment on soil Ca- exchangeable

In addition, the effect of compost treatment also had a significant impact on Mg exchange values, as shown in Figure 6. The results of the 95% HSD-Tukey test showed that the compost treatment of OPEFB 10 t ha-1 (K3) gave the highest Mg exchange averaging 4.88 cmol kg-1 and differed significantly from other treatments. The results obtained showed a decrease in Mg with increasing compost dose. The results of the soil analysis at the beginning of the research showed that the Mg value was 6.67 cmol kg-1 The content classified as low had dropped to 4.88 cmol kg-1. The decrease in Mg exchange level in soil can be caused by magnesium being lost with the leachate, magnesium being taken up by plants or other living organisms, adsorbed by clay particles, and deposited in secondary minerals. Hakim et al. (1986) found that the availability of magnesium to plants is reduced in soils with high acidity.

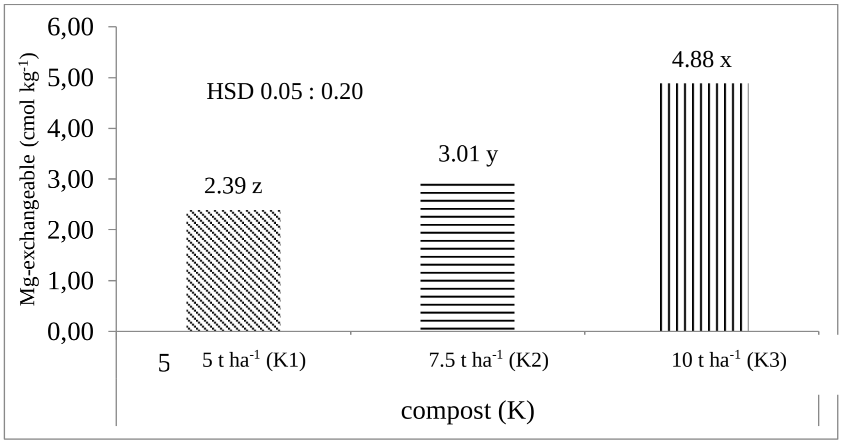

Fig.6. Effect of OPEFB compost on soil Mg-exchangeable

The results of the analysis showed that there was a very significant interaction between OPEFB and incinerator compost treatment on the K exchange. 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 differed significantly from others treatments (Figure 7). The results of the first 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 adding OPEFB compost. This is in line with Suherman's (2007) opinion that OPEFB compost is organic matter containing the main nutrients N, P, K and Mg and micronutrients. This statement is supported by the opinion of Rosmimi (2000) who says that compost applied to soil decomposes to produce compounds and nutrients available to plants. The nutrient content of OPEFB compost also helps in providing nutrients to the soil K value also depends on the soil CEC value.

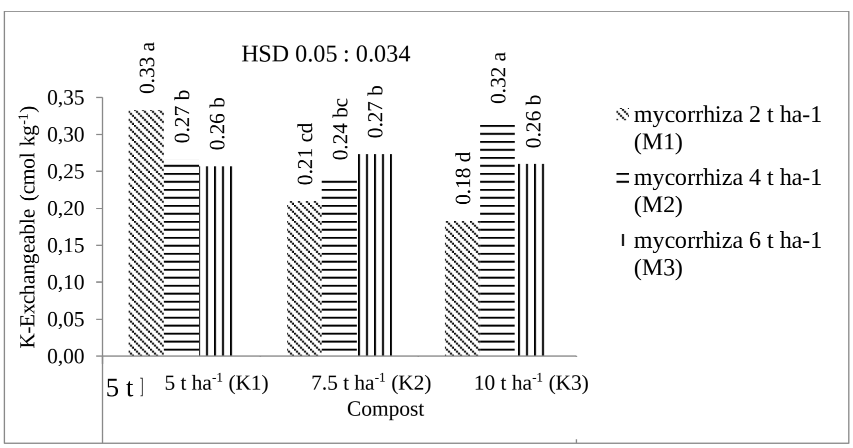

Fig. 7. Effect of OPEFB compost on soil K-Exchangeable

The effect of compost treatment and incinerator was significant to increase the average soil Na exchange. 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). Based on 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 the initial level of Na exchange increases before treatment, which is relatively small.

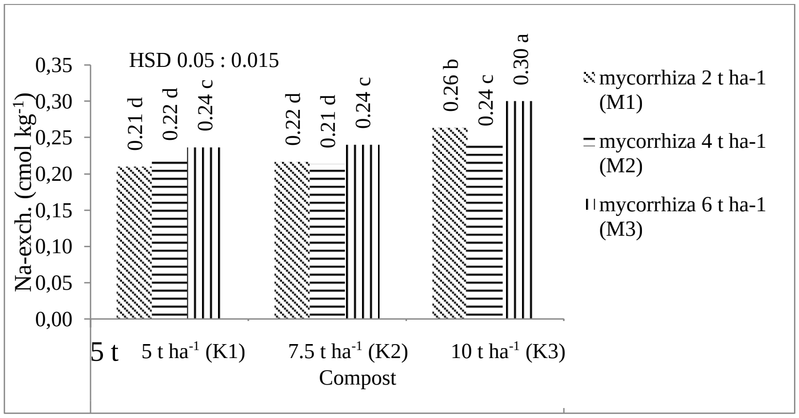

Fig. 8. Effect of OPEFB compost and MVA on soil Na-Exchangeable

Compost and incinerator treatment had a significant effect on the decrease in Al-exch value. Analysis of variance showed that there was a very significant interaction between compost and incinerator treatment on average Al exchange. K3M3) resulted in the lowest average Al exchange rate of 0.80 cmol kg-1 (Figure 9). The lowest Al exchange value was shown in the K3M3 treatment with a value of 0.8 cmol kg-1, which differed significantly from the other treatments. This value indicates that the Al exchange value decreases compared to the value before the 3.80 cmol kg-1 treatment. This indicates that the addition of OPEFB compost and MVA can reduce the aluminum content in the soil. This is in correlate with the opinion of Tan (2010) which 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 mineral soils that have a pH <5.0, most of which colloidal complexes are negatively charged (Hanafiah, 2010).

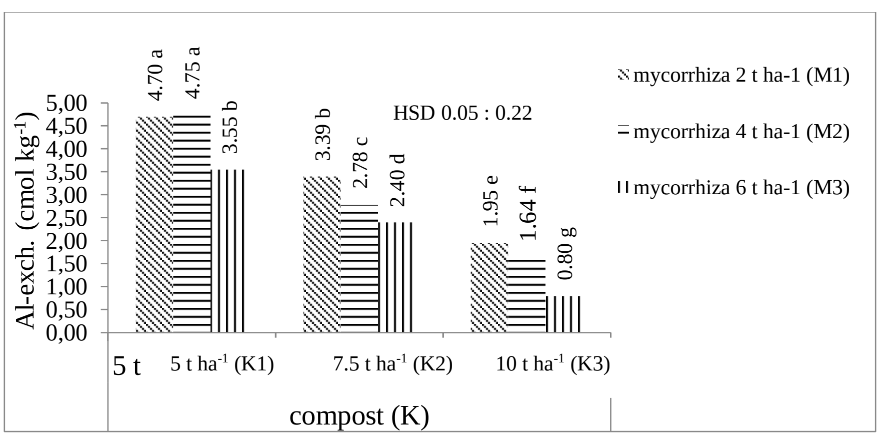

Fig. 9. Effect of OPEFB compost and MVA on soil Al-exchangeable

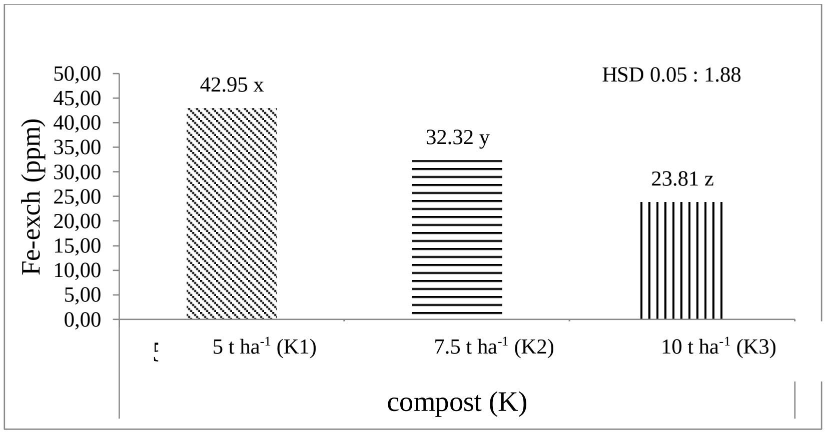

Fig. 10. Effect of OPEFB compost on soil Fe-exchangeable

In addition to the significantly reduced Al exchange content, the soil chemical parameter that decreased with compost treatment was Fe exchange. Analysis of variance showed that treatment of OPEFB compost had a significant effect on reducing soil Fe-exchange content (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t ha-1 (K3) produced the lowest average Fe exchange of 23.81 ppm 51.23 ppm, which was rated as very high, all had Compost and incinerator treatments have a significant effect on reducing Fe-Exch.

Effect of treatments on plant growth of *Calopogonium mucunoide*s

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 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, 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 gets 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 in 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)

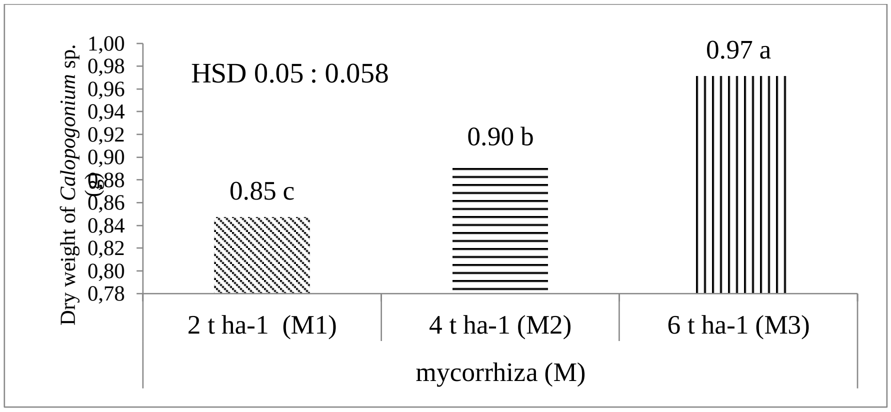

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 t ha-1 (M3) produced the highest average plant root length of 10.19 cm and differed significantly from other treatments. Analysis of variance showed that compost and incinerator treatments and their interactions had no significant impact on the average root volume of plants (Figure 13). Figure 13 shows that compost treatment of 10 t ha-1 and MVA 6 t ha-1 (K3M3) resulted in the highest average root volume of 2.50 cm3. The results of this study agree with the opinion of Charisma et al. (2012) agree that mycorrhiza can stimulate root formation, which has the ability to accelerate plant growth, resulting in healthy roots. Mycorrhiza can also increase the suction area of the root system. The increase in root volume was thought to be due to VMA's ability 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 tha It can support nutrient cycling. The long and delicate hyphal structure can penetrate the soil to absorb water, macro and micronutrients that cannot be reached by the plant roots. The use of mycorrhiza in combination treatments not only helps plant roots absorb nutrients, but can also improve post-mining soil properties. Suharno & Suncayaningsih dan Suharno (2013) also found that MVA can also help in photoremediation of soil contaminated with heavy metals.

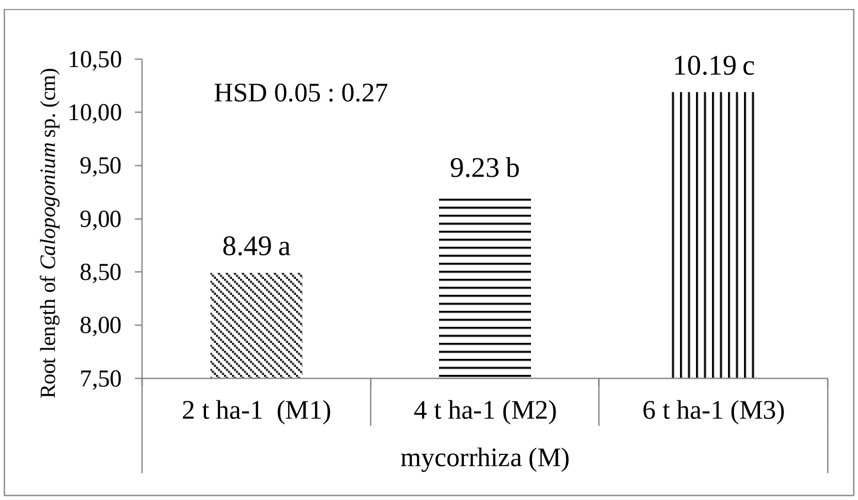

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

Infection and spores observation of MVA

The results of the observation of the percentage of MVA infection on the roots of the plant *Calopogonium mucunoides* 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 increase in 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 found in the soil after treatments are 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 was influenced by several factors, including the physical and chemical properties of the soil.

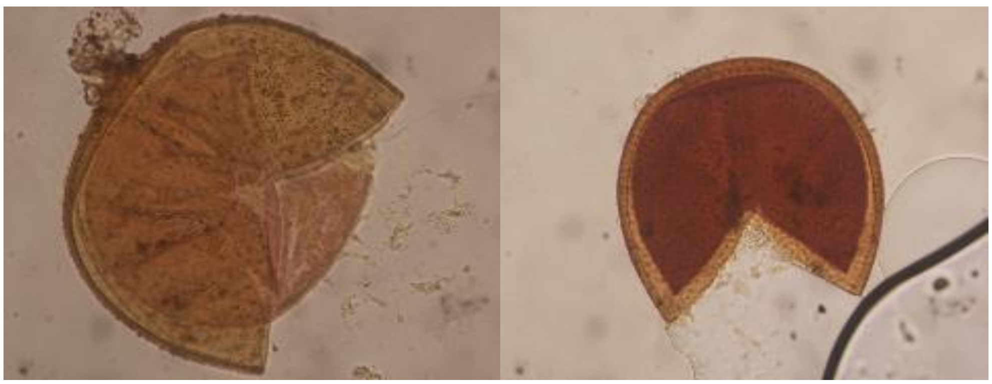

Fig. 13. Morphotype *Acalauspora sp* . dominantly found in the soil

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

Based on 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 ha^{-1} and MVA 6 t 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).

Conclusion

The results of this study can be concluded that the use of OPEFB compost 10 t ha^{-1} and MVA 6 t 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.*

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References

Abdullah, S., Y Musa, T Kuswinanti, M Jayadi, R Neswati. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology 21(39&40):82-91; 2020

Adetunjia, AT, B Ncubeb, R Mulidzic, FB Lewud. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research. V.204. 104717. https://doi.org/10.1016/j.still.2020.104717.

Allo K. M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4 (2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.

Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia. ISBN 978-602-8039-21-5. 234p.

Balai Penelitian Tanah, 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. 32 (4): 9-10. Bogor. Indonesia

Begum, N., Cheng Qin., M. A. Ahangar., S. Raza., M. I. Khan., M. Ashraf., N. Ahmed., L Zhang. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci. Vol.10. https://doi.org/10.3389/fpls.2019.01068.

Charisma A., Yuni S.R., & Isnawati (2012). Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. *Lantera Bio* Volume 1, Nomor 3, September 2012, Hal: 111 – 116

Chen, Y., Li, D., Li, D., Wu, X., & Zheng, Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi. org/10.1016/j.mcm.2010.11.054

Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

Gandahi, A. W & M. M. Hanafi. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland. pp.209-243. DOI:10.1007/978-3-319-08004-8.

Ghaida, S.H, B Wasis, S W Budi. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282-290.

Ghose, M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research. Vol.63. p.1006-1009. https://doi.org/10.1002/tqem.20150.

Goltapeth, E M, Y Z Danesh, R. Prasad, A. Varma. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A, Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

Hakim, N., Y. Nyakpa., A. Lubis., S. Nugroho., M. Saul., M A Diha., G B Hong and H H Bailey. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

Hakim, N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press. 204 p.

Hastuti, P.H, S. M. Rohmiyati. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal Vol 4 No.2. pp. 59-64.

Husna, F.D. Tuheteru, A. Arif. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity. Vol 22 No.9. https://doi.org/10.13057/biodiv/d220930.

Islami, T., W.H Utomo. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang

Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag 1:43-50.

Mahyudin, R.P., M Firmansyah, M A Purwanti, D Najmina. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering. Volume 21, Issue 5, p 221–228 https://doi.org/10.12911/22998993/122566.

Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian. Vol 29 No. 4. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154-158. p. 154-158.

Nakajima, K., K Nansai, K Matsubae, M Tomita, W Takayanagi, T Nagasaka. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment. 586. p730-737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.

Nakhone, LN, M.A Tabatabai. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S. 171: 231-241.

Ningtyas, VA., and YA Lia. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (Volvarella Volvaceae) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology. Surabaya.

Noli, ZA, Netty, WS, EM Sari. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.

Prayogo, C., M Ihsan. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management. Volume 6, number 1. doi:10.15243/jdmlm.2018.061.152.

Puspitasari D., K. Indah and H. Anton. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya. Vol 1. No. 2, September 2012

Riniarti, D., Kusumastuty, A., & Utoyo, B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research. Vol 12, No. 3, p187-195.

Rosmimi, 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.
Samsi N., Y.S Pata'dungan, A.R Tah, 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal. Vol 5, No. 2.
Sarrantonio, M., E.R. Gallandt. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production 8(1): 53-74. DOI: 10.1300/J144v08n01_04.
Sembiring, S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra. 5(2): 123-134.
Suherman, C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.
Suncayaningsih, R P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology. Vol. 10, No. 1, Pages: 31 – 42.
Sutanto, A., A.E Prasetyo, Fahroidayanti, A.F Lubis, and A.P Dongoran. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research. Vol. 13, No. 1. p. 25-33.
Tan, K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup . Boca Raton. London. New York. 362 p.
Umaternate, G.R, J Abidjulid, A D Wuntu,. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), p. 6-10. doi: https://doi.org/10.35799/jm.3.1.2014.3898.
Zaeni, A, Alwahab, Hasmawati, S Hade , Irnawati, P E Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. 1899-012031. IOP Publishing doi:10.1088/1742-6596/1899/1/012031.

1.b. Proofreading result

Use of compost from empty fruit bunches of oil palm and the arbuscular mycorrhizae to improve post-mining nickel soil fertility

ABSTRACT

The nickel mining soil of an open pit system exhibits poor soil chemistry and physical characteristics that require appropriate site-specific management to optimize it as a growing area. This study aims to analyze the efficacy of compost from oil palm empty fruit tufts (OPEFB) and vesicular-arbuscular mycorrhiza (MVA) in improving soil fertility of nickel post-mining soil. This study was conducted using a 2-factor randomized block study design. The first factor is compost with 3 treatments consisting of 5 t ha-1 (K1), 7.5 t ha-1 (K2), 10 t ha-1 (K3) and the second factor was mycorrhiza (M) in the fine crushed brick substrate up to 3 treatments consisting of 2t ha-1 (M1), 4t ha-1 (M2), 6t ha-1 (M3). A total of 9 treatment combinations were repeated three 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 P2O5, exchangeable calcium and magnesium exchangeable, and decreasand reducing exchangeable aluminium and iron. The highest soil properties values were found in the combination of compost 10 t ha-1 (K3) and MVA 6 t 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. Application of MVA at different doses had a significant effect on dry weight, root length of Calopogonium mucunoides and increased number of MVA spores in soil.

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

Introduction

Mining activities degrade the ecosystem and impact declining 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 instances of mining around the world result in soil being contaminated with metallic materials (Navarro et al., 2008; Nakajima et al., 2017) and suffering physical damage and a decrease in soil fertility quality (Ghose, 2004; Adetunji et al . , 2020; Kumar, 2013; Sembiring, 2008), including post-mining nickel earth in South Sulawesi Province, Indonesia. Nickel post mining soils made formed from ultra-mafic nickel have lower potential compared to other developing soils, because these soil reaction acidic to very acidic, and have low cation exchange capacity (Allo, 2016). One of the efforts to combat soil damage from mining is planting of legumes (LCC) (Prayogo, 2018), 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). Species of LCC widely distributed in post-mining areas include Calopogonium mucunoides, Mucuna sp, Sesbania sp, Flemingia sp, Tephrosia sp, which are useful in protecting 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).

Commented [A1]: Using compost from empty fruit

Commented [A2]: The nickel post-mining soil with an open-pit mining system has poor soil chemical and physical properties so that it requires appropriate site-specific management so that it can be optimized as a plant cultivation area

Commented [A3]: the effectiveness of compost from oil palm empty fruit bunches (OPEFB) and mycorrhizal vesicular-arbuscular (MVA)

Commented [A4]: This study was conducted using a randomized block trial design with 2 factors.

Commented [A5]: The first factor is compost with 3 treatments consisting of 5 t ha-1 (K1), 7.5 t ha-1 (K2), 10 t ha-1 (K3) and the second factor was mycorrhiza (M) in the fine-crushed brick carrier media as many as 3 treatments consisting of 2 t ha-1 (M1), 4 t ha-1 (M2), 6 t ha-1 (M3)

Commented [A6]: ...., calcium and magnesium exchangeable, and decreasing exchangeable aluminium and iron.

Commented [A7]: 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.

Commented [A8]: 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.

Commented [A9]: This is of course caused by mining activities, starting with land clearing and then dredging (open pit mining), which can have negative impacts on the ecosystem (Kumar, 2013; Chen et al., 2011)), so land reclamation must be carried out immediately.

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Commented [A13]: 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

Mycorrhizae Vesicular Arbuscular (MVA) plays a role in improving soil physical properties. According to Wright & Uphadhyaya (1998) in Musfal (2010), through its outer roots, MVA produces glomalin glycoprotein compounds and organic acids that bind soil grains into microaggregates. The use of arbuscular mycorrhizal fungi as biological agents is an environmentally friendly biological approach and has been widely developed in forestry, agriculture and plantation sectors (Husna et al., 2021; Ghaida et al., 2020). The benefits obtained by using WIP are that they do not cause pollution and also play an active role in nutrient cycling (Herawati et al., 2021). Plants infected with MVA benefit for life.

Methodology

The study was conducted using an experimental method with randomized block design 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 (stones finely broken) up to 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. Soil samples were obtaincollected from the nickel mine of PT Vale Indonesia (PTVI) located inNickel Mine at Sorowako Village, Nuha District, East Luwu Regency at coordinates 1212111.838 E and 02330.965 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. 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. Soil sample 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). Spore density analysis using the wet sieve method. Parameters of Calapogonium mucunoides plants that were measured were: plant dry weight, root length and root volume 49 days 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%.

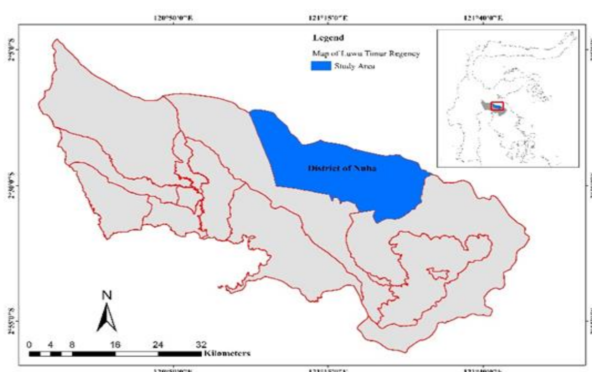

Fig 1. Soil Sampling Location

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Commented [A15]: 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.

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Commented [A17]: The advantages obtained by the use of MVA are that they does not cause environmental pollution, and also play an active role in the nutrient cycle (Herawati et al., 2021).

Commented [A18]: Plants that have been infected with MVA, will benefit for the life of the plant.

Commented [A19]: The study was conducted using a randomized block design experimental method with 2 factors, namely OPEBF compost factor with 3 levels

Commented [A20]: Soil samples were obtained from the nickel mine of PT Vale Indonesia (PTVI) located in Sorowako Village, Nuha District, East Luwu Regency at coordinates 121º21′11.838″ E and 02º33′0.965″ S as shown in Figure 1.

Commented [A21]: Spore density analyzed using the wet sieved method. Parameters of Calapogonium mucunoides plants that were measured were: dry weight of plants, root length and root volume at 49 day after planting (DAP).

Results & Discussion

This study uses post-nickel topsoil from the reclamation area originating from the post-mining area of a nickel mining company in South Sulawesi, Indonesia. The results of the soil property analysis of the post-nickel soil sample are presented in Table 1.

Table 1. The results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil Characteristics	Value	Criteria*
pH (soil reaction)		
• H_2O	5.47	Slightly acid
• KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 cmol kg^{-1}	Low
Exchangeable basic cations		
• 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)

The results of the initial soil analysis before treatment showed that the post nickel mining soil had low soil fertility as shown by soil fertility parameters such as pH, which was classified as slightly acidic, C-organic, CEC, and P available were all very low, as were the number of cations Mg>Ca and very high levels of Fe-exch and Al-exch. According to Umarternate et al. (2014), acidic soils with pH < 5.5 are dominated by Fe3+ and Al3+ cations, which affect P availability. In acidic soils, the availability of P in rare earths exceeds 0.01% of total P. Most P forms are bound by soil colloids, making them unavailable to plants (Umaternate et al., 2014). Post-mining nickel soil analysis results showed that the CEC of the soil was low (<16 cmol kg-1). This is closely related to the dominant soil-forming factors in this region, namely ultramafic parent materials and the high precipitation and temperature factors that lead to intensive weathering and leaching processes in this region, as the organic matter content becomes low (<1%) and the pH -Value of soil is acidic.

Effect of treatments on soil chemical properties

Compost treatment had a significant effect on the average increase of SOC (Fig. 2) and the highest was found in the compost treatment (K3) worth 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 in the soil. Compost treatment also increases SOC in the soil because 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 OPEFB compost are 42.8% C; 0.80% K2O; 2.90% N; 0.22% P2 O5 ; 0.30% Mg; 100 ppm B; 23 ppm Cu; and 51 ppm Zn.

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Commented [A26]: 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.

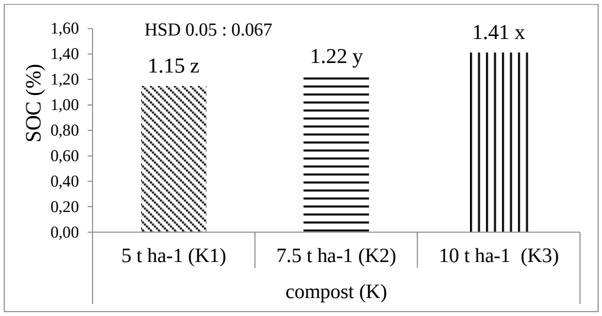

Fig 2. Effect of OPEFB compost on SOC

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

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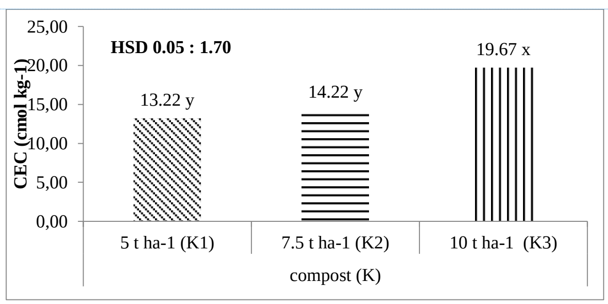

Fig. 3. Effect of TKSS compost on soil CEC

The results of this study also showed that the effect of compost and incinerator treatment in increasing the available soil P-value was very significant on increasing the available P value of the soil including the interaction effect of compost and incinerator as shown in Fig. 4. The results of the 95% HSD Tukey test as shown in 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 OPEFB compost. According to Ningtyas & Lia (2010), OPEFB compost contains macro nutrients, namely 2.15% for N-Total; 1.54% for P2 O5 ; 0:15% for K2O; and contains a small amount of micro elements such as Cu, Zn, Mn, Fe, Bo and Mo. Gandahi &Hanafi (2014) stated that the availability of P in soil is due to the direct addition of organic matter and the result of the mineralization process of organic Material increases so that it can release fixed P.

Commented [A28]: and MVA treatment was very significant

Commented [A29]: MVA

Commented [A30]: 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

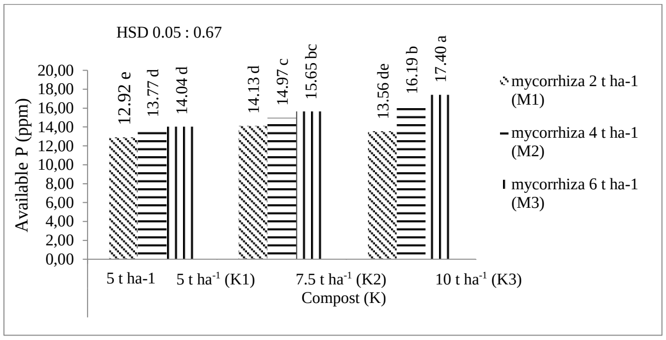

Fig. 4. Effect of OPEFB and MVA compost on the soil available-P

Furthermore, the results of the analysis of variance showed that there was a very significant interaction between compost and incinerator treatments in mean Ca exchange, as shown in Figure 5. The results of the 95% HSD Tukey test showed that the compost treatment was 10 t ha-1 and mycorrhiza 6 t ha-1 (K3M3) gave the highest Ca-exchange average of 3.33 cmol kg-1 and distinguished differ significantly from other treatments. The Ca exchange data after treatment showed a lower value than the soil analysis results before treatment, namely 3.83 cmol kg-1. The decrease in Ca can be caused by the exchange or uptake of Ca by plant roots either by root scavenging or by mass flow and can be caused by the acidity of the post-nickel mining soil, which is classified as slightly acidic.

Commented [A31]: MVA treatments on the average Ca-Exch as shown in Figure 5

Commented [A32]: 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.

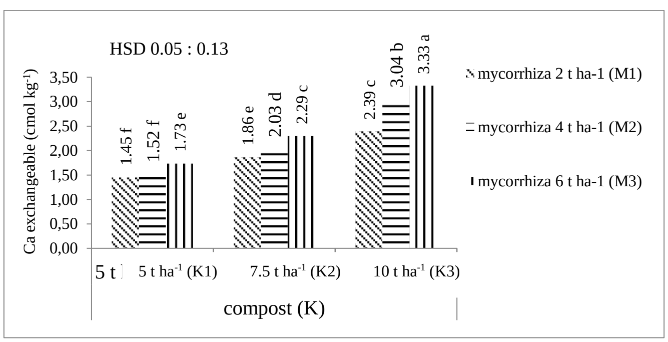

Fig. 5. Effect of OPEFB and MVA compost treatment on soil Ca- exchangeable

In addition, the effect of compost treatment also had a significant impact on Mg exchange values, as shown in Figure 6. The results of the 95% HSD-Tukey test showed that the compost treatment of OPEFB 10 t ha-1 (K3) gave the highest Mg exchange averaging 4.88 cmol kg-1 and differed significantly from other treatments. The results obtained showed a decrease in Mg with increasing compost dose. The results of the soil analysis at the beginning of the research showed that the Mg value was 6.67 cmol kg-1 The content classified as low had dropped to 4.88 cmol kg-1. The decrease in Mg exchange level in soil can be caused by magnesium being lost with the leachate, magnesium being taken up by plants or other living organisms, adsorbed by clay particles, and deposited in secondary minerals. Hakim et al. (1986) found that the availability of magnesium to plants is reduced in soils with high acidity.

Commented [A33]: In addition, the effect of compost treatment also significantly affected Mg-exch levels as shown in Figure 6. The results of the 95% HSD Tukey test showed that the compost treatment of 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 soils that have high acidity

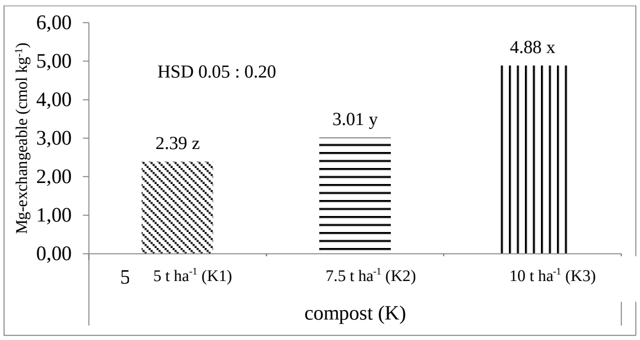

Fig.6. Effect of OPEFB compost on soil Mg-exchangeable

The results of the analysis showed that there was a very significant interaction between OPEFB and incinerator compost treatment on the K exchange. 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 differed significantly from others treatments (Figure 7). The results of the first 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 adding OPEFB compost. This is in line with Suherman's (2007) opinion that OPEFB compost is organic matter containing the main nutrients N, P, K and Mg and micronutrients. This statement is supported by the opinion of Rosmimi (2000) who says that compost applied to soil decomposes to produce compounds and nutrients available to plants. The nutrient content of OPEFB compost also helps in providing nutrients to the soil K value also depends on the soil CEC value.

Commented [A34]: The results of the analysis showed that there was a very significant interaction between 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 OPEFB compost. This is in line with the opinion of Suherman (2007) that OPEFB compost is organic material that contains the main nutrients N, P, K and Mg and contains micro nutrients. This statement is reinforced by the opinion of Rosmimi (2000) who says that compost given to the soil will decompose to produce compounds and nutrients that are available to plants. The nutrient content of 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.

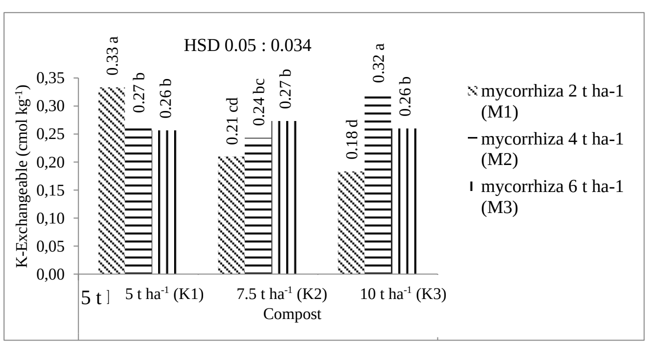

Fig. 7. Effect of OPEFB compost on soil K-Exchangeable

The effect of compost treatment and incinerator was significant to increase the average soil Na exchange. 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). Based on 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

Commented [A35]: MVA

Commented [A36]: Na-Exch of the soil significantly different from the other treatments. This value also shows that the initial level of Na exchange increases before treatment, which is relatively small.

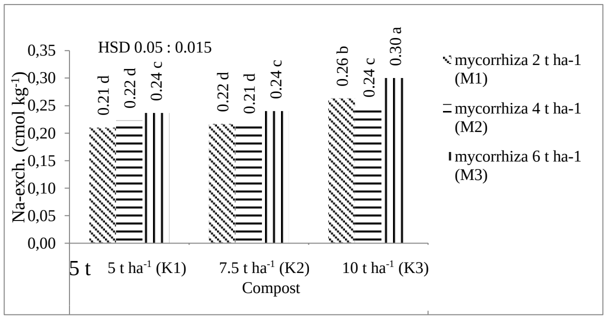

Fig. 8. Effect of OPEFB compost and MVA on soil Na-Exchangeable

Compost and incinerator treatment had a significant effect on the decrease in Al-exch value. Analysis of variance showed that there was a very significant interaction between compost and incinerator treatment on average Al exchange. K3M3) resulted in the lowest average Al exchange rate of 0.80 cmol kg-1 (Figure 9). The lowest Al exchange value was shown in the K3M3 treatment with a value of 0.8 cmol kg-1, which differed significantly from the other treatments. This value indicates that the Al exchange value decreases compared to the value before the 3.80 cmol kg-1 treatment. This indicates that the addition of OPEFB compost and MVA can reduce the aluminum content in the soil. This is in correlate with the opinion of Tan (2010) which 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 mineral soils that have a pH <5.0, most of which colloidal complexes are negatively charged (Hanafiah, 2010).

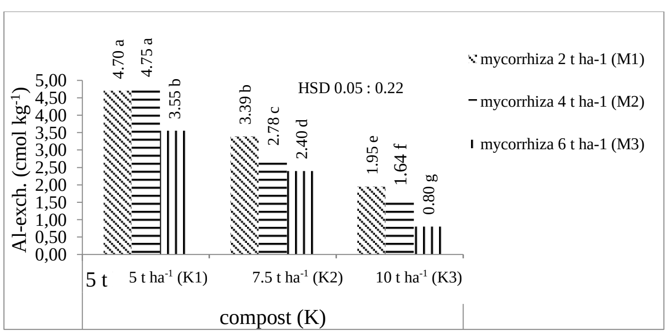

Fig. 9. Effect of OPEFB compost and MVA on soil Al-exchangeable

Commented [A37]: This value also shows that there is an increase in the initial value of Na-exch before being treated which is relatively low

Commented [A38]: MVA

Commented [A39]: 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}.

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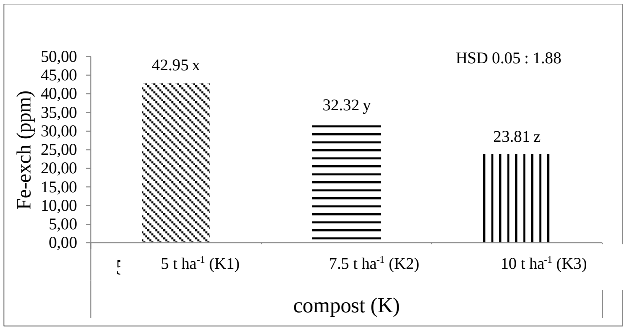

Fig. 10. Effect of OPEFB compost on soil Fe-exchangeable

In addition to the significantly reduced Al exchange content, the soil chemical parameter that decreased with compost treatment was Fe exchange. Analysis of variance showed that treatment of OPEFB compost had a significant effect on reducing soil Fe-exchange content (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t ha-1 (K3) produced the lowest average Fe exchange of 23.81 ppm 51.23 ppm, which was rated as very high, all had Compost and incinerator treatments have a significant effect on reducing Fe-Exch.

Commented [A41]: In addition to the significantly decreased Al-exch content, the chemical parameter of the soil that decreased with the compost treatment was Fe-exch. Analysis of variance showed that the treatment of OPEFB compost had a significant effect on reducing soil Fe-Exch levels (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t 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 which was classified as very high, all compost and MVA treatments had a significant effect on the decrease in Fe-Exch

Effect of treatments on plant growth of *Calopogonium mucunoide*s

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 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, 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 gets 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 in 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)

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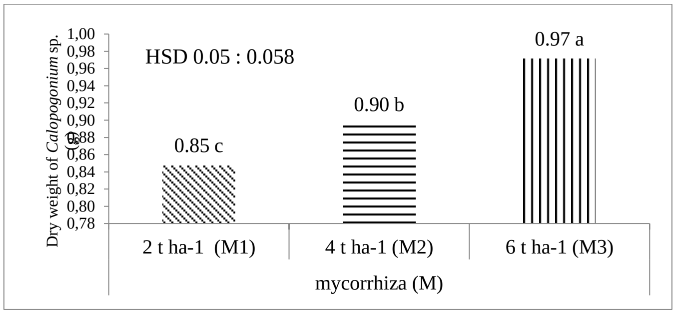

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 t ha-1 (M3) produced the highest average plant root length of 10.19 cm and differed significantly from other treatments. Analysis of variance showed that compost and incinerator treatments and their interactions had no significant impact on the average root volume of plants (Figure 13). Figure 13 shows that compost treatment of 10 t ha-1 and MVA 6 t ha-1 (K3M3) resulted in the highest average root volume of 2.50 cm3. The results of this study agree with the opinion of Charisma et al. (2012) agree that mycorrhiza can stimulate root formation, which has the ability to accelerate plant growth, resulting in healthy roots. Mycorrhiza can also increase the suction area of the root system. The increase in root volume was thought to be due to VMA's ability 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 tha It can support nutrient cycling. The long and delicate hyphal structure can penetrate the soil to absorb water, macro and micronutrients that cannot be reached by the plant roots. The use of mycorrhiza in combination treatments not only helps plant roots absorb nutrients, but can also improve post-mining soil properties. Suharno & Suncayaningsih dan Suharno (2013) also found that MVA can also help in photoremediation of soil contaminated with heavy metals.

Commented [A43]: 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 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 post-mining soil properties. Suharno & Suncayaningsih dan Suharno (2013) also found that MVA can also assist in the photo-remediation process on soil contaminated with heavy metals.

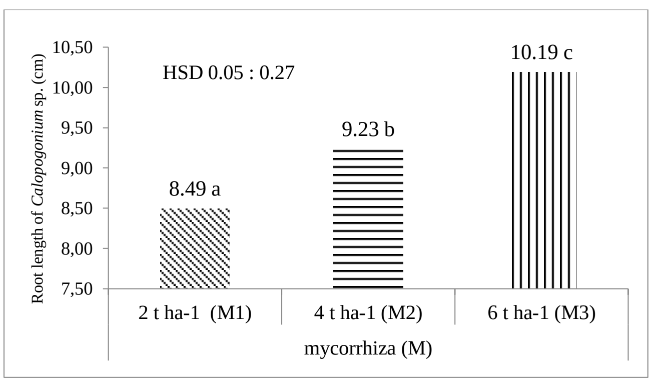

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

Infection and spores observation of MVA

The results of the observation of the percentage of MVA infection on the roots of the plant *Calopogonium mucunoides* 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 increase in 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 found in the soil after treatments are 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 was influenced by several factors, including the physical and chemical properties of the soil.

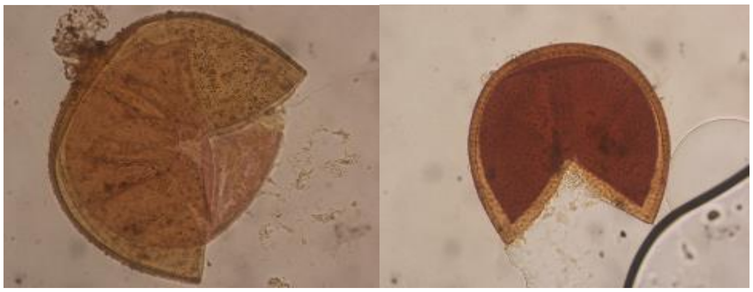

Fig. 13. Morphotype *Acalauspora sp* . dominantly found in the soil

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

Based on 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 ha^{-1} and MVA 6 t 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).

Conclusion

The results of this study can be concluded that the use of OPEFB compost 10 t ha^{-1} and MVA 6 t 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.*

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References

Abdullah, S., Y Musa, T Kuswinanti, M Jayadi, R Neswati. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology 21(39&40):82-91; 2020

Adetunjia, AT, B Ncubeb, R Mulidzic, FB Lewud. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research. V.204. 104717. https://doi.org/10.1016/j.still.2020.104717.

Allo K. M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4 (2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.

Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia. ISBN 978-602-8039-21-5. 234p.

Balai Penelitian Tanah, 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. 32 (4): 9-10. Bogor. Indonesia

Begum, N., Cheng Qin., M. A. Ahangar., S. Raza., M. I. Khan., M. Ashraf., N. Ahmed., L Zhang. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci. Vol.10. https://doi.org/10.3389/fpls.2019.01068.

Charisma A., Yuni S.R., & Isnawati (2012). Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. *Lantera Bio* Volume 1, Nomor 3, September 2012, Hal: 111 – 116

Chen, Y., Li, D., Li, D., Wu, X., & Zheng, Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi. org/10.1016/j.mcm.2010.11.054

Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

Gandahi, A. W & M. M. Hanafi. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland. pp.209-243. DOI:10.1007/978-3-319-08004-8.

Ghaida, S.H, B Wasis, S W Budi. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282-290.

Ghose, M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research. Vol.63. p.1006-1009. https://doi.org/10.1002/tqem.20150.

Goltapeth, E M, Y Z Danesh, R. Prasad, A. Varma. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A, Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

Hakim, N., Y. Nyakpa., A. Lubis., S. Nugroho., M. Saul., M A Diha., G B Hong and H H Bailey. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

Hakim, N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press. 204 p.

Hastuti, P.H, S. M. Rohmiyati. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal Vol 4 No.2. pp. 59-64.

Husna, F.D. Tuheteru, A. Arif. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity. Vol 22 No.9. https://doi.org/10.13057/biodiv/d220930.

Islami, T., W.H Utomo. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang

Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag 1:43-50.

Mahyudin, R.P., M Firmansyah, M A Purwanti, D Najmina. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering. Volume 21, Issue 5, p 221–228 https://doi.org/10.12911/22998993/122566.

Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian. Vol 29 No. 4. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154-158. p. 154-158.

Nakajima, K., K Nansai, K Matsubae, M Tomita, W Takayanagi, T Nagasaka. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment. 586. p730-737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.

Nakhone, LN, M.A Tabatabai. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S. 171: 231-241.

Ningtyas, VA., and YA Lia. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (Volvarella Volvaceae) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology. Surabaya.

Noli, ZA, Netty, WS, EM Sari. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.

Prayogo, C., M Ihsan. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management. Volume 6, number 1. doi:10.15243/jdmlm.2018.061.152.

Puspitasari D., K. Indah and H. Anton. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya. Vol 1. No. 2, September 2012

Riniarti, D., Kusumastuty, A., & Utoyo, B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research. Vol 12, No. 3, p187-195.

Rosmimi, 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.
Samsi N., Y.S Pata'dungan, A.R Tah, 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal. Vol 5, No. 2.
Sarrantonio, M., E.R. Gallandt. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production 8(1): 53-74. DOI: 10.1300/J144v08n01_04.
Sembiring, S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra. 5(2): 123-134.
Suherman, C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.
Suncayaningsih, R P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology. Vol. 10, No. 1, Pages: 31 – 42.
Sutanto, A., A.E Prasetyo, Fahroidayanti, A.F Lubis, and A.P Dongoran. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research. Vol. 13, No. 1. p. 25-33.
Tan, K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup . Boca Raton. London. New York. 362 p.
Umaternate, G.R, J Abidjulid, A D Wuntu,. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), p. 6-10. doi: https://doi.org/10.35799/jm.3.1.2014.3898.
Zaeni, A, Alwahab, Hasmawati, S Hade , Irnawati, P E Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. 1899-012031. IOP Publishing doi:10.1088/1742-6596/1899/1/012031.

1.c. Documents from proofreading services

Using of oil palm empty fruit bunches compost and mycorrhizae arbuscular for improving the fertility of nickel post-mining soil

ABSTRACT

The nickel post-mining soil with an open-pit mining system has poor soil chemical and physical properties so that it requires appropriate site-specific management so that it can be optimized as a plant cultivation area. This study aims 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 ha-1 (K1), 7.5 t ha-1 (K2), 10 t ha-1 (K3) and the second factor was mycorrhiza (M) in the fine-crushed brick carrier media as many as 3 treatments consisting of 2 t ha-1 (M1), 4 t ha-1 (M2), 6 t 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 P2O5, calcium and magnesium exchangeable, and decreasing exchangeable aluminium and iron. The highest soil properties values were found in the combination of compost 10 t ha-1 (K3) and MVA 6 t 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. Nickel post mining soils made formed from ultra-mafic nickel have lower potential compared to other developing soils, because these soil reaction acidic to very acidic, and have low cation exchange capacity (Allo, 2016). One of the efforts to manage 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). 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 does not cause environmental pollution, and also play an active role in the nutrient cycle (Herawati et al., 2021). 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 (bricks fine-crushed) 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. Soil samples were obtained from the nickel mine of PT Vale Indonesia (PTVI) located in 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. 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. Soil sample 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). Spore density analyzed using the wet sieved method. Parameters of *Calapogonium mucunoides* plants that were measured 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%.

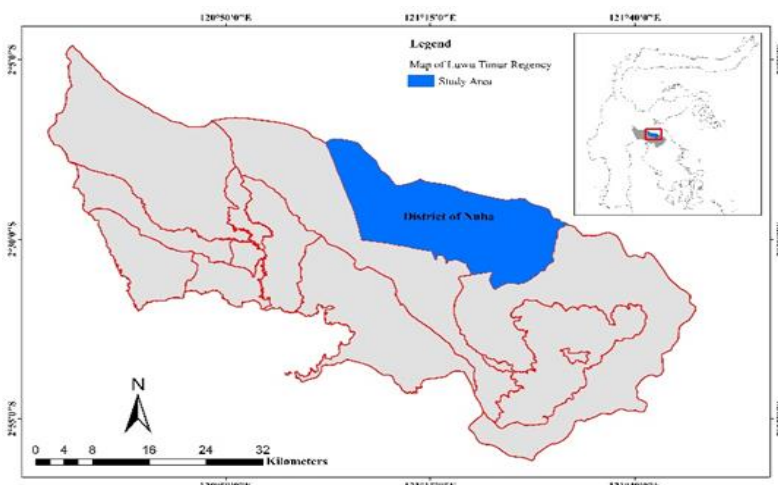

Fig 1. Soil Sampling Location

Results & Discussion

This study uses 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 the post-nickel soil sample are shown in Table 1.

Table 1. The results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil Characteristics	**Value**	**Criteria***
pH (soil reaction)		
• H_2O	5.47	Slightly acid
• KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 cmol kg^{-1}	Low
Exchangeable basic cations		
• 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)

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) 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

Compost treatment had a significant effect on the average increase of SOC (Fig. 2) and the highest was found in the compost treatment (K3) worth 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 in the soil. Compost treatment also increases SOC in the soil because 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 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.

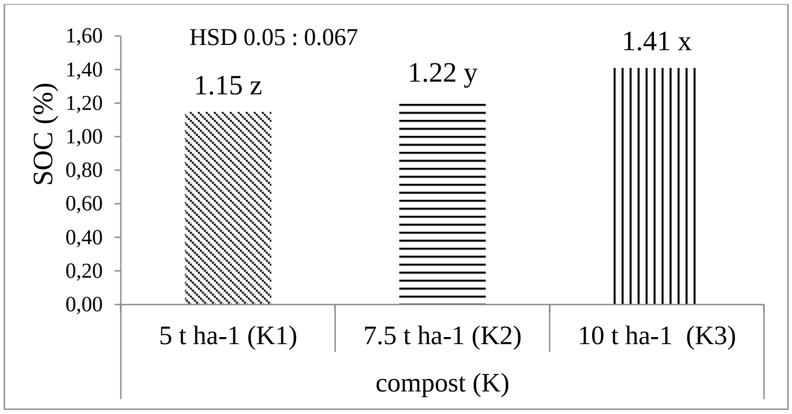

Fig 2. Effect of OPEFB compost on SOC

The effect of adding OPEFB compost was also significant for the increase in 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 14.51cmol kg^{-1}. This indicates that the increase in soil CEC value is strongly influenced by the addition of 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).

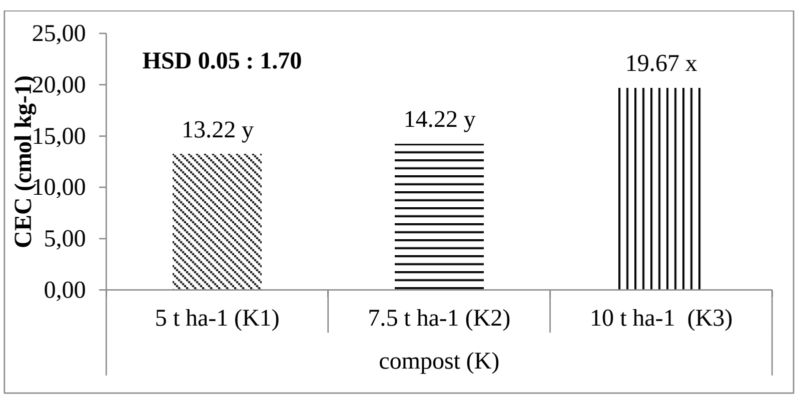

Fig. 3. Effect of TKSS compost on soil CEC

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 Fig. 4. The results of the 95% HSD Tukey test as shown in 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 OPEFB compost. According to Ningtyas & Lia (2010), OPEFB compost contains macro nutrients, namely 2.15% for N-Total; 1.54% for P2 O5 ; 0:15% for K2O; and contains a small amount of micro elements such as Cu, Zn, Mn, Fe, Bo and Mo. Gandahi &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.

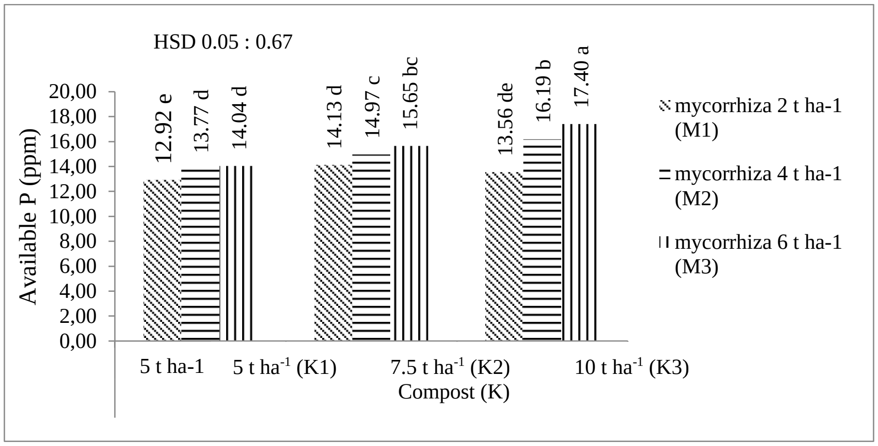

Fig. 4. Effect of OPEFB and MVA compost on the soil available-P

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.

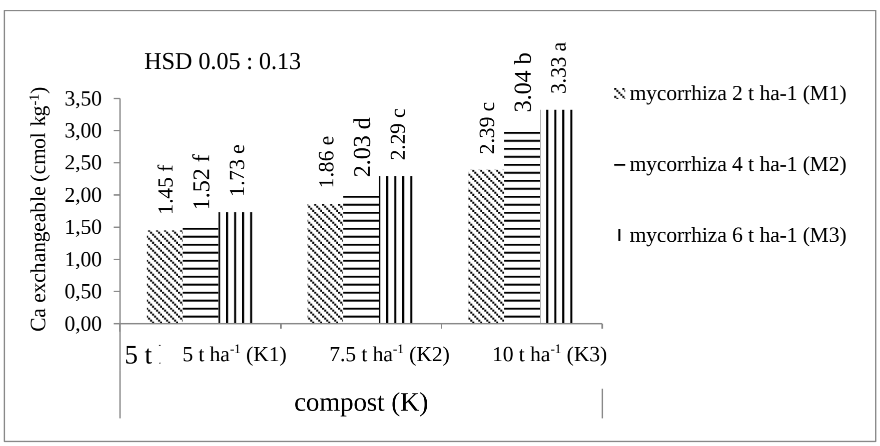

Fig. 5. Effect of OPEFB and MVA compost treatment on soil Ca- exchangeable

In addition, the effect of compost treatment also significantly affected Mg-exch levels as shown in Figure 6. The results of the 95% HSD Tukey test showed that the compost treatment of 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 soils that have high acidity.

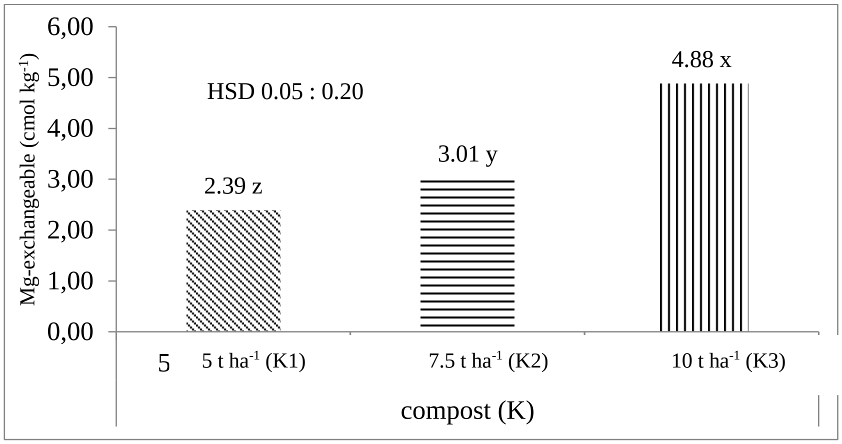

Fig.6. Effect of OPEFB compost on soil Mg-exchangeable

The results of the analysis showed that there was a very significant interaction between 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 OPEFB compost. This is in line with the opinion of Suherman (2007) that OPEFB compost is organic material that contains the main nutrients N, P, K and Mg and contains micro nutrients. This statement is reinforced by the opinion of Rosmimi (2000) who says that compost given to the soil will decompose to produce compounds and nutrients that are available to plants. The nutrient content of 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.

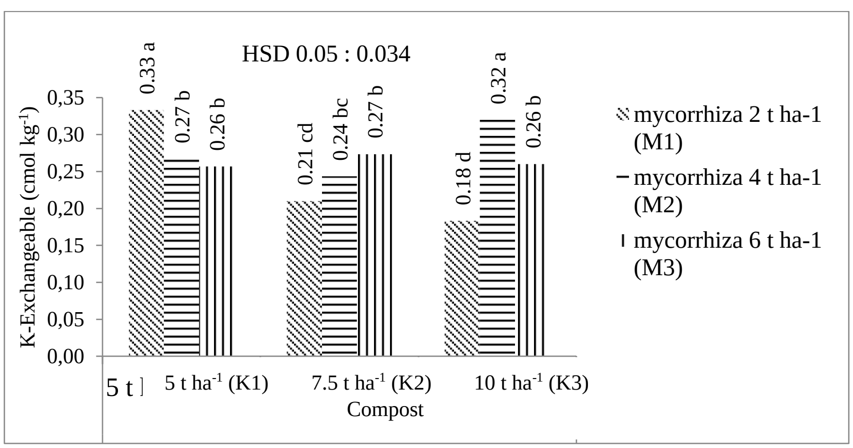

Fig. 7. Effect of OPEFB compost on soil K-Exchangeable

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). Based on 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.

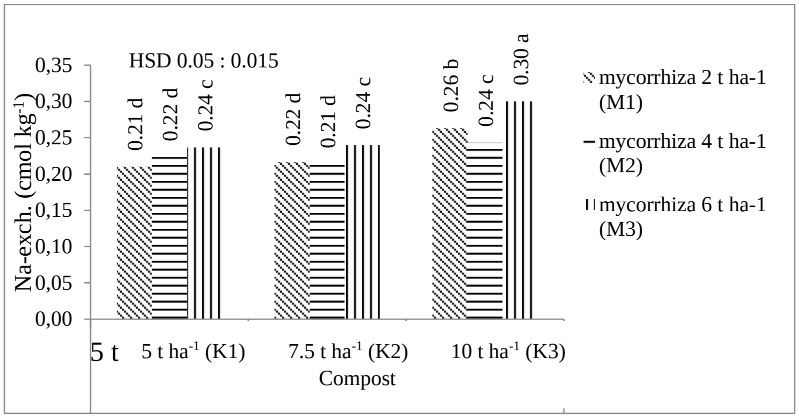

Fig. 8. Effect of OPEFB compost and MVA on soil Na-Exchangeable

Compost and MVA treatment had a significant effect on the decrease in 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 indicates that the addition of OPEFB compost and MVA can reduce the aluminum content in the soil. This is in correlate with the opinion of Tan (2010) which 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 mineral soils that have a pH <5.0, most of which colloidal complexes are negatively charged (Hanafiah, 2010).

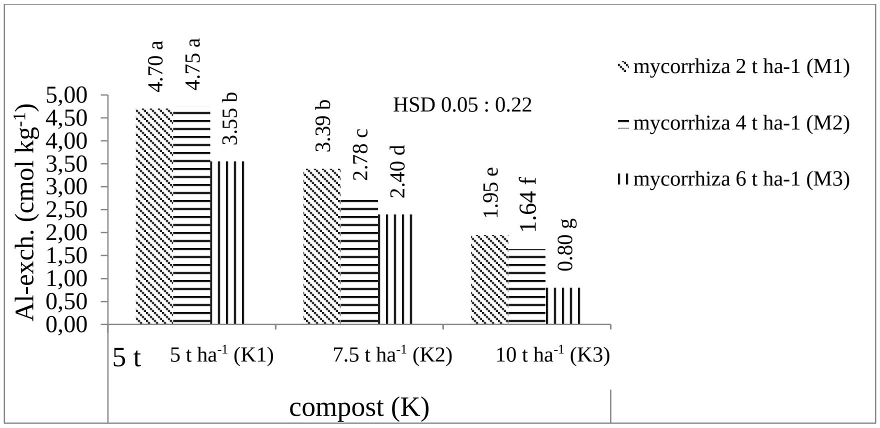

Fig. 9. Effect of OPEFB compost and MVA on soil Al-exchangeable

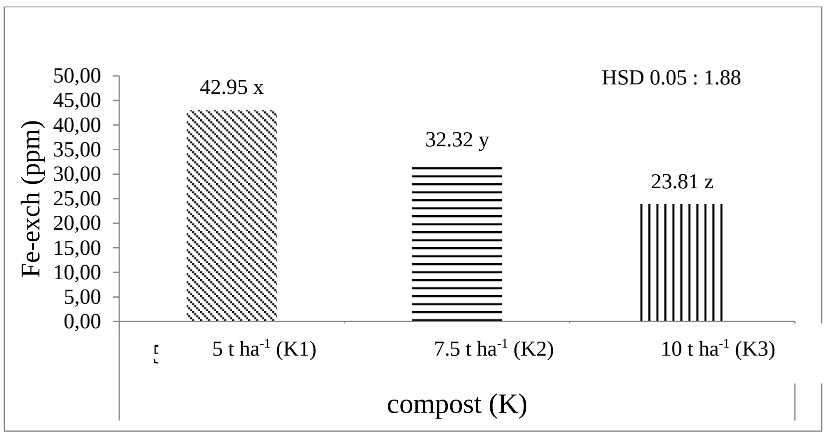

Fig. 10. Effect of OPEFB compost on soil Fe-exchangeable

In addition to the significantly decreased Al-exch content, the chemical parameter of the soil that decreased with the compost treatment was Fe-exch. Analysis of variance showed that the treatment of OPEFB compost had a significant effect on reducing soil Fe-Exch levels (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t 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 which was classified as very high, all compost and MVA treatments had a significant effect on the decrease in Fe-Exch.

Effect of treatments on plant growth of *Calopogonium mucunoide*s

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 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, 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 gets 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 in 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)

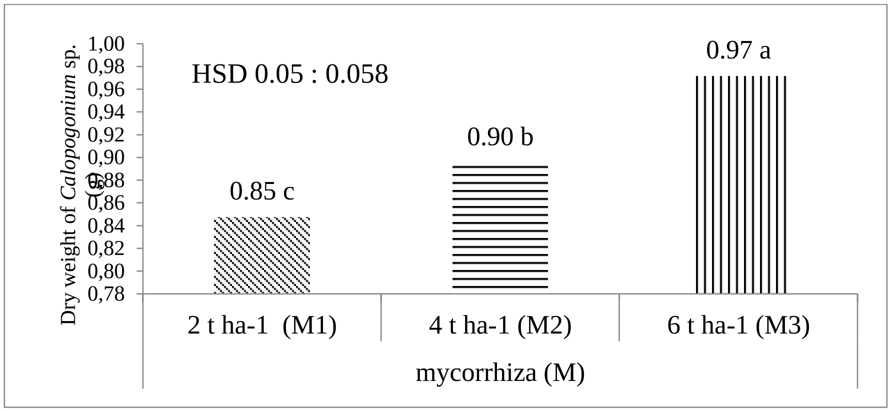

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 t 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 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 post-mining soil properties. Suharno & Suncayaningsih dan Suharno (2013) also found that MVA can also assist in the photo-remediation process on soil contaminated with heavy metals.

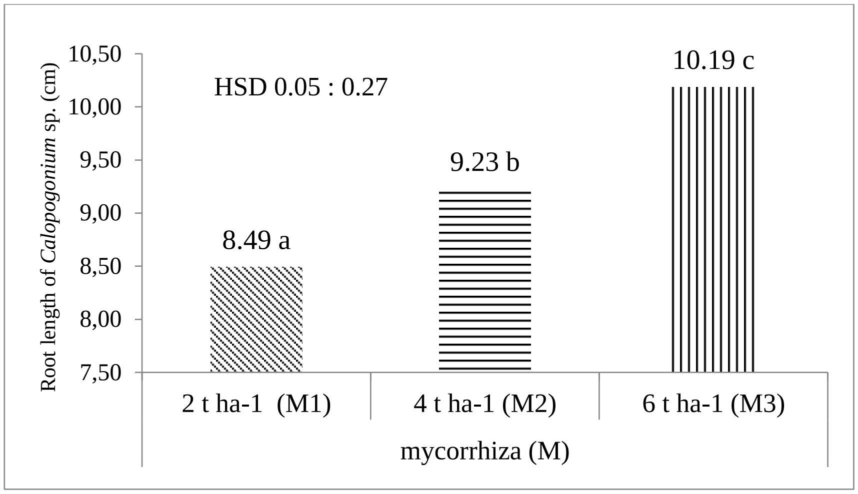

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

Infection and spores observation of MVA

The results of the observation of the percentage of MVA infection on the roots of the plant *Calopogonium mucunoides* 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 increase in 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 found in the soil after treatments are 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 was influenced by several factors, including the physical and chemical properties of the soil.

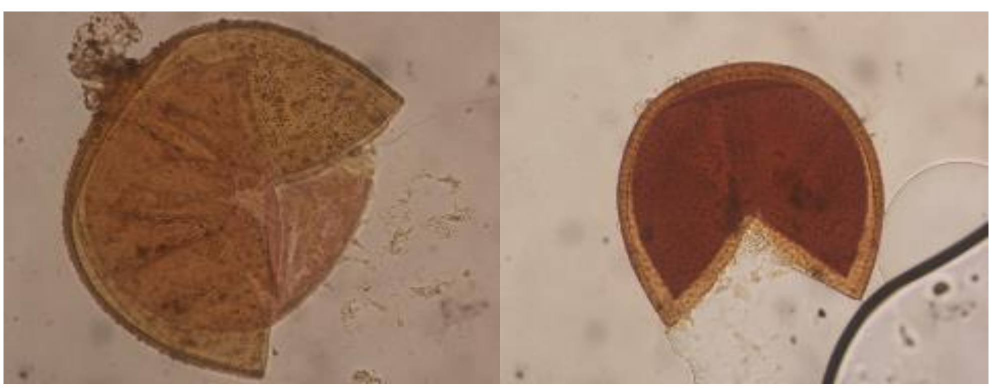

Fig. 13. Morphotype *Acalauspora sp* . dominantly found in the soil

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

Based on 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 ha^{-1} and MVA 6 t 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).

Conclusion

The results of this study can be concluded that the use of OPEFB compost 10 t ha^{-1} and MVA 6 t 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.*

Acknowledgment

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References

Abdullah, S., Y Musa, T Kuswinanti, M Jayadi, R Neswati. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology 21(39&40):82-91; 2020

Adetunjia, AT, B Ncubeb, R Mulidzic, FB Lewud. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research. V.204. 104717. https://doi.org/10.1016/j.still.2020.104717.

Allo K. M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4 (2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.

Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia. ISBN 978-602-8039-21-5. 234p.

Balai Penelitian Tanah, 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. 32 (4): 9-10. Bogor. Indonesia

Begum, N., Cheng Qin., M. A. Ahangar., S. Raza., M. I. Khan., M. Ashraf., N. Ahmed., L Zhang. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci. Vol.10. https://doi.org/10.3389/fpls.2019.01068.

Charisma A., Yuni S.R., & Isnawati (2012). Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. *Lantera Bio* Volume 1, Nomor 3, September 2012, Hal: 111 – 116

Chen, Y., Li, D., Li, D., Wu, X., & Zheng, Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi. org/10.1016/j.mcm.2010.11.054

Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

Gandahi, A. W & M. M. Hanafi. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland. pp.209-243. DOI:10.1007/978-3-319-08004-8.

Ghaida, S.H, B Wasis, S W Budi. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282-290.

Ghose, M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research. Vol.63. p.1006-1009. https://doi.org/10.1002/tqem.20150.

Goltapeth, E M, Y Z Danesh, R. Prasad, A. Varma. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A, Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

Hakim, N., Y. Nyakpa., A. Lubis., S. Nugroho., M. Saul., M A Diha., G B Hong and H H Bailey. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

Hakim, N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press. 204 p.

Hastuti, P.H, S. M. Rohmiyati. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal Vol 4 No.2. pp. 59-64.

Husna, F.D. Tuheteru, A. Arif. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity. Vol 22 No.9. https://doi.org/10.13057/biodiv/d220930.

Islami, T., W.H Utomo. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang

Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag 1:43-50.

Mahyudin, R.P., M Firmansyah, M A Purwanti, D Najmina. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering. Volume 21, Issue 5, p 221–228 https://doi.org/10.12911/22998993/122566.

Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian. Vol 29 No. 4. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154-158. p. 154-158.

Nakajima, K., K Nansai, K Matsubae, M Tomita, W Takayanagi, T Nagasaka. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment. 586. p730-737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.

Nakhone, LN, M.A Tabatabai. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S. 171: 231-241.

Ningtyas, VA., and YA Lia. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (Volvarella Volvaceae) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology. Surabaya.

Noli, ZA, Netty, WS, EM Sari. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.

Prayogo, C., M Ihsan. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management. Volume 6, number 1. doi:10.15243/jdmlm.2018.061.152.

Puspitasari D., K. Indah and H. Anton. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya. Vol 1. No. 2, September 2012

Riniarti, D., Kusumastuty, A., & Utoyo, B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research. Vol 12, No. 3, p187-195.

Rosmimi, 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.

Samsi N., Y.S Pata'dungan, A.R Tah, 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal. Vol 5, No. 2.

Sarrantonio, M., E.R. Gallandt. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production 8(1): 53-74. DOI: 10.1300/J144v08n01_04.

Sembiring, S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra. 5(2): 123-134.

Suherman, C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.

Suncayaningsih, R P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology. Vol. 10, No. 1, Pages: 31 – 42.

Sutanto, A., A.E Prasetyo, Fahroidayanti, A.F Lubis, and A.P Dongoran. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research. Vol. 13, No. 1. p. 25-33.

Tan, K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup . Boca Raton. London. New York. 362 p.

Umaternate, G.R, J Abidjulid, A D Wuntu,. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), p. 6-10. doi: https://doi.org/10.35799/jm.3.1.2014.3898.

Zaeni, A, Alwahab, Hasmawati, S Hade , Irnawati, P E Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. 1899-012031. IOP Publishing doi:10.1088/1742-6596/1899/1/012031.

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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 so that it requires appropriate site-specific management so that it can be optimized as a plant cultivation area. This study aims 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 ha-1 (K1), 7.5 t ha-1 (K2), 10 t ha-1 (K3) and the second factor was mycorrhiza (M) in the fine-crushed brick carrier media as many as 3 treatments consisting of 2 t ha-1 (M1), 4 t ha-1 (M2), 6 t 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 P2O5, calcium and magnesium exchangeable, and decreasing exchangeable aluminium and iron. The highest soil properties values were found in the combination of compost 10 t ha-1 (K3) and MVA 6 t 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. Nickel post mining soils made formed from ultra-mafic nickel have lower potential compared to other developing soils, because these soil reaction acidic to very acidic, and have low cation exchange capacity (Allo, 2016). One of the efforts to manage 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 vesicular 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). 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 does not cause environmental pollution, and also play an active role in the nutrient cycle (Herawati et al., 2021). 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 (bricks fine-crushed) 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. Soil samples were obtained from the nickel mine of PT Vale Indonesia (PTVI) located in Sorowako Village, Nuha District, East Luwu Regency at coordinates 121°21′11.838″ E and 02°33′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. OPEFB compost is made using the Berkeley method, which is to the 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. Soil sample 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). Spore density analyzed using the wet sieved method. Parameters of *Calapogonium mucunoides* plants that were measured 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%.

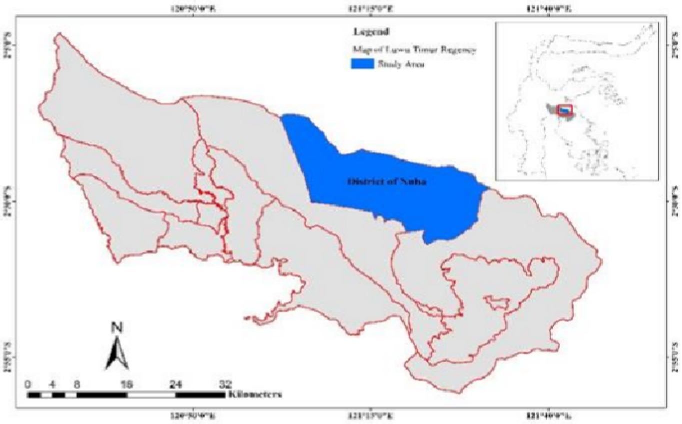

Fig 1. Soil Sampling Location

Results & Discussion

This study uses 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 the post-nickel soil sample are shown in Table 1.

Table 1. The results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil Characteristics	**Value**	**Criteria***
pH (soil reaction)		
• H_2O	5.47	Slightly acid
• KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 cmol kg^{-1}	Low
Exchangeable basic cations		
• Ca	3.83 [illegible]	Low
• Mg	6.67 [illegible]	High
• K	0.22 [illegible]	Low
• Na	0.21 [illegible]	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)

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 Umaternate et al. (2014) 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

Compost treatment had a significant effect on the average increase of SOC (Fig. 2) and the highest was found in the compost treatment (K3) worth 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 in the soil. Compost treatment also increases SOC in the soil because 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 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.

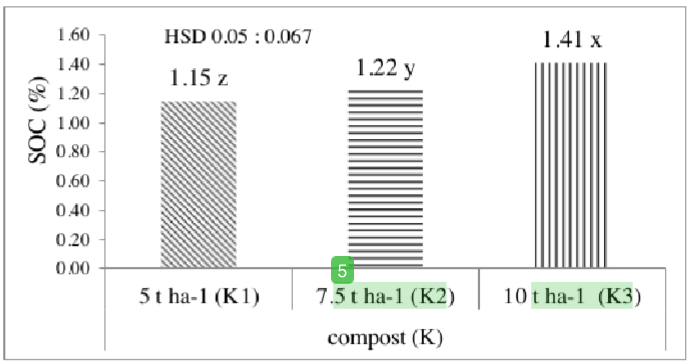

Fig 2. Effect of OPEFB compost on SOC

The effect of adding OPEFB compost was also significant for the increase in 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 14.51cmol kg^{-1}. This indicates that the increase in soil CEC value is strongly influenced by the addition of 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).

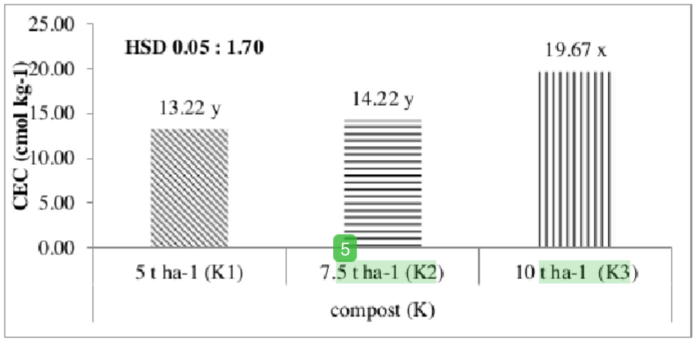

Fig. 3. Effect of TKSS compost on soil CEC

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 Fig. 4. The results of the 95% HSD Tukey test as shown in 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 OPEFB compost. According to Ningtyas & Lia (2010), OPEFB compost contains macro nutrients, namely 2.15% for N-Total; 1.54% for P2 O5 ; 0:15% for K2O; and contains a small amount of micro elements such as Cu, Zn, Mn, Fe, Bo and Mo. Gandahi &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.

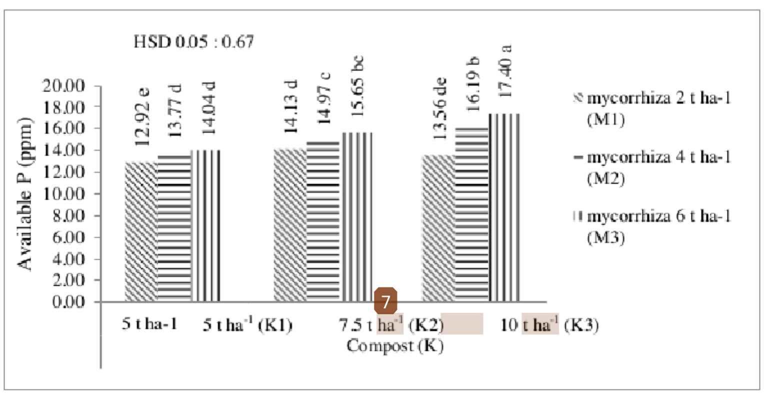

Fig. 4. Effect of OPEFB and MVA compost on the soil available-P

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.

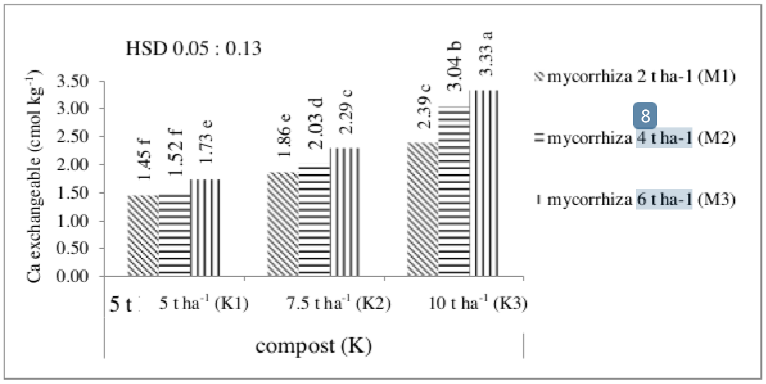

Fig. 5. Effect of OPEFB and MVA compost treatment on soil Ca- exchangeable

In addition, the effect of compost treatment also significantly affected Mg-exch levels as shown in Figure 6. The results of the 95% HSD Tukey test showed that the compost treatment of 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 soils that have high acidity.

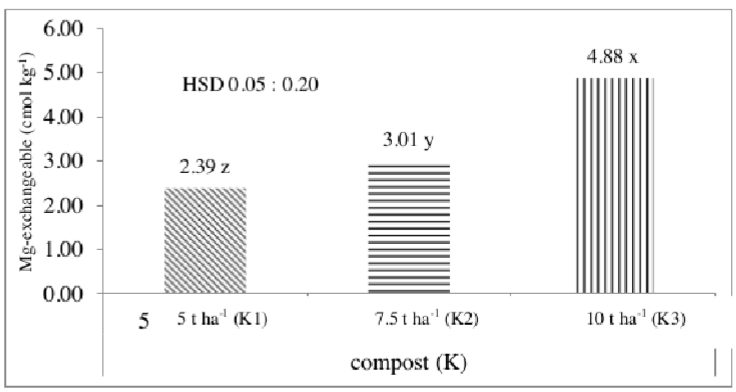

Fig.6. Effect of OPEFB compost on soil Mg-exchangeable

The results of the analysis showed that there was a very significant interaction between 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 OPEFB compost. This is in line with the opinion of Suherman (2007) that OPEFB compost is organic material that contains the main nutrients N, P, K and Mg and contains micro nutrients. This statement is reinforced by the opinion of Rosmimi (2000) who says that compost given to the soil will decompose to produce compounds and nutrients that are available to plants. The nutrient content of 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.

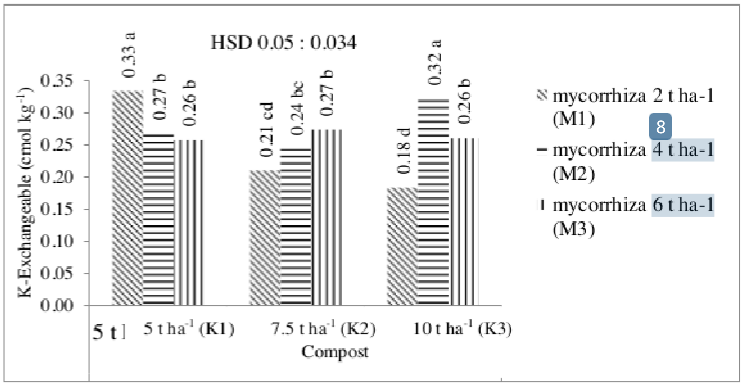

Fig. 7. Effect of OPEFB compost on soil K-Exchangeable

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). Based on 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.

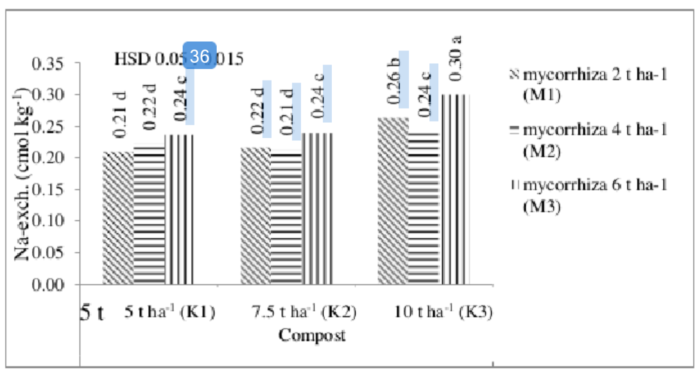

Fig. 8. Effect of OPEFB compost and MVA on soil Na-Exchangeable

Compost and MVA treatment had a significant effect on the decrease in 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 indicates that the addition of OPEFB compost and MVA can reduce the aluminum content in the soil. This is in correlate with the opinion of Tan (2010) which 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 mineral soils that have a pH <5.0, most of which colloidal complexes are negatively charged (Hanafiah, 2010).

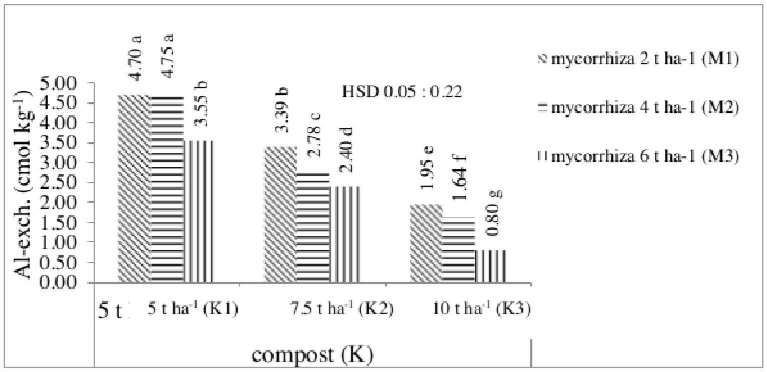

Fig. 9. Effect of OPEFB compost and MVA on soil Al-exchangeable

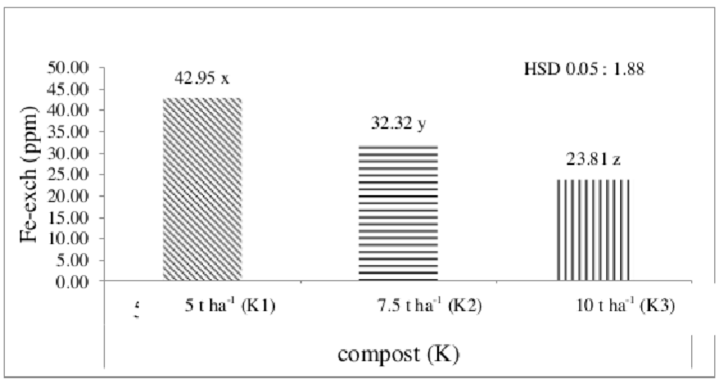

Fig. 10. Effect of OPEFB compost on soil Fe-exchangeable

In addition to the significantly decreased Al-exch content, the chemical parameter of the soil that decreased with the compost treatment was Fe-exch. Analysis of variance showed that the treatment of OPEFB compost had a significant effect on reducing soil Fe-Exch levels (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t 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 which was classified as very high, all compost and MVA treatments had a significant effect on the decrease in Fe-Exch.

Effect of treatments on plant growth of *Calopogonium mucunoides*

The results showed that the MVA treatment had a significant effect, while the OPEFB compost treatment and 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 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, 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 gets 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 in 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)

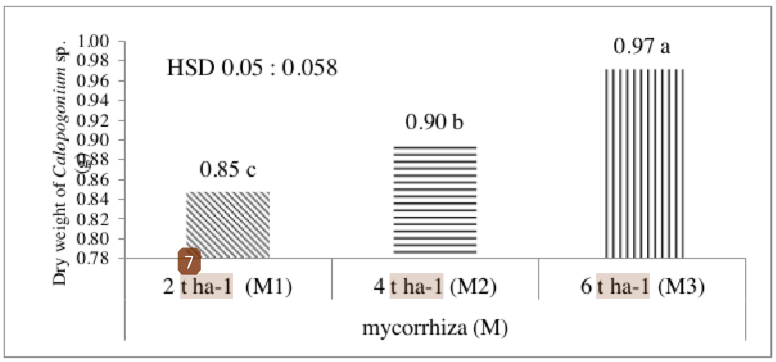

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 t 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 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 increased 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 post-mining soil properties. Suharno & Suncayaningsih dan Suharno (2013) also found that MVA can also assist in the photo-remediation process on soil contaminated with heavy metals.

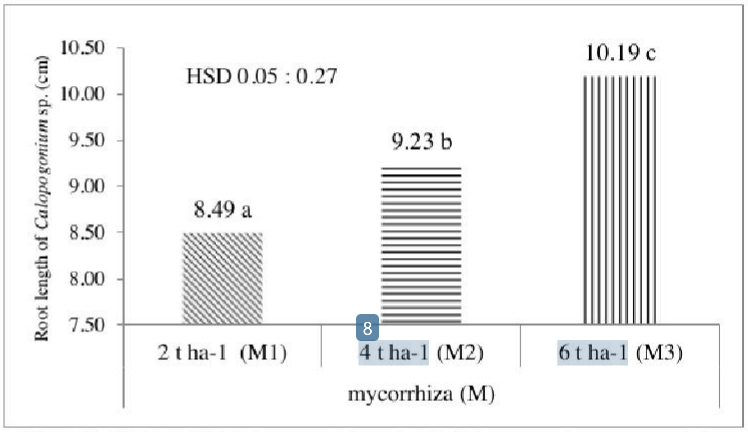

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

Infection and spores observation of MVA

The results of the observation of the percentage of MVA infection on the roots of the plant *Calopogonium mucunoides* 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 increase in 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 found in the soil after treatments are 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 was influenced by several factors, including the physical and chemical properties of the soil.

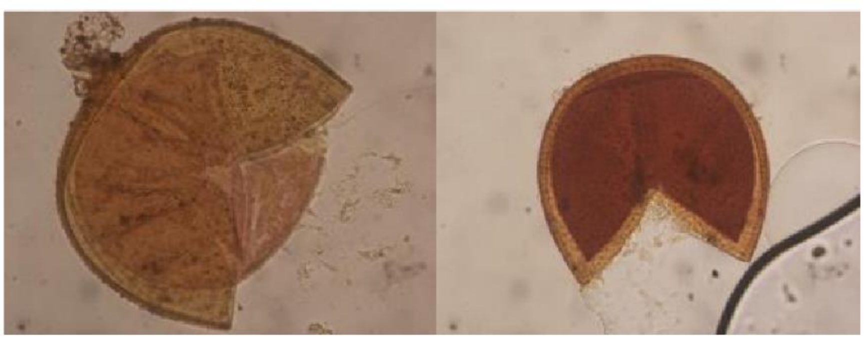
Fig. 13. Morphotype *Acalauspora sp* . dominantly found in the soil

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

Treatment	Morphotype	Spore Count	Total
[illegible]	Small Yellow Round	5	5
[illegible]	Small Yellow Round	6	6
[illegible]	Small Yellow Round	9	9
[illegible]	Small Yellow Round	4	4
[illegible]	Small Yellow Round	23	23
[illegible]	Small Yellow Round	25	25
[illegible]	Small Yellow Round	16	16
K3M2	Small Yellow Round	7	9
	Small Clear Round	2	
K3M3	Small Yellow Round	99	99

Based on 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 ha^{-1} and MVA 6 t 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).

Conclusion

The results of this study can be concluded that the use of OPEFB compost 10 t ha^{-1} and MVA 6 t 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*.

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References

Abdullah, S., Y Musa, T Kuswinanti, M Jayadi, R Neswati. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology 21(39&40):82-91; 2020

Adetunjia, AT, B Ncubeb, R Mulidzic, FB Lewud. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research. V.204. 104717. https://doi.org/10.1016/j.still.2020.104717.

Allo K. M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4 (2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.

Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia. ISBN 978-602-8039-21-5. 234p.

Balai Penelitian Tanah, 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. 32 (4): 9-10. Bogor. Indonesia

Begum, N., Cheng Qin., M. A. Ahangar., S. Raza., M. I. Khan., M. Ashraf., N. Ahmed., L Zhang. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci. Vol.10. https://doi.org/10.3389/fpls.2019.01068.

Charisma A., Yuni S.R., & Isnawati (2012). Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. *Lantera Bio* Volume 1, Nomor 3, September 2012, Hal: 111 – 116

Chen, Y., Li, D., Li, D., Wu, X., & Zheng, Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi. org/10.1016/j.mcm.2010.11.054

Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

Gandahi, A. W & M. M. Hanafi. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland. pp.209-243. DOI:10.1007/978-3-319-08004-8.

Ghaida, S.H, B Wasis, S W Budi. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282-290.

Ghose, M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research. Vol.63. p.1006-1009. https://doi.org/10.1002/tqem.20150.

Goltapeth, E M, Y Z Danesh, R. Prasad, A. Varma. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A, Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

Hakim, N., Y. Nyakpa., A. Lubis., S. Nugroho., M. Saul., M A Diha., G B Hong and H H Bailey. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

Hakim, N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press. 204 p.

Hastuti, P.H, S. M. Rohmiyati. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal Vol 4 No.2. pp. 59-64.

Husna, F.D. Tuheteru, A. Arif. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity. Vol 22 No.9. https://doi.org/10.13057/biodiv/d220930.

Islami, T., W.H Utomo. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang

Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag 1:43-50.

Mahyudin, R.P., M Firmansyah, M A Purwanti, D Najmina. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering. Volume 21, Issue 5, p 221–228 https://doi.org/10.12911/22998993/122566.

Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian. Vol 29 No. 4. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154-158. p. 154-158.

Nakajima, K., K Nansai, K Matsubae, M Tomita, W Takayanagi, T Nagasaka. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment. 586. p730-737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.

Nakhone, LN, M.A Tabatabai. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S. 171: 231-241.

Ningtyas, VA., and YA Lia. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (Volvarella Volvaceae) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology. Surabaya.

Noli, ZA, Netty, WS, EM Sari. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.

Prayogo, C., M Ihsan. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management. Volume 6, number 1. doi:10.15243/jdmlm.2018.061.152.

Puspitasari D., K. Indah and H. Anton. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya. Vol 1. No. 2, September 2012

Riniarti, D., Kusumastuty, A., & Utoyo, B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research. Vol 12, No. 3, p187-195.

Rosmimi, 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.

Samsi N., Y.S Pata'dungan, A.R Tah, 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal. Vol 5, No. 2.

Sarrantonio, M., E.R. Gallandt. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production 8(1): 53-74. DOI: 10.1300/J144v08n01_04.

Sembiring, S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra. 5(2): 123-134.

Suherman, C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.

Suncayaningsih, R P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology. Vol. 10, No. 1, Pages: 31 – 42.

Sutanto, A., A.E Prasetyo, Fahroidayanti, A.F Lubis, and A.P Dongoran. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research. Vol. 13, No. 1. p. 25-33.

Tan, K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup . Boca Raton. London. New York. 362 p.

Umaternate, G.R, J Abidjulid, A D Wuntu,. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), p. 6-10. doi: https://doi.org/10.35799/jm.3.1.2014.3898.

Zaeni, A, Alwahab, Hasmawati, S Hade , Irnawati, P E Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. 1899-012031. IOP Publishing doi:10.1088/1742-6596/1899/1/012031.

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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 so that it requires appropriate site-specific management so that it can be optimized as a plant cultivation area. This study aims 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 ha^{-1} (K1), 7.5 t ha^{-1} (K2), 10 t ha^{-1} (K3) and the second factor was mycorrhiza (M) in the fine-crushed brick carrier media as many as 3 treatments consisting of 2 t ha^{-1} (M1), 4 t ha^{-1} (M2), 6 t 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, and decreasing exchangeable aluminium and iron. The highest soil properties values were found in the combination of compost 10 t ha^{-1} (K3) and MVA 6 t 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. Nickel post mining soils made formed from ultra-mafic nickel have lower potential compared to other developing soils, because these soil reaction acidic to very acidic, and have low cation exchange capacity (Allo, 2016). One of the efforts to manage 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). 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 does not cause environmental pollution, and also play an active role in the nutrient cycle (Herawati et al., 2021). 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 (bricks fine-crushed) 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. Soil samples were obtained from the nickel mine of PT Vale Indonesia (PTVI) located in 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. 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. Soil sample 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). Spore density analyzed using the wet sieved method. Parameters of *Calapogonium mucunoides* plants that were measured 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%.

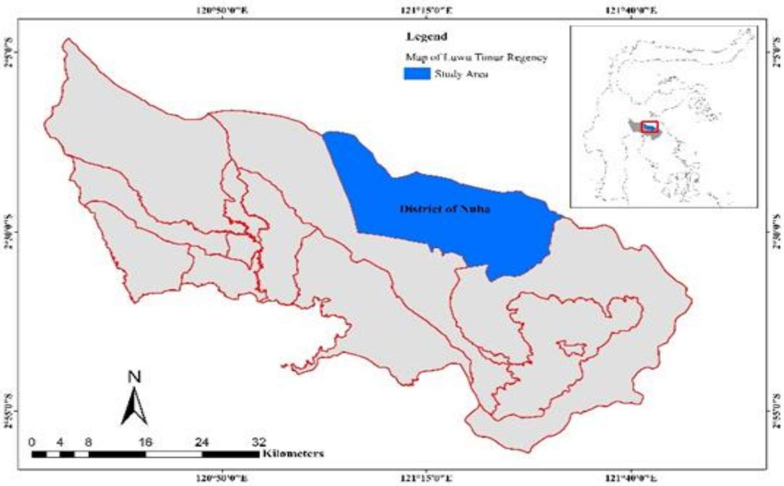

Fig 1. Soil Sampling Location

Results & Discussion

This study uses 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 the post-nickel soil sample are shown in Table 1.

Table 1. The results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil Characteristics	**Value**	**Criteria***
pH (soil reaction)		
• H_2O	5.47	Slightly acid
• KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 cmol kg^{-1}	Low
Exchangeable basic cations		
• 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)

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) 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

Compost treatment had a significant effect on the average increase of SOC (Fig. 2) and the highest was found in the compost treatment (K3) worth 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 in the soil. Compost treatment also increases SOC in the soil because 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 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.

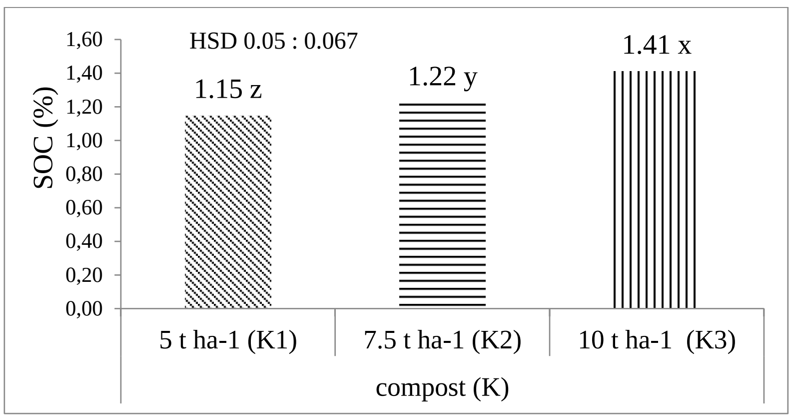

Fig 2. Effect of OPEFB compost on SOC

The effect of adding OPEFB compost was also significant for the increase in 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 14.51cmol kg^{-1}. This indicates that the increase in soil CEC value is strongly influenced by the addition of 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).

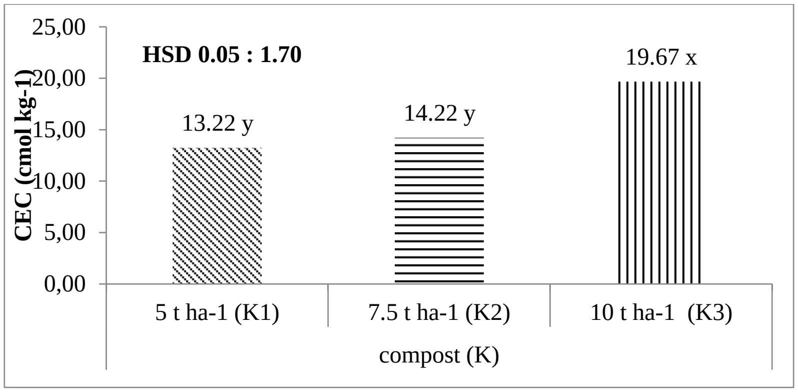

Fig. 3. Effect of TKSS compost on soil CEC

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 Fig. 4. The results of the 95% HSD Tukey test as shown in 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 OPEFB compost. According to Ningtyas & Lia (2010), OPEFB compost contains macro nutrients, namely 2.15% for N-Total; 1.54% for P2 O5 ; 0:15% for K2O; and contains a small amount of micro elements such as Cu, Zn, Mn, Fe, Bo and Mo. Gandahi &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.

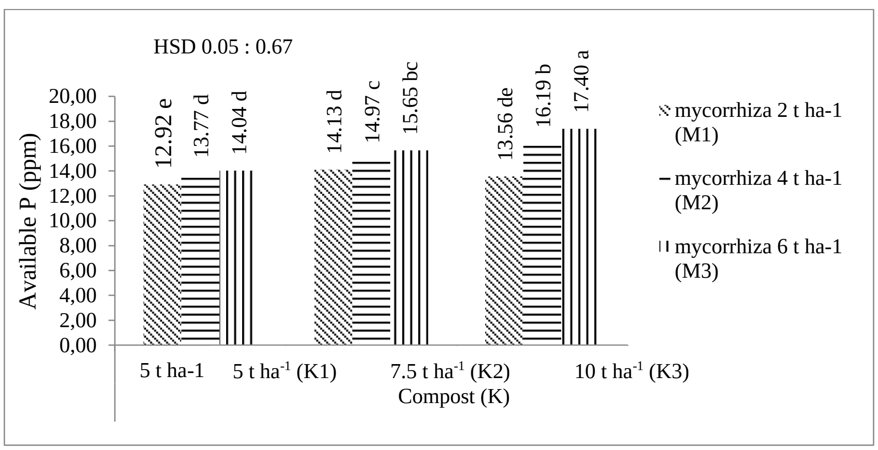

Fig. 4. Effect of OPEFB and MVA compost on the soil available-P

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.

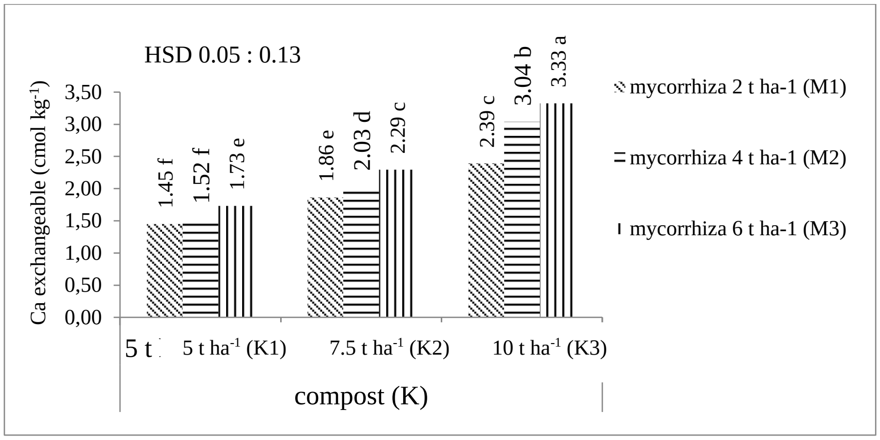

Fig. 5. Effect of OPEFB and MVA compost treatment on soil Ca- exchangeable

In addition, the effect of compost treatment also significantly affected Mg-exch levels as shown in Figure 6. The results of the 95% HSD Tukey test showed that the compost treatment of 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 soils that have high acidity.

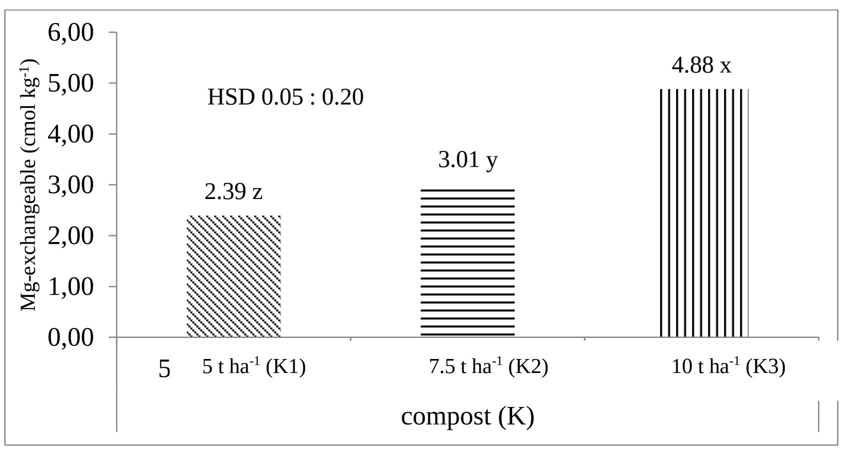

Fig.6. Effect of OPEFB compost on soil Mg-exchangeable

The results of the analysis showed that there was a very significant interaction between 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 OPEFB compost. This is in line with the opinion of Suherman (2007) that OPEFB compost is organic material that contains the main nutrients N, P, K and Mg and contains micro nutrients. This statement is reinforced by the opinion of Rosmimi (2000) who says that compost given to the soil will decompose to produce compounds and nutrients that are available to plants. The nutrient content of 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.

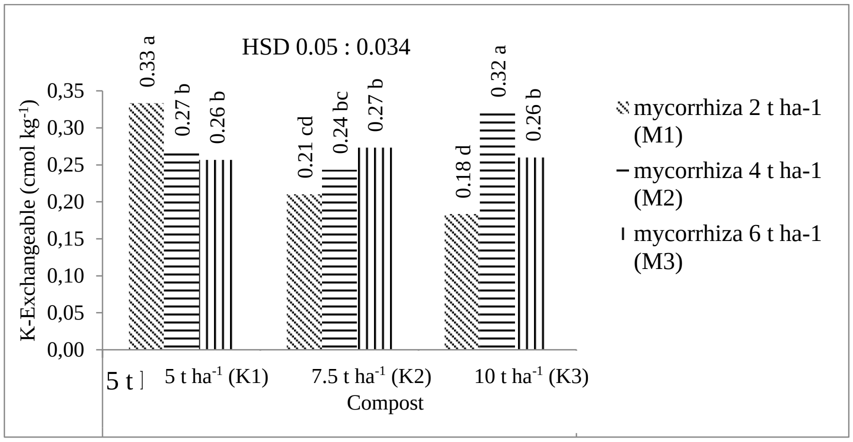

Fig. 7. Effect of OPEFB compost on soil K-Exchangeable

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). Based on 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.

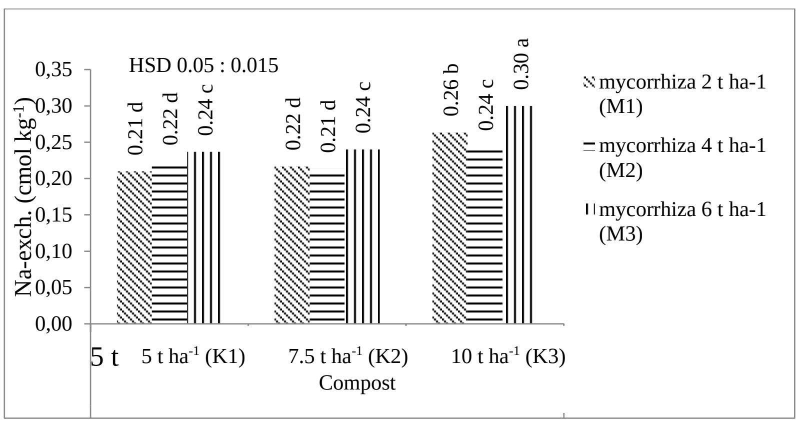

Fig. 8. Effect of OPEFB compost and MVA on soil Na-Exchangeable

Compost and MVA treatment had a significant effect on the decrease in 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 indicates that the addition of OPEFB compost and MVA can reduce the aluminum content in the soil. This is in correlate with the opinion of Tan (2010) which 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 mineral soils that have a pH <5.0, most of which colloidal complexes are negatively charged (Hanafiah, 2010).

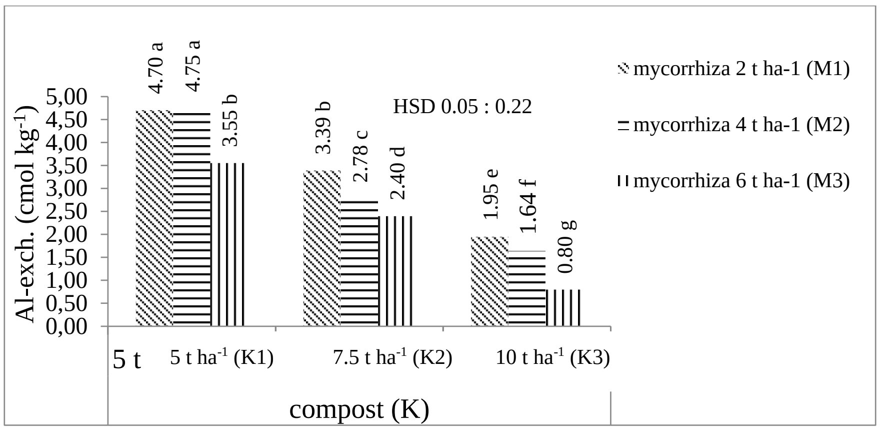

Fig. 9. Effect of OPEFB compost and MVA on soil Al-exchangeable

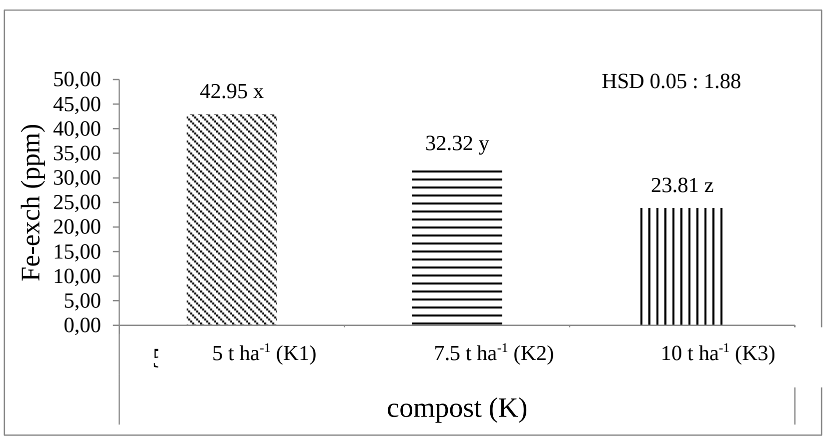

Fig. 10. Effect of OPEFB compost on soil Fe-exchangeable

In addition to the significantly decreased Al-exch content, the chemical parameter of the soil that decreased with the compost treatment was Fe-exch. Analysis of variance showed that the treatment of OPEFB compost had a significant effect on reducing soil Fe-Exch levels (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t 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 which was classified as very high, all compost and MVA treatments had a significant effect on the decrease in Fe-Exch.

Effect of treatments on plant growth of *Calopogonium mucunoide*s

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 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, 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 gets 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 in 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)

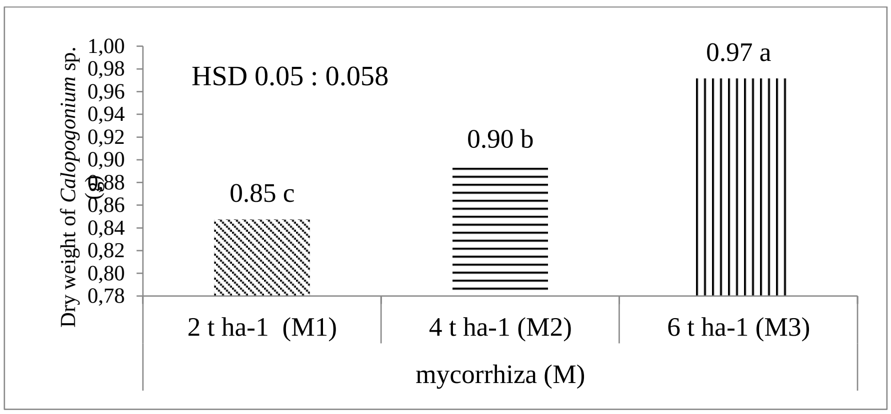

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 t 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 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 post-mining soil properties. Suharno & Suncayaningsih dan Suharno (2013) also found that MVA can also assist in the photo-remediation process on soil contaminated with heavy metals.

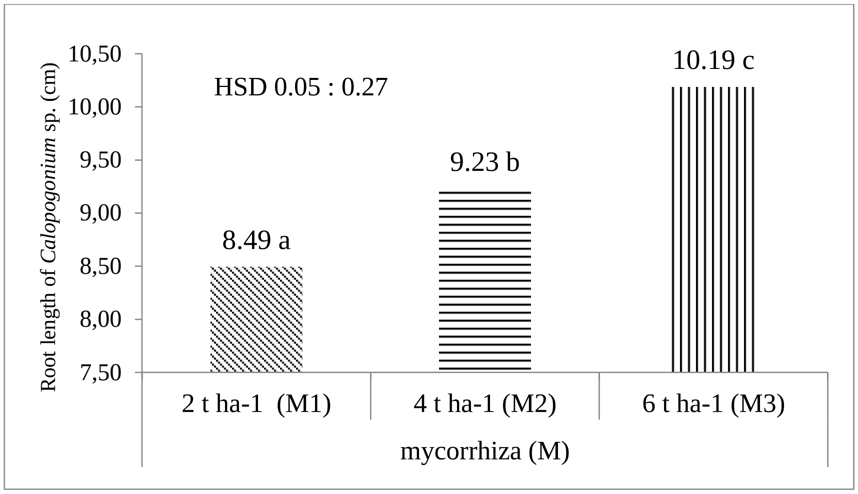

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

Infection and spores observation of MVA

The results of the observation of the percentage of MVA infection on the roots of the plant *Calopogonium mucunoides* 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 increase in 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 found in the soil after treatments are 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 was influenced by several factors, including the physical and chemical properties of the soil.

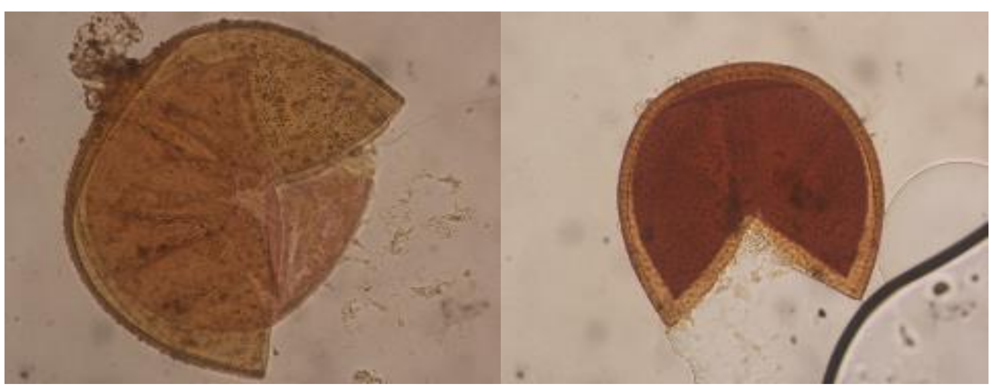

Fig. 13. Morphotype *Acalauspora sp* . dominantly found in the soil

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

Based on 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 ha^{-1} and MVA 6 t 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).

Conclusion

The results of this study can be concluded that the use of OPEFB compost 10 t ha^{-1} and MVA 6 t 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.*

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References

Abdullah, S., Y Musa, T Kuswinanti, M Jayadi, R Neswati. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology 21(39&40):82-91; 2020

Adetunjia, AT, B Ncubeb, R Mulidzic, FB Lewud. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research. V.204. 104717. https://doi.org/10.1016/j.still.2020.104717.

Allo K. M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4 (2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.

Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia. ISBN 978-602-8039-21-5. 234p.

Balai Penelitian Tanah, 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. 32 (4): 9-10. Bogor. Indonesia

Begum, N., Cheng Qin., M. A. Ahangar., S. Raza., M. I. Khan., M. Ashraf., N. Ahmed., L Zhang. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci. Vol.10. https://doi.org/10.3389/fpls.2019.01068.

Charisma A., Yuni S.R., & Isnawati (2012). Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. *Lantera Bio* Volume 1, Nomor 3, September 2012, Hal: 111 – 116

Chen, Y., Li, D., Li, D., Wu, X., & Zheng, Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi. org/10.1016/j.mcm.2010.11.054

Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

Gandahi, A. W & M. M. Hanafi. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland. pp.209-243. DOI:10.1007/978-3-319-08004-8.

Ghaida, S.H, B Wasis, S W Budi. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282-290.

Ghose, M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research. Vol.63. p.1006-1009. https://doi.org/10.1002/tqem.20150.

Goltapeth, E M, Y Z Danesh, R. Prasad, A. Varma. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A, Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

Hakim, N., Y. Nyakpa., A. Lubis., S. Nugroho., M. Saul., M A Diha., G B Hong and H H Bailey. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

Hakim, N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press. 204 p.

Hastuti, P.H, S. M. Rohmiyati. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal Vol 4 No.2. pp. 59-64.

Husna, F.D. Tuheteru, A. Arif. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity. Vol 22 No.9. https://doi.org/10.13057/biodiv/d220930.

Islami, T., W.H Utomo. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang

Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag 1:43-50.

Mahyudin, R.P., M Firmansyah, M A Purwanti, D Najmina. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering. Volume 21, Issue 5, p 221–228 https://doi.org/10.12911/22998993/122566.

Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian. Vol 29 No. 4. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154-158. p. 154-158.

Nakajima, K., K Nansai, K Matsubae, M Tomita, W Takayanagi, T Nagasaka. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment. 586. p730-737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.

Nakhone, LN, M.A Tabatabai. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S. 171: 231-241.

Ningtyas, VA., and YA Lia. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (Volvarella Volvaceae) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology. Surabaya.

Noli, ZA, Netty, WS, EM Sari. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.

Prayogo, C., M Ihsan. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management. Volume 6, number 1. doi:10.15243/jdmlm.2018.061.152.

Puspitasari D., K. Indah and H. Anton. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya. Vol 1. No. 2, September 2012

Riniarti, D., Kusumastuty, A., & Utoyo, B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research. Vol 12, No. 3, p187-195.

Rosmimi, 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.

Samsi N., Y.S Pata'dungan, A.R Tah, 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal. Vol 5, No. 2.

Sarrantonio, M., E.R. Gallandt. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production 8(1): 53-74. DOI: 10.1300/J144v08n01_04.

Sembiring, S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra. 5(2): 123-134.

Suherman, C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.

Suncayaningsih, R P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology. Vol. 10, No. 1, Pages: 31 – 42.

Sutanto, A., A.E Prasetyo, Fahroidayanti, A.F Lubis, and A.P Dongoran. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research. Vol. 13, No. 1. p. 25-33.

Tan, K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup . Boca Raton. London. New York. 362 p.

Umaternate, G.R, J Abidjulid, A D Wuntu,. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), p. 6-10. doi: https://doi.org/10.35799/jm.3.1.2014.3898.

Zaeni, A, Alwahab, Hasmawati, S Hade , Irnawati, P E Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. 1899-012031. IOP Publishing doi:10.1088/1742-6596/1899/1/012031.

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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. ~~so that~~ Thus, it requires appropriate site-specific management so that it can be optimized as a plant cultivation area. This study ~~aims~~ 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 ha-1 (K1), 7.5 t ha-1 (K2), 10 t 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 ha-1 (M1), 4 t ha-1 (M2), 6 t 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, ~~and~~ as well as decreasing exchangeable ~~aluminium~~aluminum and iron. The highest soil properties values were found in the combination of compost 10 t ha-1 (K3) and MVA 6 t 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 ~~N~~nickel post mining soils ~~made~~ formed from ultra-mafic nickel have lower potential compared to other developing soils, because the pH of these ~~soil reaction~~ ranges from acidic to very acidic; moreover, ~~and~~ 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 ~~T~~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

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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 ~~does~~ do not cause environmental pollution, and also play an active role in the nutrient cycle (Herawati et al., 2021). The ~~P~~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 (bricks fine-crushed) 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 ~~S~~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~~,~~. ~~t~~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 ~~S~~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 ~~S~~spore density was analyzed using the wet sieved method. The measured ~~P~~parameters of the *Calapogonium mucunoides* plants ~~that were measured~~ 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 ~~uses~~ 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 ~~the~~ post-nickel soil sample are shown in Table 1.

Table 1. The results of the analysis of the chemical properties of the post-nickel mine site of the study

*Criteria according to the Balai Penelitian Tanah (2009)

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 ~~C~~compost treatment had a significant effect on the average increase of SOC (Fig. 2) and the highest was found in the compost treatment (K3), ~~worth~~ reaching1.41% 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.

Fig 2. Effect of the OPEFB compost on SOC

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).

Fig. 3. Effect of TKSS compost on soil CEC

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 Fig. 4. The results of the 95% HSD Tukey test as shown in 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 &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.

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

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

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.

ig.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

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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 ~~and contains~~as well as micro nutrients. This statement is reinforced by the opinion of Rosmimi (2000) who says 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.

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

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). ~~Based~~ On the basis of~~on~~ 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.

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

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 ~~indicates~~ shows that the addition of the OPEFB compost and MVA can reduce the aluminum content in the soil. This ~~is in~~ correlates with the opinion of Tan (2010) ~~which~~ 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 ~~of which~~ colloidal complexes of which are negatively charged (Hanafiah, 2010).

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

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

In addition to the significantly decreased Al-exch 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 effect on reducing the soil Fe-Exch levels (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t 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 ~~which~~ i.e. was classified as very high, all compost and MVA treatments had a significant effect on the decrease in Fe-Exch.

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 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 ~~gets~~ 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 ~~in~~ 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)

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

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 t 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 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.

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

Infection and spores observation of MVA

The results of the observation of the percentage of MVA infection on the roots of the ~~plant~~ *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 increase in~~ 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 ~~are~~ 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 was influenced by several factors, including the physical and chemical properties of the soil.

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

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

~~Based~~ On the basis of ~~on~~ 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 ha $^{-1}$ and MVA 6 t 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 ha^{-1} and MVA 6 t 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.*

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References

Abdullah, S., Y Musa, T Kuswinanti, M Jayadi, R Neswati. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology 21(39&40):82-91; 2020

Adetunjia, AT, B Ncubeb, R Mulidzic, FB Lewud. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research. V.204. 104717. https://doi.org/10.1016/j.still.2020.104717.

Allo K. M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4 (2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.

Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia. ISBN 978-602-8039-21-5. 234p.

Balai Penelitian Tanah, 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. 32 (4): 9-10. Bogor. Indonesia

Begum, N., Cheng Qin., M. A. Ahangar., S. Raza., M. I. Khan., M. Ashraf., N. Ahmed., L Zhang. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci. Vol.10. https://doi.org/10.3389/fpls.2019.01068.

Charisma A., Yuni S.R., & Isnawati (2012). Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. *Lantera Bio* Volume 1, Nomor 3, September 2012, Hal: 111 – 116

Chen, Y., Li, D., Li, D., Wu, X., & Zheng, Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi. org/10.1016/j.mcm.2010.11.054

Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

Gandahi, A. W & M. M. Hanafi. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland. pp.209-243. DOI:10.1007/978-3-319-08004-8.

Ghaida, S.H, B Wasis, S W Budi. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282-290.

Ghose, M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research. Vol.63. p.1006-1009. https://doi.org/10.1002/tqem.20150.

Goltapeth, E M, Y Z Danesh, R. Prasad, A. Varma. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A, Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

Hakim, N., Y. Nyakpa., A. Lubis., S. Nugroho., M. Saul., M A Diha., G B Hong and H H Bailey. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

Hakim, N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press. 204 p.

Hastuti, P.H, S. M. Rohmiyati. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal Vol 4 No.2. pp. 59-64.
Husna, F.D. Tuheteru, A. Arif. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity. Vol 22 No.9. https://doi.org/10.13057/biodiv/d220930.
Islami, T., W.H Utomo. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang
Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag 1:43-50.
Mahyudin, R.P., M Firmansyah, M A Purwanti, D Najmina. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering. Volume 21, Issue 5, p 221–228 https://doi.org/10.12911/22998993/122566.
Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian. Vol 29 No. 4. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154-158. p. 154-158.
Nakajima, K., K Nansai, K Matsubae, M Tomita, W Takayanagi, T Nagasaka. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment. 586. p730-737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.
Nakhone, LN, M.A Tabatabai. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S. 171: 231-241.
Ningtyas, VA., and YA Lia. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (Volvarella Volvaceae) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology. Surabaya.
Noli, ZA, Netty, WS, EM Sari. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.
Prayogo, C., M Ihsan. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management. Volume 6, number 1. doi:10.15243/jdmlm.2018.061.152.
Puspitasari D., K. Indah and H. Anton. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya. Vol 1. No. 2, September 2012
Riniarti, D., Kusumastuty, A., & Utoyo, B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research. Vol 12, No. 3, p187-195.
Rosmimi, 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.
Samsi N., Y.S Pata'dungan, A.R Tah, 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal. Vol 5, No. 2.
Sarrantonio, M., E.R. Gallandt. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production 8(1): 53-74. DOI: 10.1300/J144v08n01_04.
Sembiring, S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra. 5(2): 123-134.
Suherman, C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.
Suncayaningsih, R P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology. Vol. 10, No. 1, Pages: 31 – 42.

Sutanto, A., A.E Prasetyo, Fahroidayanti, A.F Lubis, and A.P Dongoran. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research. Vol. 13, No. 1. p. 25-33.
Tan, K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup . Boca Raton. London. New York. 362 p.
Umaternate, G.R, J Abidjulid, A D Wuntu,. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), p. 6-10. doi: https://doi.org/10.35799/jm.3.1.2014.3898.
Zaeni, A, Alwahab, Hasmawati, S Hade , Irnawati, P E Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. 1899-012031. IOP Publishing doi:10.1088/1742-6596/1899/1/012031.

4.a. Email from publisher accepted with minor revisions (01-12-2021)

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JEENG-02771-2021-01
Using of oil palm empty fruit bunch compost and mycorrhizae arbuscular for improving the fertility of nickel post-mining soil

Dear Dr. Risma Neswati,

I am pleased to inform you that your manuscript, entitled: Using of oil palm empty fruit bunch compost and mycorrhizae arbuscular for improving the fertility of nickel post-mining soil, might be accepted for publication in our journal, pending some minor changes suggested by reviewers (see below).

Please revise your paper strictly according to the attached Reviewers comments. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Authors of our journal are requested to prepare a revised version of their manuscript as soon as possible. This may ensure fast publication if an article is finally accepted.

Thank you for submitting your work to us.

Kindest regards,
Prof. Gabriel Borowski
Editor-in-Chief
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- https://www.editorialsystem.com/dl/df/7231/a719c97a6294921e24f7dff7ab9d148f/ (Editor)

4.b. Manuscript with minor revisions

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 ha-1 (K1), 7.5 t ha-1 (K2), 10 t 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 ha-1 (M1), 4 t ha-1 (M2), 6 t 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 ha-1 (K3) and MVA 6 t 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.

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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),

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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.

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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 (bricks fine-crushed) 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%.

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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.

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Table 1. The results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil Characteristics	Value	Criteria*
pH (soil reaction)		
• H_2O	5.47	Slightly acid
• KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 cmol kg^{-1}	Low
Exchangeable basic cations		
• 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)

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.

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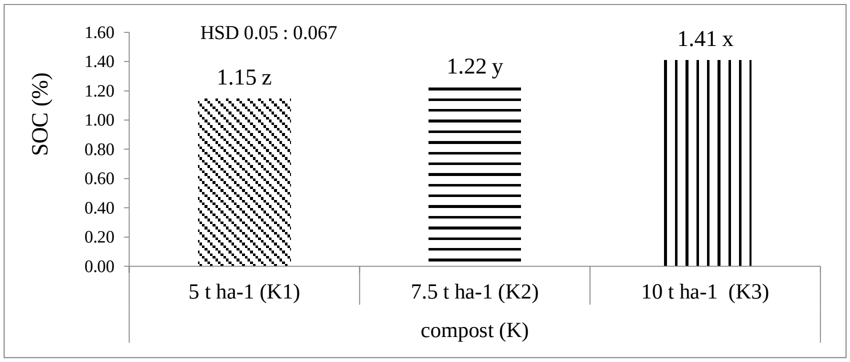

Fig 2. Effect of the OPEFB compost on SOC

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).

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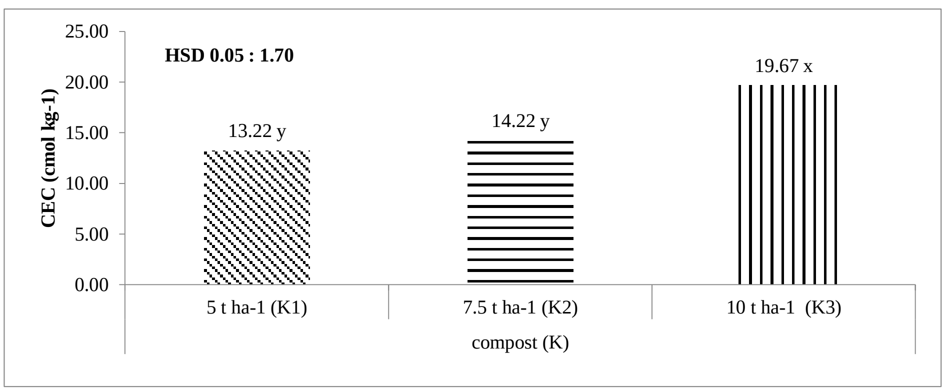

Fig. 3. Effect of TKSS compost on soil CEC

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 Fig. 4. The results of the 95% HSD Tukey test as shown in 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 &Hanafi (2014) stated that the availability of P

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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.

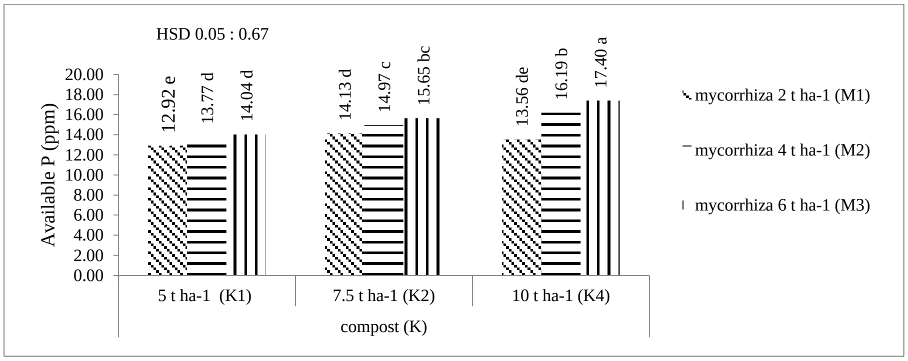

Fig. 4. Effect of the OPEFB and MVA compost on the soil available-P

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.

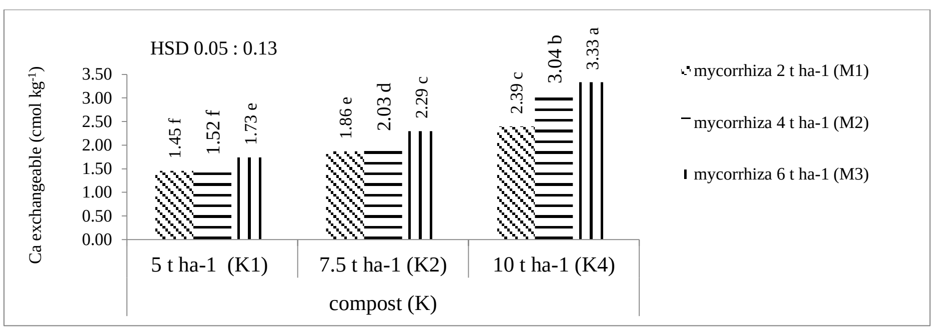

Fig. 5. Effect of the OPEFB and MVA compost treatment on soil Ca- exchangeable

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.

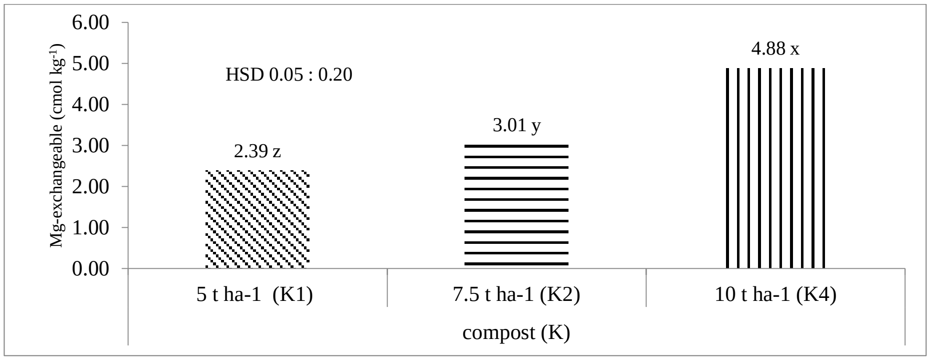

Figure.6. Effect of the OPEFB compost on soil Mg-exchangeable

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) who says 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.

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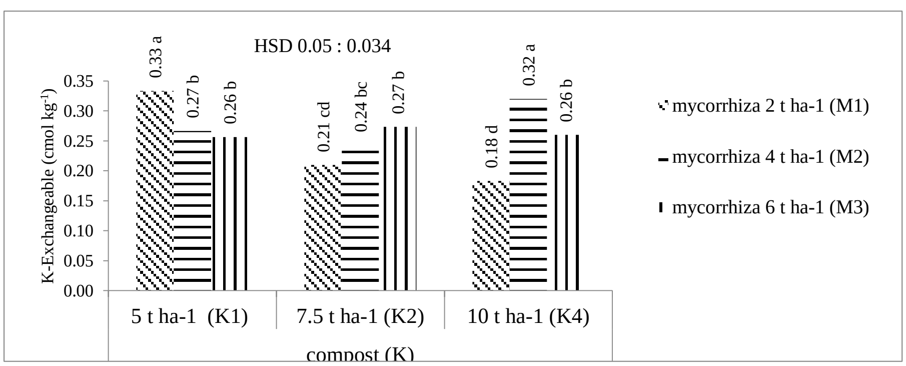

Fig. 7. Effect of the OPEFB compost on soil K-Exchangeable

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.

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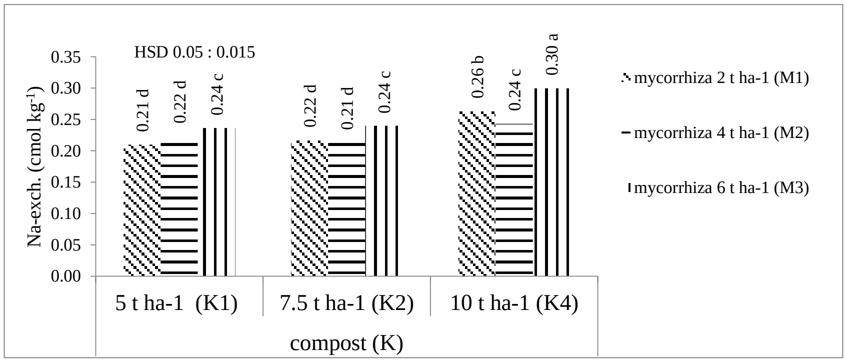

Fig. 8. Effect of the OPEFB compost and MVA on soil Na-Exchangeable

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).

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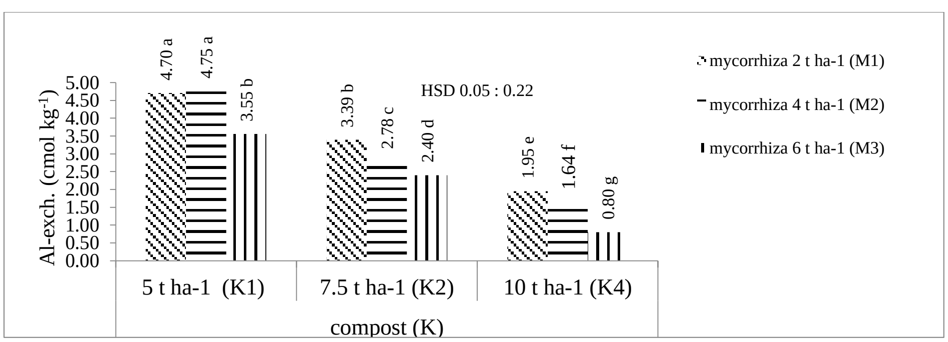

Fig. 9. Effect of the OPEFB compost and MVA on soil Al-exchangeable

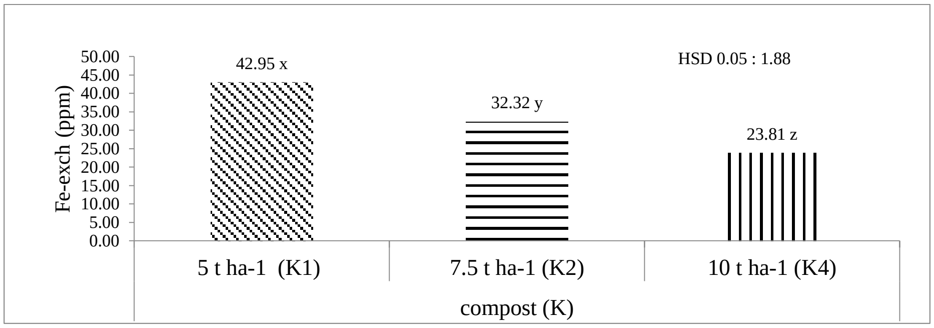

Fig. 10. Effect of the OPEFB compost on soil Fe-exchangeable

In addition to the significantly decreased Al-exch 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 effect on reducing the soil Fe-Exch levels (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t 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-Exch.

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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 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)

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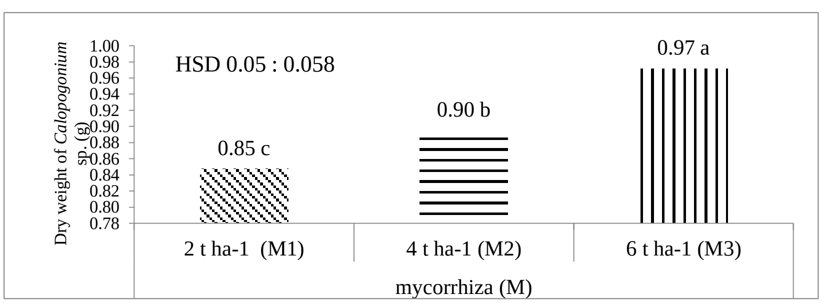

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 t 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 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.

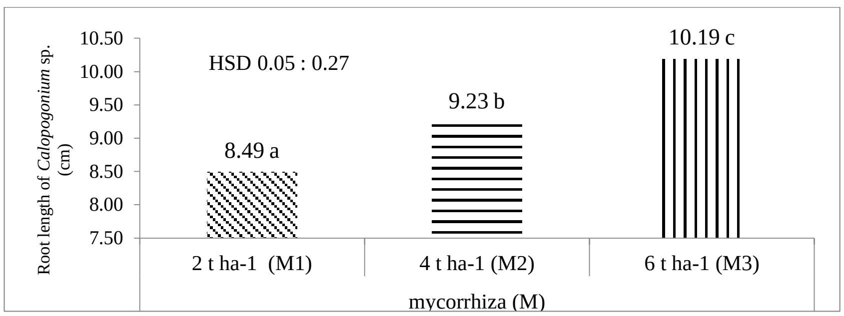

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

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.

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

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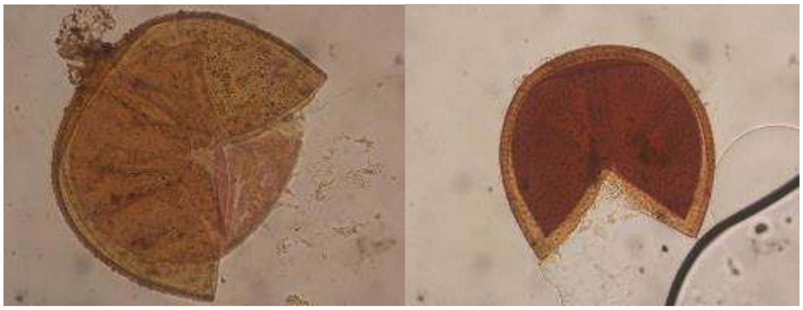

Fig. 13. Morphotype *Acalauspora sp* . dominantly found in the soil

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

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 ha^{-1} and MVA 6 t 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).

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Conclusions

The results of this study can be concluded that the use of the OPEFB compost 10 t ha^{-1} and MVA 6 t 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.*

Comment [3]: What it means for readers? Can improving the chemical quality of the soil, also mean improve potential plant growth?

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References

Abdullah, S., Y Musa, T Kuswinanti, M Jayadi, R Neswati. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology 21(39&40):82-91; 2020

Adetunjia, AT, B Ncubeb, R Mulidzic, FB Lewud. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research. V.204. 104717. https://doi.org/10.1016/j.still.2020.104717.

Allo K. M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4 (2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.

Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia. ISBN 978-602-8039-21-5. 234p.

Balai Penelitian Tanah, 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. 32 (4): 9-10. Bogor. Indonesia

Begum, N., Cheng Qin., M. A. Ahangar., S. Raza., M. I. Khan., M. Ashraf., N. Ahmed., L Zhang. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci. Vol.10. https://doi.org/10.3389/fpls.2019.01068.

Charisma A., Yuni S.R., & Isnawati (2012). Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. *Lantera Bio* Volume 1, Nomor 3, September 2012, Hal: 111 – 116

Chen, Y., Li, D., Li, D., Wu, X., & Zheng, Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi. org/10.1016/j.mcm.2010.11.054

Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

Gandahi, A. W & M. M. Hanafi. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland. pp.209-243. DOI:10.1007/978-3-319-08004-8.

Ghaida, S.H, B Wasis, S W Budi. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282-290.

Ghose, M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research. Vol.63. p.1006-1009. https://doi.org/10.1002/tqem.20150.

Goltapeth, E M, Y Z Danesh, R. Prasad, A. Varma. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A, Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

Hakim, N., Y. Nyakpa., A. Lubis., S. Nugroho., M. Saul., M A Diha., G B Hong and H H Bailey. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

Hakim, N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press. 204 p.

Hastuti, P.H, S. M. Rohmiyati. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal Vol 4 No.2. pp. 59-64.

Husna, F.D. Tuheteru, A. Arif. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity. Vol 22 No.9. https://doi.org/10.13057/biodiv/d220930.

Islami, T., W.H Utomo. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang

Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag 1:43-50.

Mahyudin, R.P., M Firmansyah, M A Purwanti, D Najmina. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering. Volume 21, Issue 5, p 221–228 https://doi.org/10.12911/22998993/122566.

Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian. Vol 29 No. 4. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154-158. p. 154-158.

Nakajima, K., K Nansai, K Matsubae, M Tomita, W Takayanagi, T Nagasaka. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment. 586. p730-737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.

Nakhone, LN, M.A Tabatabai. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S. 171: 231-241.

Ningtyas, VA., and YA Lia. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (Volvarella Volvaceae) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology. Surabaya.

Noli, ZA, Netty, WS, EM Sari. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.

Prayogo, C., M Ihsan. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management. Volume 6, number 1. doi:10.15243/jdmlm.2018.061.152.

Puspitasari D., K. Indah and H. Anton. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya. Vol 1. No. 2, September 2012

Riniarti, D., Kusumastuty, A., & Utoyo, B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research. Vol 12, No. 3, p187-195.

Rosmimi, 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.

Samsi N., Y.S Pata'dungan, A.R Tah, 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal. Vol 5, No. 2.

Sarrantonio, M., E.R. Gallandt. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production 8(1): 53-74. DOI: 10.1300/J144v08n01_04.

Sembiring, S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra. 5(2): 123-134.

Suherman, C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.

Suncayaningsih, R P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology. Vol. 10, No. 1, Pages: 31 – 42.

Sutanto, A., A.E Prasetyo, Fahroidayanti, A.F Lubis, and A.P Dongoran. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research. Vol. 13, No. 1. p. 25-33.

Tan, K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup . Boca Raton. London. New York. 362 p.

Umaternate, G.R, J Abidjulid, A D Wuntu,. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara

District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), p. 6-10. doi: https://doi.org/10.35799/jm.3.1.2014.3898.
Zaeni, A, Alwahab, Hasmawati, S Hade , Irnawati, P E Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. 1899-012031. IOP Publishing doi:10.1088/1742-6596/1899/1/012031.

4.c. Article after first revisions

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 ha-1 (K1), 7.5 t ha-1 (K2), 10 t 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 ha-1 (M1), 4 t ha-1 (M2), 6 t 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 ha-1 (K3) and MVA 6 t 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 (bricks fine-crushed) 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%.

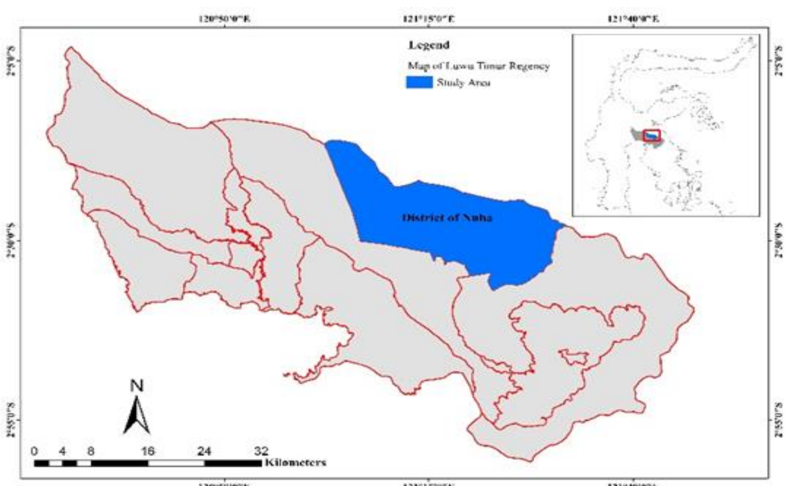

Fig 1. Soil Sampling Location

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.

Table 1. The results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil Characteristics	Value	Criteria*
pH (soil reaction)		
• H_2O	5.47	Slightly acid
• KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 cmol kg^{-1}	Low
Exchangeable basic cations		
• 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)

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), reaching1.41% 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.

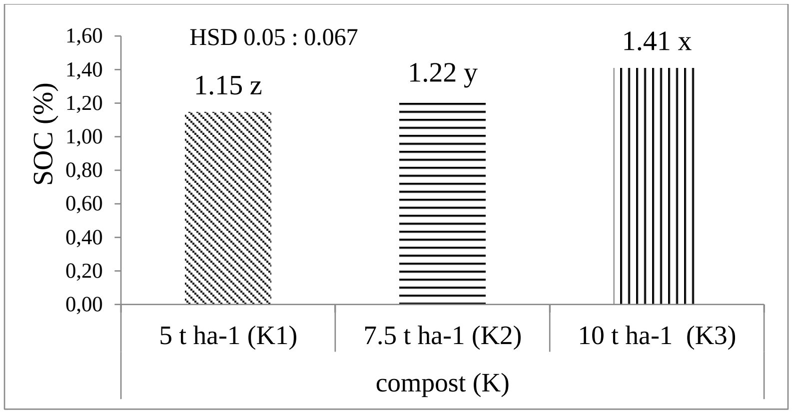

Fig 2. Effect of the OPEFB compost on SOC

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).

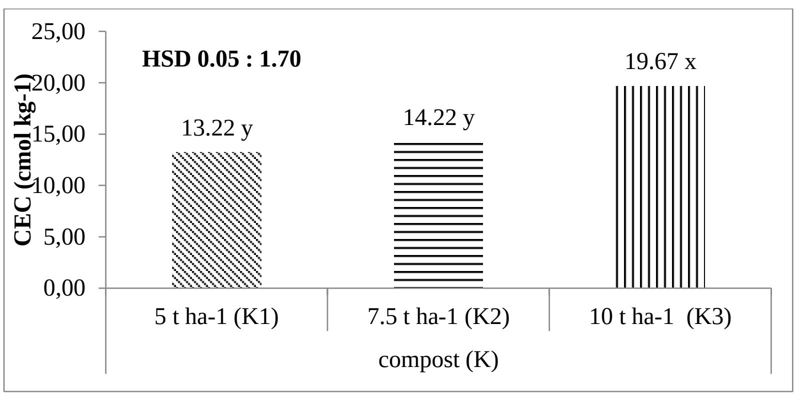

Fig. 3. Effect of TKSS compost on soil CEC

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 Fig. 4. The results of the 95% HSD Tukey test as shown in 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 &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.

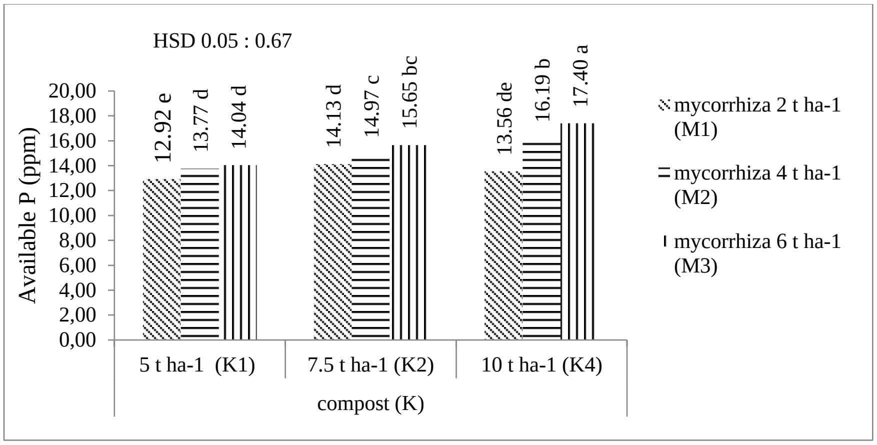

Fig. 4. Effect of the OPEFB and MVA compost on the soil available-P

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.

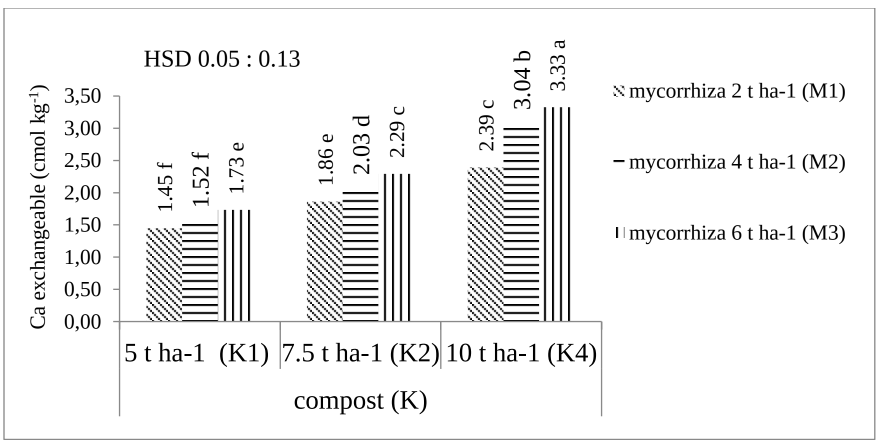

Fig. 5. Effect of the OPEFB and MVA compost treatment on soil Ca- exchangeable

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.

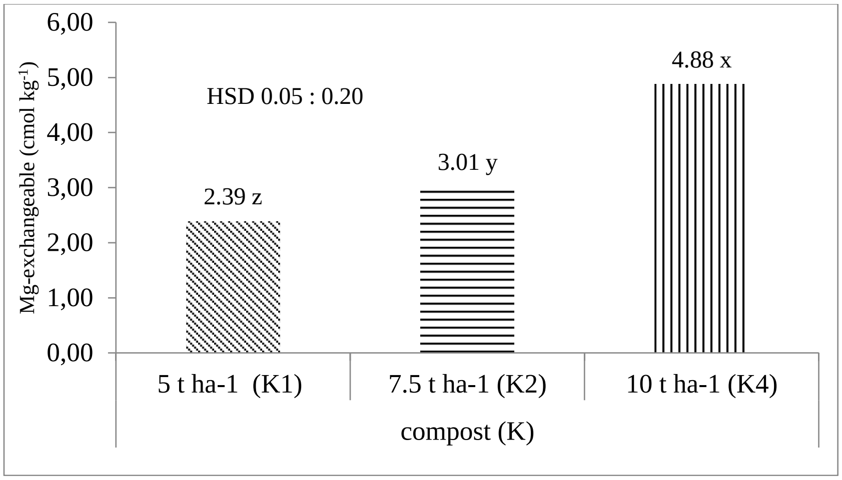

Fig.6. Effect of the OPEFB compost on soil Mg-exchangeable

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) who says 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.

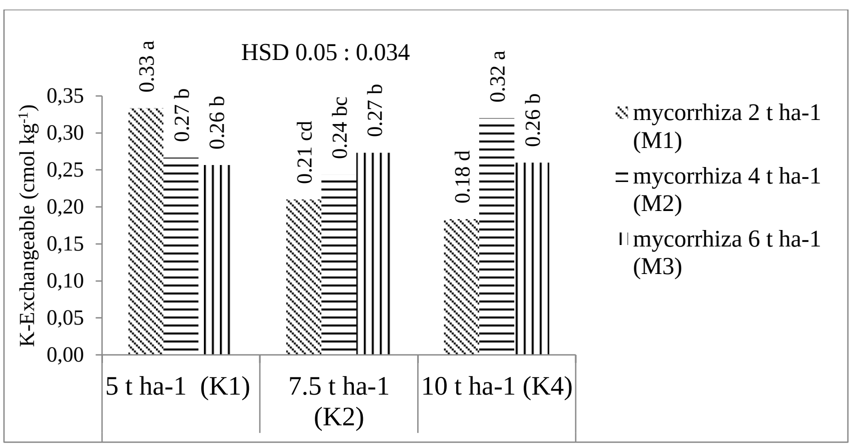

Fig. 7. Effect of the OPEFB compost on soil K-Exchangeable

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.

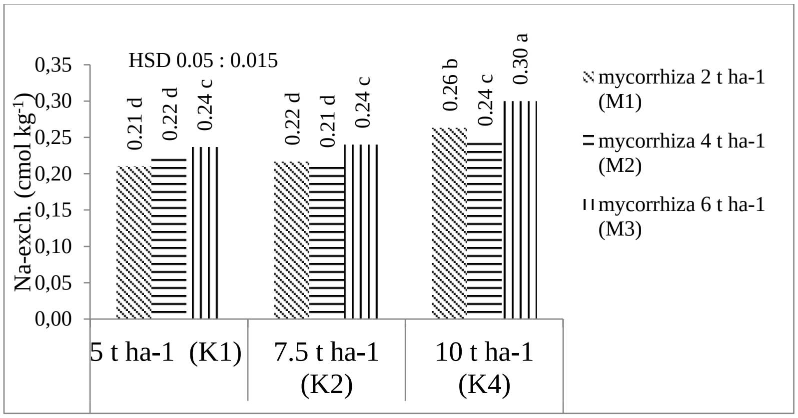

Fig. 8. Effect of the OPEFB compost and MVA on soil Na-Exchangeable

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).

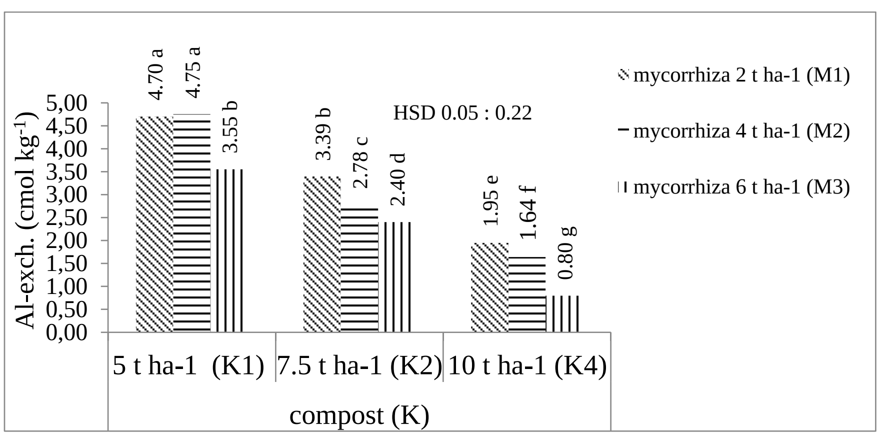

Fig. 9. Effect of the OPEFB compost and MVA on soil Al-exchangeable

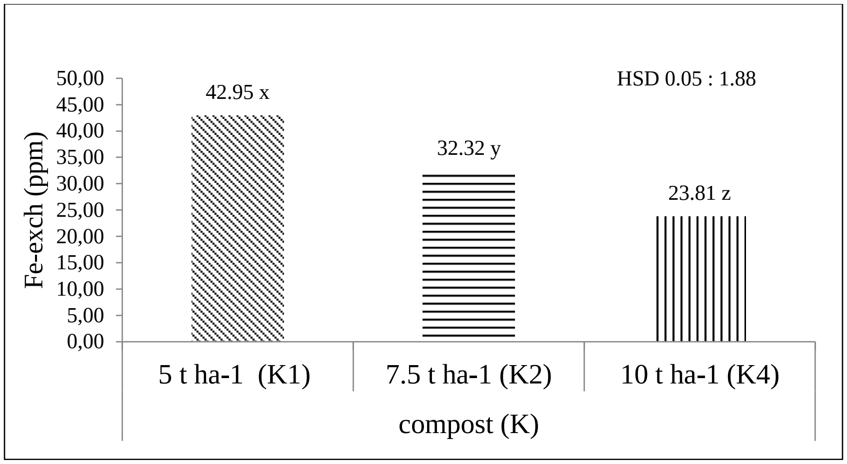

Fig. 10. Effect of the OPEFB compost on soil Fe-exchangeable

In addition to the significantly decreased Al-exch 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 effect on reducing the soil Fe-Exch levels (Figure 10). The results of the 95% Tukey test showed that the compost treatment of compost 10 t 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-Exch.

Effect of treatments on the plant growth of *Calopogonium mucunoide*s

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 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)

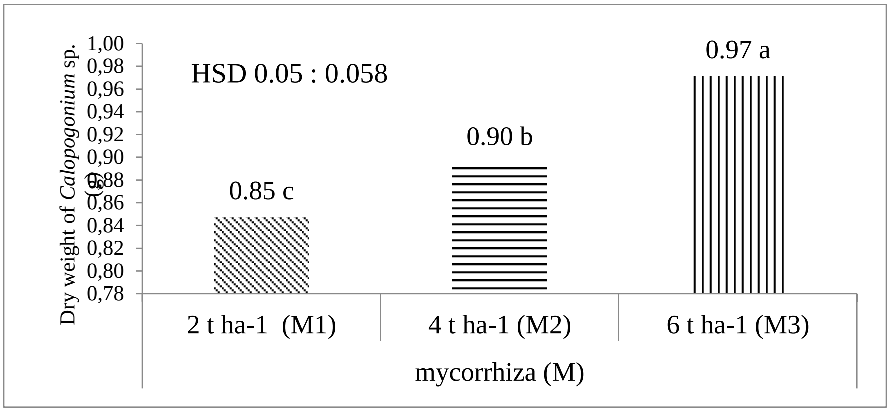

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

The results of the 95% HSD Tukey test showed that the MVA treatment of 6 t 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 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.

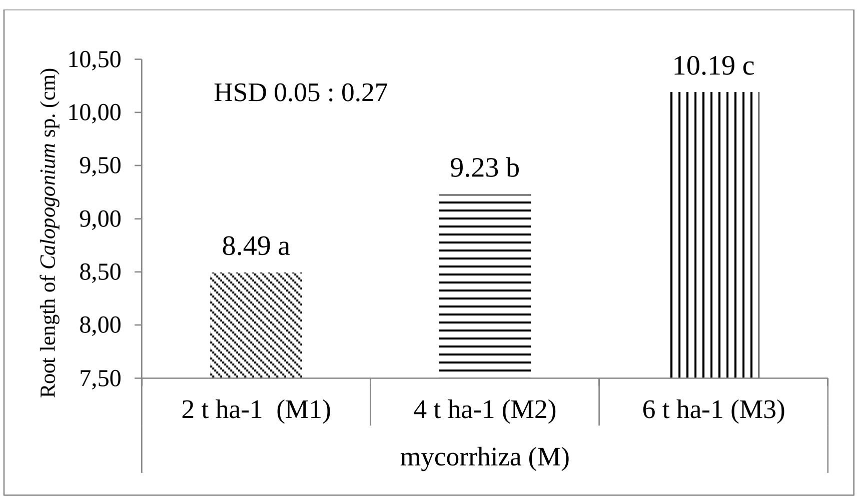

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

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

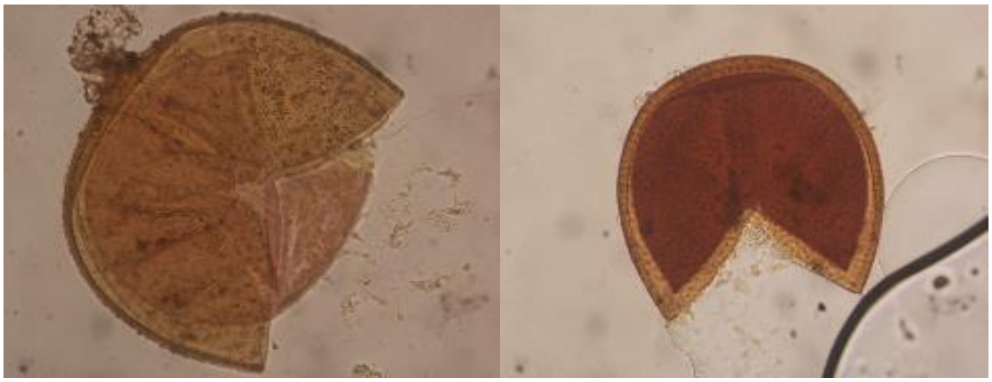

Fig. 13. Morphotype *Acalauspora sp* . dominantly found in the soil

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

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 ha^{-1} and MVA 6 t 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 ha^{-1} and MVA 6 t 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.*

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References

Abdullah, S., Y Musa, T Kuswinanti, M Jayadi, R Neswati. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology 21(39&40):82-91; 2020

Adetunjia, AT, B Ncubeb, R Mulidzic, FB Lewud. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research. V.204. 104717. https://doi.org/10.1016/j.still.2020.104717.

Allo K. M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4 (2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.

Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia. ISBN 978-602-8039-21-5. 234p.

Balai Penelitian Tanah, 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. 32 (4): 9-10. Bogor. Indonesia

Begum, N., Cheng Qin., M. A. Ahangar., S. Raza., M. I. Khan., M. Ashraf., N. Ahmed., L Zhang. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci. Vol.10. https://doi.org/10.3389/fpls.2019.01068.

Charisma A., Yuni S.R., & Isnawati (2012). Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. *Lantera Bio* Volume 1, Nomor 3, September 2012, Hal: 111 – 116

Chen, Y., Li, D., Li, D., Wu, X., & Zheng, Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi. org/10.1016/j.mcm.2010.11.054

Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

Gandahi, A. W & M. M. Hanafi. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland. pp.209-243. DOI:10.1007/978-3-319-08004-8.

Ghaida, S.H, B Wasis, S W Budi. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282-290.

Ghose, M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research. Vol.63. p.1006-1009. https://doi.org/10.1002/tqem.20150.

Goltapeth, E M, Y Z Danesh, R. Prasad, A. Varma. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A, Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

Hakim, N., Y. Nyakpa., A. Lubis., S. Nugroho., M. Saul., M A Diha., G B Hong and H H Bailey. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

Hakim, N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press. 204 p.

Hastuti, P.H, S. M. Rohmiyati. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal Vol 4 No.2. pp. 59-64.
Husna, F.D. Tuheteru, A. Arif. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity. Vol 22 No.9. https://doi.org/10.13057/biodiv/d220930.
Islami, T., W.H Utomo. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang
Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag 1:43-50.
Mahyudin, R.P., M Firmansyah, M A Purwanti, D Najmina. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering. Volume 21, Issue 5, p 221–228 https://doi.org/10.12911/22998993/122566.
Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian. Vol 29 No. 4. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154-158. p. 154-158.
Nakajima, K., K Nansai, K Matsubae, M Tomita, W Takayanagi, T Nagasaka. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment. 586. p730-737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.
Nakhone, LN, M.A Tabatabai. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S. 171: 231-241.
Ningtyas, VA., and YA Lia. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (Volvarella Volvaceae) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology. Surabaya.
Noli, ZA, Netty, WS, EM Sari. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.
Prayogo, C., M Ihsan. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management. Volume 6, number 1. doi:10.15243/jdmlm.2018.061.152.
Puspitasari D., K. Indah and H. Anton. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya. Vol 1. No. 2, September 2012
Riniarti, D., Kusumastuty, A., & Utoyo, B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research. Vol 12, No. 3, p187-195.
Rosmimi, 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.
Samsi N., Y.S Pata'dungan, A.R Tah, 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal. Vol 5, No. 2.
Sarrantonio, M., E.R. Gallandt. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production 8(1): 53-74. DOI: 10.1300/J144v08n01_04.
Sembiring, S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra. 5(2): 123-134.
Suherman, C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.
Suncayaningsih, R P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology. Vol. 10, No. 1, Pages: 31 – 42.

Sutanto, A., A.E Prasetyo, Fahroidayanti, A.F Lubis, and A.P Dongoran. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research. Vol. 13, No. 1. p. 25-33.
Tan, K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup . Boca Raton. London. New York. 362 p.
Umaternate, G.R, J Abidjulid, A D Wuntu,. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), p. 6-10. doi: https://doi.org/10.35799/jm.3.1.2014.3898.
Zaeni, A, Alwahab, Hasmawati, S Hade , Irnawati, P E Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. 1899-012031. IOP Publishing doi:10.1088/1742-6596/1899/1/012031.

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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%.

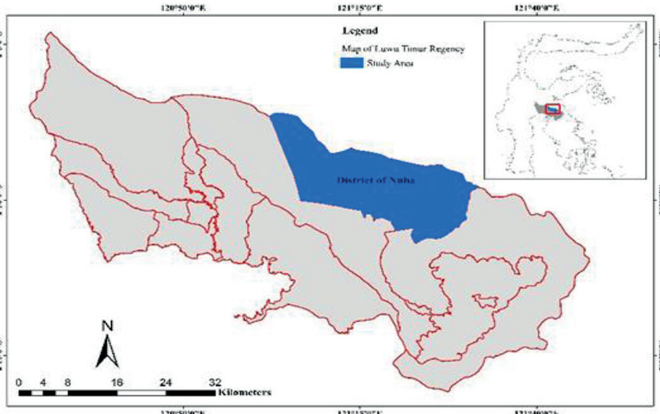

Fig. 1. Soil sampling location

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 results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil characteristics	Value	Criteria*
pH (soil reaction)		
H_2O	5.47	Slightly acid
KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 cmol kg^{-1}	Low
Exchangeable basic cations		
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)

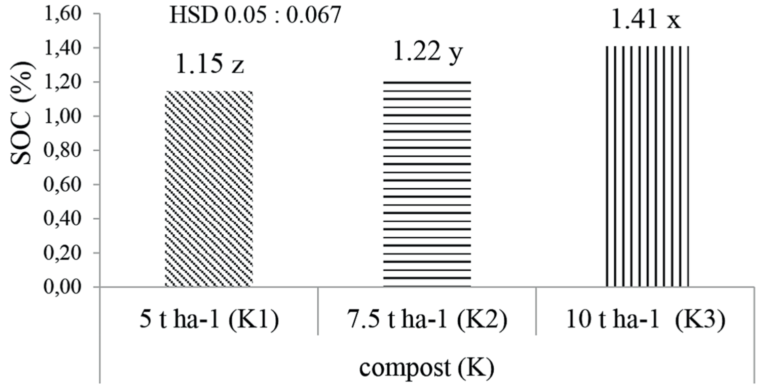

Fig. 2. Effect of the OPEFB compost on SOC

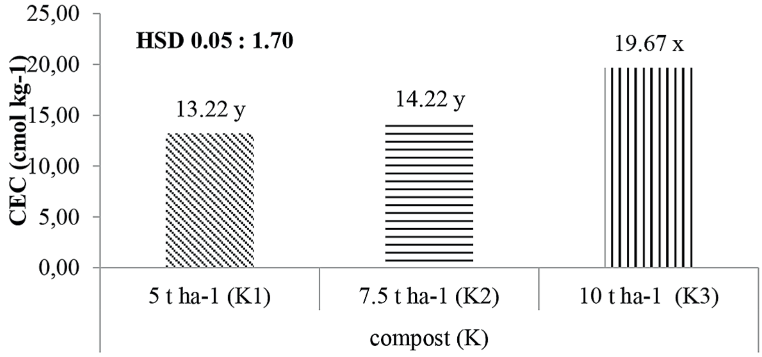

Fig. 3. Effect of OPEFB compost on soil CEC

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.

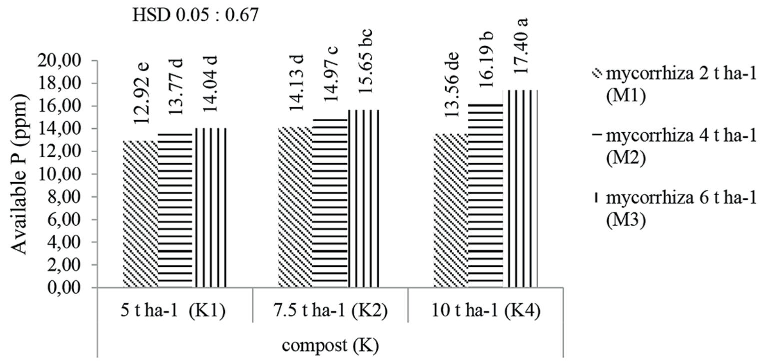

Fig. 4. Effect of the OPEFB and MVA compost on the soil available-P

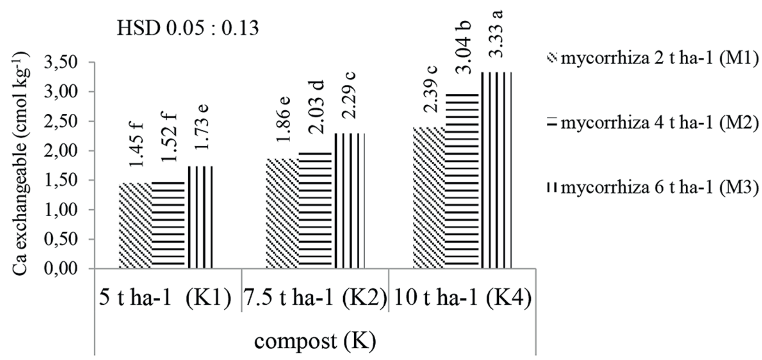

Fig. 5. Effect of the OPEFB and MVA compost treatment on soil Ca- exchangeable

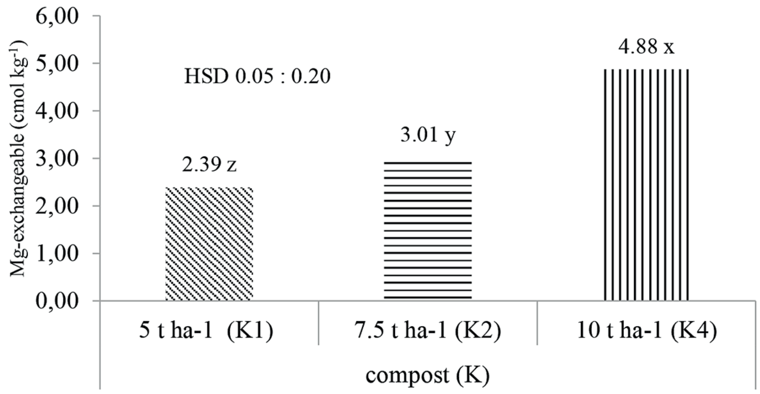

Fig. 6. Effect of the OPEFB compost on soil Mg-exchangeable

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

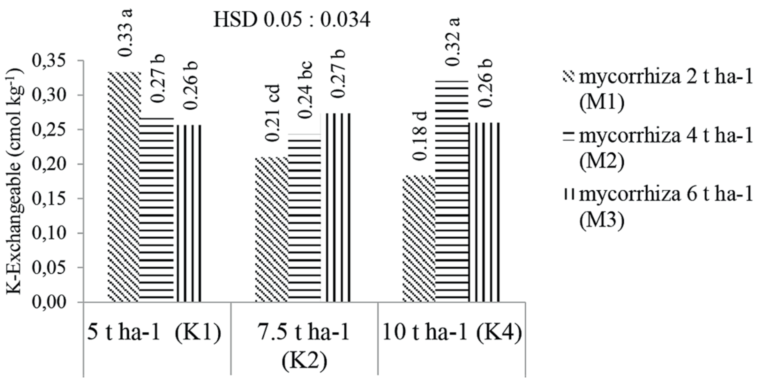

Fig. 7. Effect of the OPEFB compost on soil K-Exchangeable

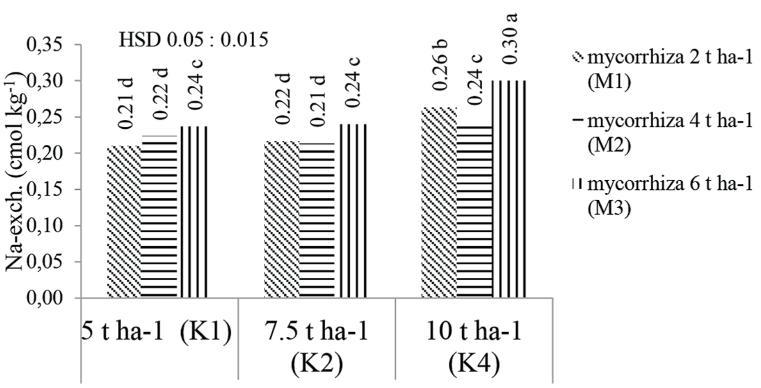

Fig. 8. Effect of the OPEFB compost and MVA on soil Na-Exchangeable

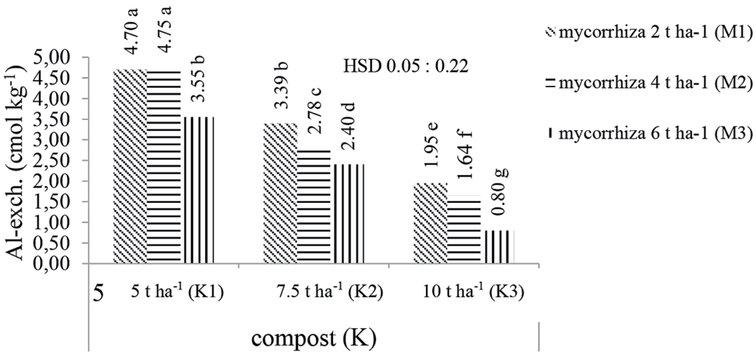

Fig. 9. Effect of the OPEFB compost and MVA on soil Al-exchangeable

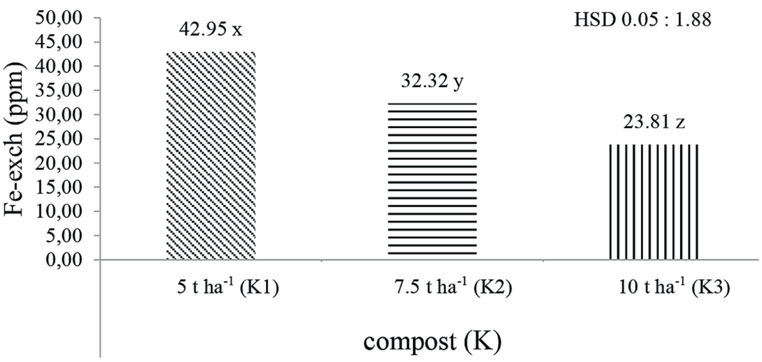

Fig. 10. Effect of the OPEFB compost on soil Fe-exchangeable

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·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·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·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

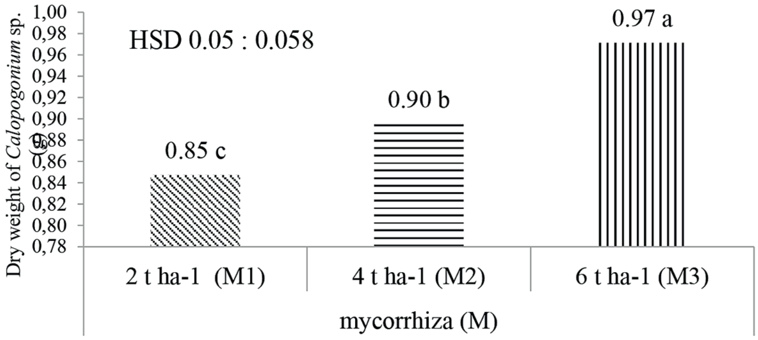

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

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

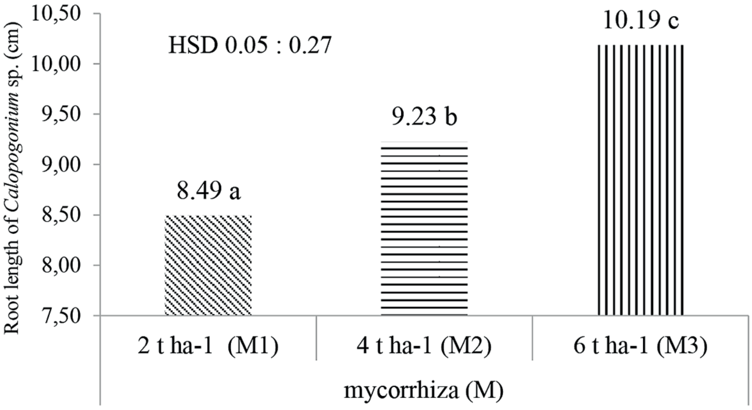

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

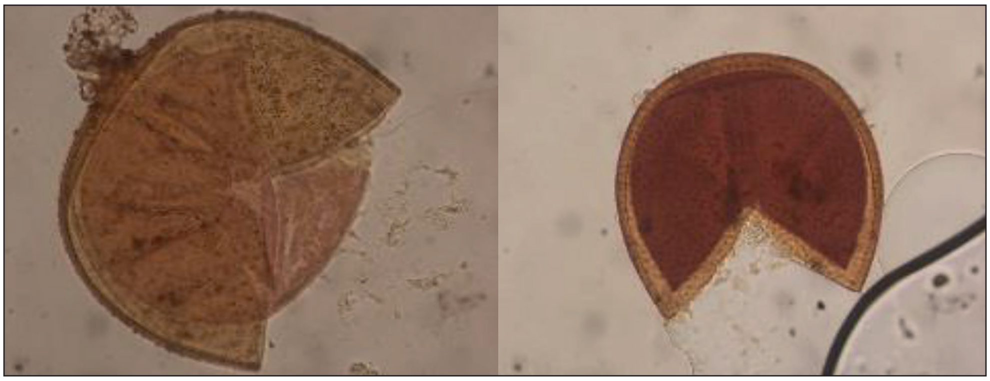

Fig. 13. Morphotype *Acalauspora sp.* dominantly found in the soil

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·ha^{-1} and MVA 6 t·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·ha^{-1} and MVA 6 t·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.*

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REFERENCES

1. Abdullah S., Musa Y., Kuswinanti T., Jayadi M., Neswati R. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology, 21(39–40), 82–91.
2. Adetunjia A.T., Ncubeb B., Mulidzic R., Lewud F.B. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research, 204, 104717. https://doi.org/10.1016/j.still.2020.104717.
3. Allo K.M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4(2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.
4. Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia, 234.

5. Balai Penelitian Tanah. 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. Bogor. Indonesia, 32(4), 9–10.

6. Begum N., Cheng Qin., Ahangar M.A., Raza S., Khan M.I., Ashraf M., Ahmed N., Zhang L. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci., 10. https://doi.org/10.3389/fpls.2019.01068

7. Charisma A., Yuni S.R., Isnawati. 2012. Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. Lantera Bio, 1(3), 111–116.

8. Chen Y., Li D., Li D., Wu X., Zheng Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi.org/10.1016/j.mcm.2010.11.054

9. Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.

10. Gandahi A.W., Hanafi M.M. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland, 209–243. https://doi.org/10.1007/978–3-319–08004–8

11. Ghaida S.H., Wasis B., Budi S.W. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282–290.

12. Ghose M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research, 63, 1006–1009. https://doi.org/10.1002/tqem.20150

13. Goltapeth E.M., Danesh Y.Z., Prasad R., Varma A. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A., Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.

14. Hakim N., Nyakpa Y., Lubis A., Nugroho S., Saul M., Diha M.A., Hong G.B., Bailey H.H. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.

15. Hakim N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press, 204.

16. Hastuti P.H, Rohmiyati S.M. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal, 4(2), 59–64.

17. Husna F.D., Arif T.A. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity, 22(9). https://doi.org/10.13057/biodiv/d220930

18. Islami T., Utomo W.H. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang

19. Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag, 1, 43–50.

20. Mahyudin R.P., Firmansyah M., Purwanti M.A., Najmina D. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering, 21(5), 221–228. https://doi.org/10.12911/22998993/122566

21. Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian, 29(4), 154–158. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154–158

22. Nakajima K., Nansai K., Matsubae K., Tomita M., Takayanagi W., Nagasaka T. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment, 586, 730–737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.

23. Nakhone L.N., Tabatabai M.A. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S., 171, 231–241.

24. Ningtyas V.A., Lia Y.A. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (*Volvarella volvaceae*) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology, Surabaya.

25. Noli Z.A., Netty W.S., Sari E.M. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.

26. Prayogo C., Ihsan M. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management, 6(1). http://dx.doi.org/10.15243/jdmlm.2018.061.152

27. Puspitasari D., Indah K., Anton H. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya, 1(2).

28. Riniarti D., Kusumastuty A., Utoyo B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate

Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research, 12(3), 187–195.

29. Rosmimi. 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.
30. Samsi N., Pata'dungan Y.S., Tah A.R. 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal, 5(2).
31. Sarrantonio M., Gallandt E.R. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production, 8(1), 53–74. https://doi.org/10.1300/J144v08n01_04
32. Sembiring S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra, 5(2), 123–134.
33. Suherman C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.
34. Suncayaningsih R.P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology, 10(1), 31–42.
35. Sutanto A., Prasetyo A.E., Fahroidayanti A.F., Lubis, Dongoran A.P. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research, 13(1), 25–33.
36. Tan K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup. Boca Raton. London. New York, 362.
37. Umaternate G.R, Abidjulid J., Wuntu A.D. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), 6–10. https://doi.org/10.35799/jm.3.1.2014.3898
38. Zaeni A., Alwahab, Hasmawati, Hade S., Irnawati P.E., Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. IOP Publishing, 1899–012031. https://doi.org/10.1088/1742–6596/1899/1/012031

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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%.

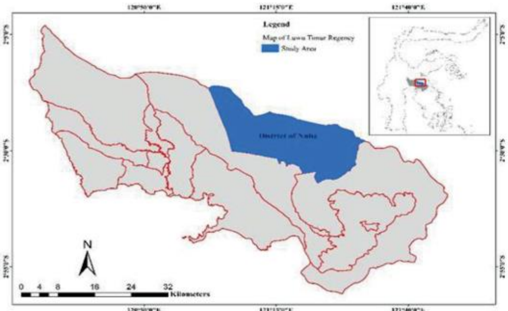

Fig. 1. Soil sampling location

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 $cmol \cdot kg^{-1}$). 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 $t \cdot ha^{-1}$ of 19.67 $cmol \cdot kg^{-1}$ 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 $t \cdot ha^{-1}$) significantly affected the increase in the CEC value of the soil, which was initially 14.51 $cmol \cdot kg^{-1}$. 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 results of the analysis of the chemical properties of the post-nickel mine site of the study

Soil characteristics	Value	Criteria*
pH (soil reaction)		
H_2O	5.47	Slightly acid
KCl	5.79	Slightly acid
C-Organic (SOC)	0.63%	Very low
Cation exchange capacity (CEC)	14.51 $cmol\ kg^{-1}$	Low
Exchangeable basic cations		
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)

Commented [RN1]: pH (soil reaction) only for pH H_20 and pH KCl, not include for C-organic, CEC

Exchangeable basic cations only for Ca, Mg, K, Na cations, not include for Available -P. Al Exch and Fe Exch.

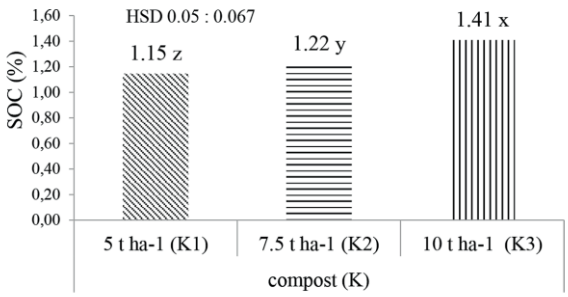

Fig. 2. Effect of the OPEFB compost on SOC

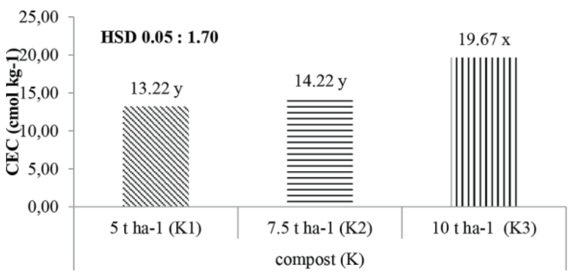

Fig. 3. Effect of OPEFB compost on soil CEC

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.

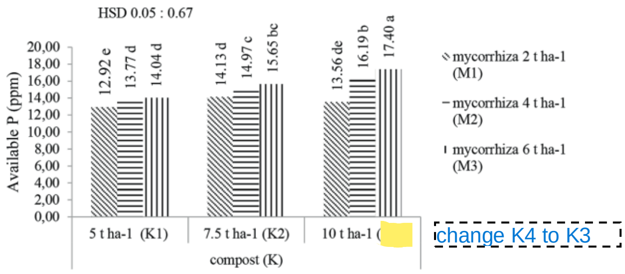

Fig. 4. Effect of the OPEFB and MVA compost on the soil available-P

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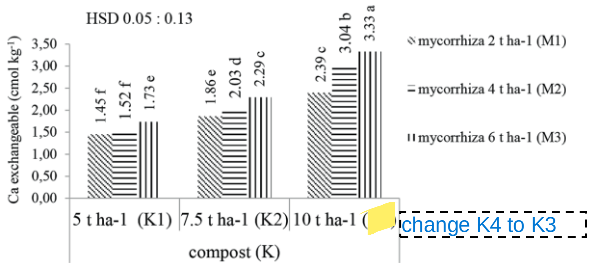

Fig. 5. Effect of the OPEFB and MVA compost treatment on soil Ca- exchangeable

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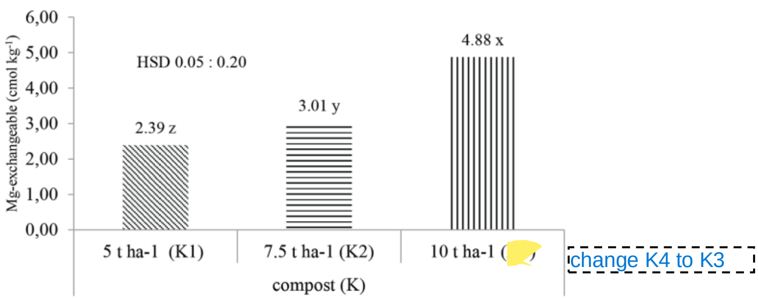

Fig. 6. Effect of the OPEFB compost on soil Mg-exchangeable

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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

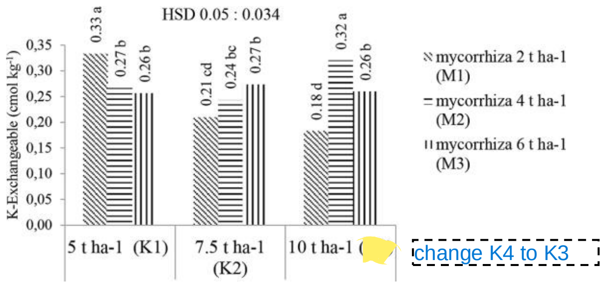

Fig. 7. Effect of the OPEFB compost on soil K-Exchangeable

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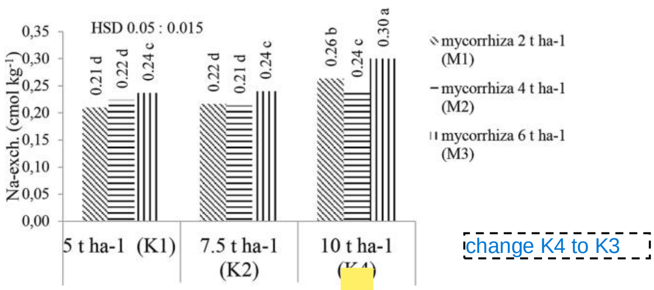

Fig. 8. Effect of the OPEFB compost and MVA on soil Na-Exchangeable

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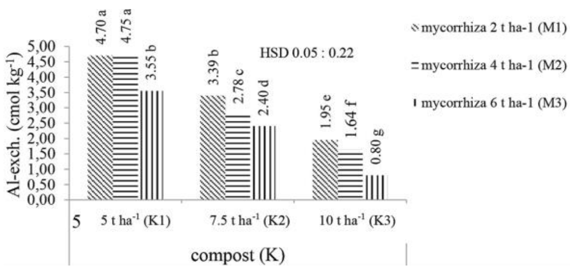

Fig. 9. Effect of the OPEFB compost and MVA on soil Al-exchangeable

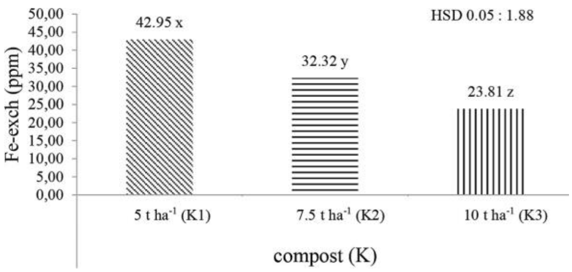

Fig. 10. Effect of the OPEFB compost on soil Fe-exchangeable

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

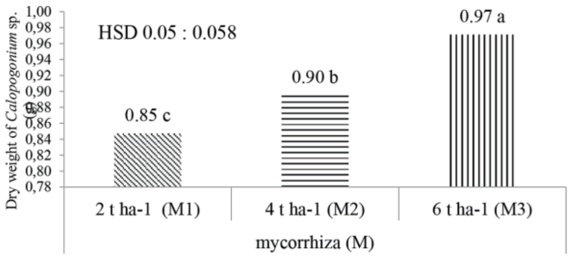

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

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

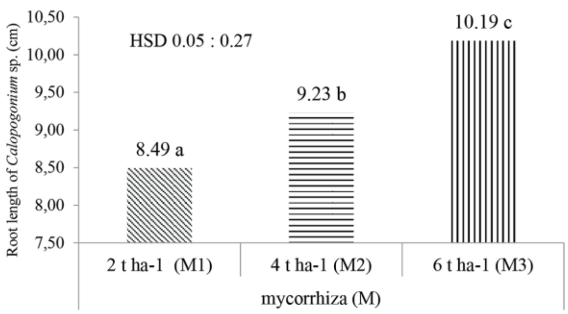

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

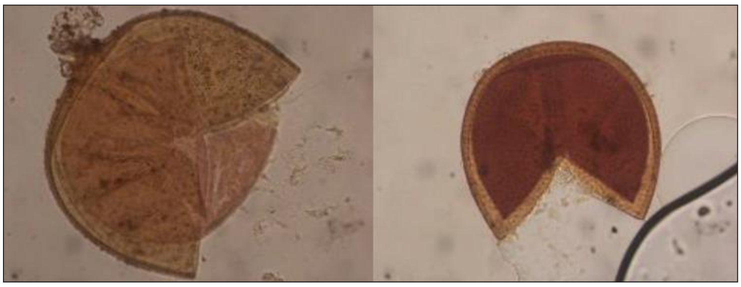

Fig. 13. Morphotype *Acalauspora sp.* dominantly found in the soil

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.*

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REFERENCES

1. Abdullah S., Musa Y., Kuswinanti T., Jayadi M., Neswati R. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology, 21(39–40), 82–91.
2. Adetunjia A.T., Ncubeb B., Mulidzic R., Lewud F.B. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research, 204, 104717. https://doi.org/10.1016/j.still.2020.104717.
3. Allo K.M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4(2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.
4. Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia, 234.

5. Balai Penelitian Tanah. 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. Bogor. Indonesia, 32(4), 9–10.
6. Begum N., Cheng Qin., Ahangar M.A., Raza S., Khan M.I., Ashraf M., Ahmed N., Zhang L. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci., 10. https://doi.org/10.3389/fpls.2019.01068
7. Charisma A., Yuni S.R., Isnawati. 2012. Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. Lantera Bio, 1(3), 111–116.
8. Chen Y., Li D., Li D., Wu X., Zheng Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi.org/10.1016/j.mcm.2010.11.054
9. Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.
10. Gandahi A.W., Hanafi M.M. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland, 209–243. https://doi.org/10.1007/978–3-319–08004–8
11. Ghaida S.H., Wasis B., Budi S.W. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282–290.
12. Ghose M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research, 63, 1006–1009. https://doi.org/10.1002/tqem.20150
13. Goltapeth E.M., Danesh Y.Z., Prasad R., Varma A. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A., Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.
14. Hakim N., Nyakpa Y., Lubis A., Nugroho S., Saul M., Diha M.A., Hong G.B., Bailey H.H. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.
15. Hakim N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press, 204.
16. Hastuti P.H, Rohmiyati S.M. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal, 4(2), 59–64.
17. Husna F.D., Arif T.A. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity, 22(9). https://doi.org/10.13057/biodiv/d220930
18. Islami T., Utomo W.H. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang
19. Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag, 1, 43–50.
20. Mahyudin R.P., Firmansyah M., Purwanti M.A., Najmina D. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering, 21(5), 221–228. https://doi.org/10.12911/22998993/122566
21. Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian, 29(4), 154–158. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154–158
22. Nakajima K., Nansai K., Matsubae K., Tomita M., Takayanagi W., Nagasaka T. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment, 586, 730–737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.
23. Nakhone L.N., Tabatabai M.A. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S., 171, 231–241.
24. Ningtyas V.A., Lia Y.A. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (*Volvarella volvaceae*) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology, Surabaya.
25. Noli Z.A., Netty W.S., Sari E.M. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.
26. Prayogo C., Ihsan M. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management, 6(1). http://dx.doi.org/10.15243/jdmlm.2018.061.152
27. Puspitasari D., Indah K., Anton H. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya, 1(2).
28. Riniarti D., Kusumastuty A., Utoyo B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate

Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research, 12(3), 187–195.
29. Rosmimi. 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.
30. Samsi N., Pata'dungan Y.S., Tah A.R. 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal, 5(2).
31. Sarrantonio M., Gallandt E.R. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production, 8(1), 53–74. https://doi.org/10.1300/J144v08n01_04
32. Sembiring S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra, 5(2), 123–134.
33. Suherman C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.
34. Suncayaningsih R.P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology, 10(1), 31–42.
35. Sutanto A., Prasetyo A.E., Fahroidayanti A.F., Lubis, Dongoran A.P. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research, 13(1), 25–33.
36. Tan K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup. Boca Raton. London. New York, 362.
37. Umaternate G.R, Abidjulid J., Wuntu A.D. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), 6–10. https://doi.org/10.35799/jm.3.1.2014.3898
38. Zaeni A., Alwahab, Hasmawati, Hade S., Irnawati P.E., Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. IOP Publishing, 1899–012031. https://doi.org/10.1088/1742–6596/1899/1/012031

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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%.

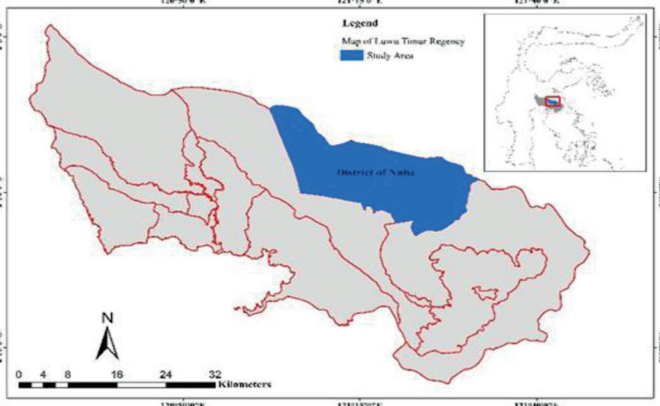

Fig. 1. Soil sampling location

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)

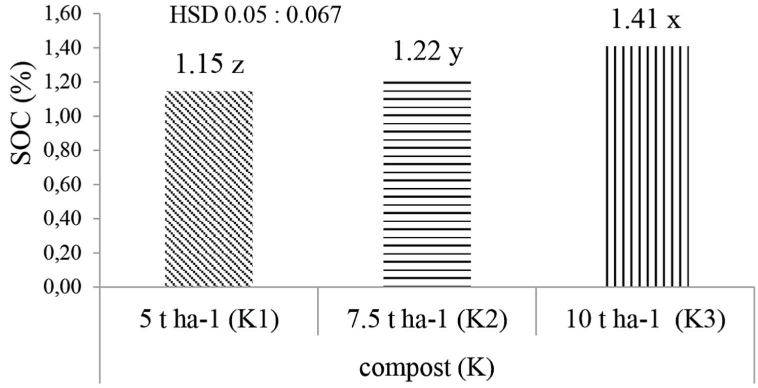

Fig. 2. Effect of the OPEFB compost on SOC

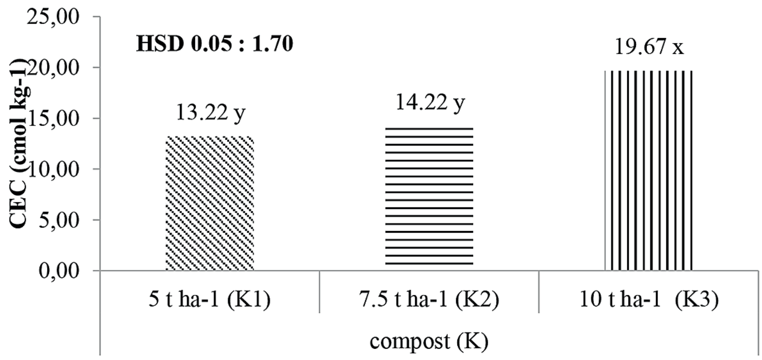

Fig. 3. Effect of OPEFB compost on soil CEC

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.

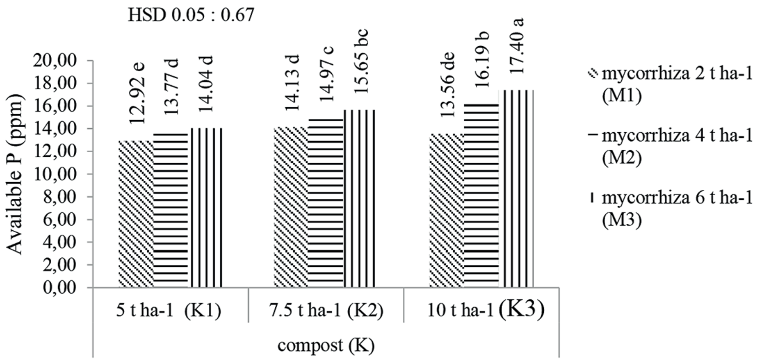

Fig. 4. Effect of the OPEFB and MVA compost on the soil available-P

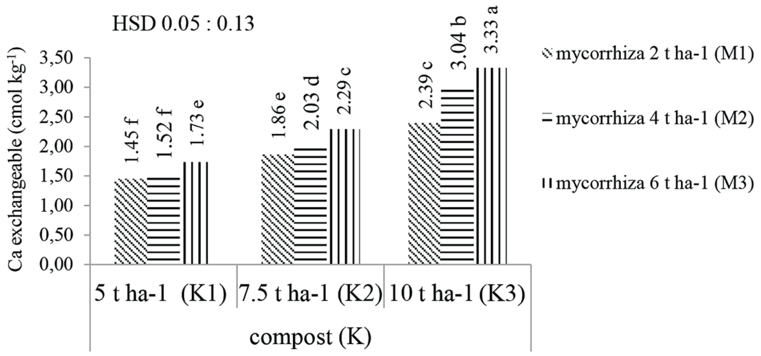

Fig. 5. Effect of the OPEFB and MVA compost treatment on soil Ca- exchangeable

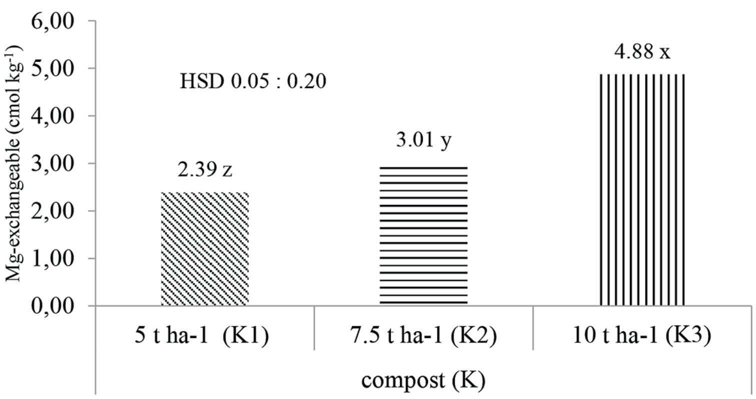

Fig. 6. Effect of the OPEFB compost on soil Mg-exchangeable

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 $t{\cdot}ha^{-1}$ and MVA 2 $t{\cdot}ha^{-1}$ (K1M1) produced the highest K average of 0.33 $cmol{\cdot}kg^{-1}$ 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 $cmol{\cdot}kg^{-1}$ (which was low) and increased to 0.33 $cmol{\cdot}kg^{-1}$. 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

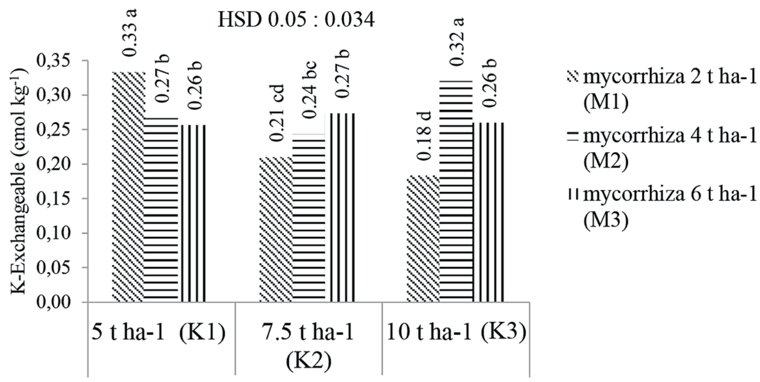

Fig. 7. Effect of the OPEFB compost on soil K-Exchangeable

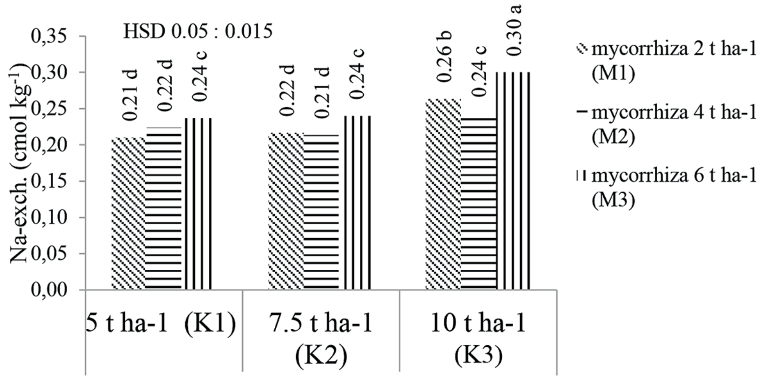

Fig. 8. Effect of the OPEFB compost and MVA on soil Na-Exchangeable

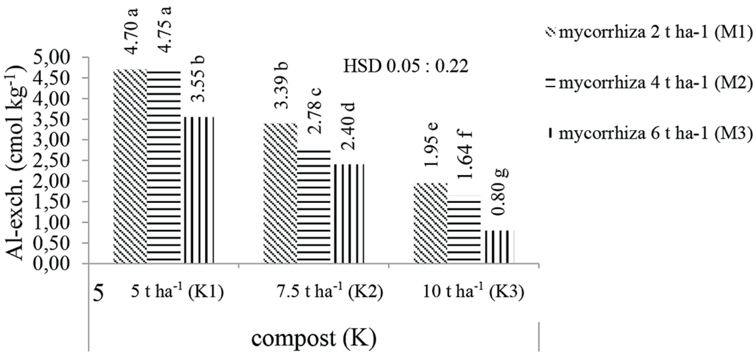

Fig. 9. Effect of the OPEFB compost and MVA on soil Al-exchangeable

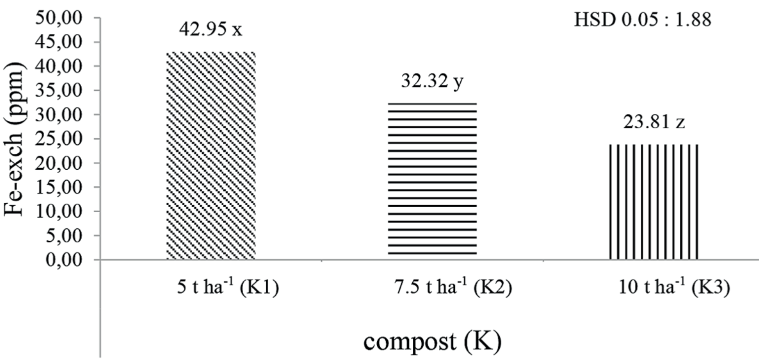

Fig. 10. Effect of the OPEFB compost on soil Fe-exchangeable

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·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·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·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

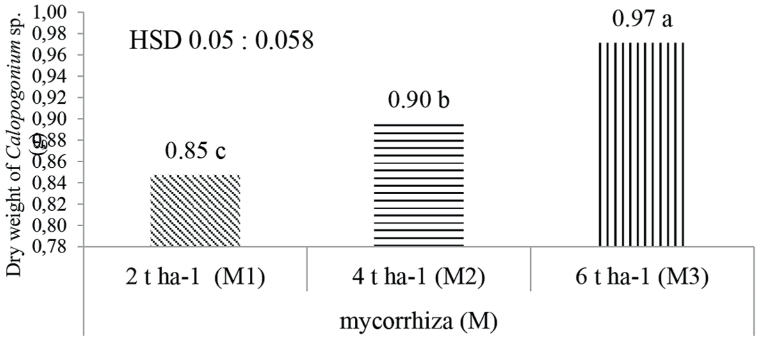

Fig. 11. Effect of MVA on plant dry weight of *Calopogonium mucunoides*

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

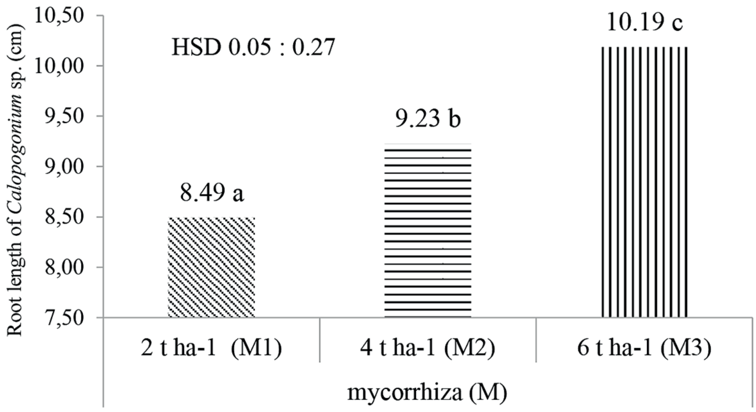

Fig. 12. Effect of MVA on root length of *Calapogonium mucunoides*

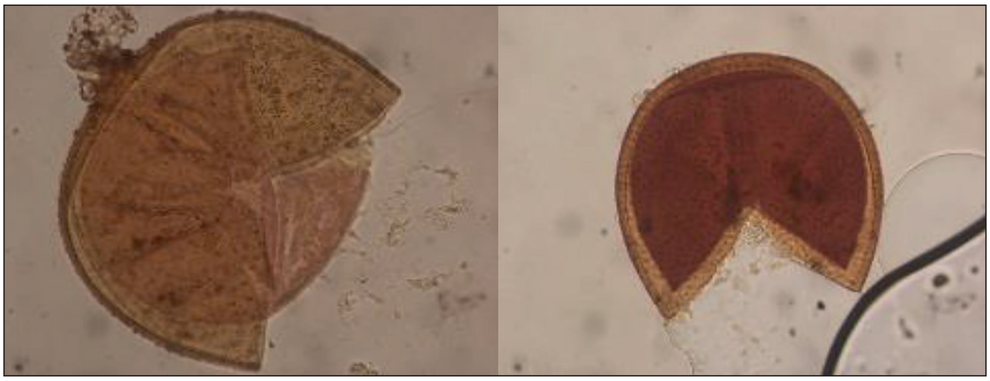

Fig. 13. Morphotype *Acalauspora sp.* dominantly found in the soil

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·ha^{-1} and MVA 6 t·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·ha^{-1} and MVA 6 t·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.*

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REFERENCES

1. Abdullah S., Musa Y., Kuswinanti T., Jayadi M., Neswati R. 2020. Arbuscular Mycorrhizae Exploration and Identification on Sugarcane Plantations In Humid Tropic Area of Indonesia. Plant Cell Biotechnology Molecular Biology, 21(39–40), 82–91.
2. Adetunjia A.T., Ncubeb B., Mulidzic R., Lewud F.B. 2020. Management impact and benefit of cover crops on soil quality: A review. Soil & Tillage Research, 204, 104717. https://doi.org/10.1016/j.still.2020.104717.
3. Allo K.M. 2016. Kondisi Sifat Fisik dan Kimia Tanah Pada Bekas Tambang Nikkel Serta Pengaruhnya Terhadap Pertumbuhan Trengguli dan Mahoni. Jurnal Hutan Tropis 4(2). Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan Makassar.
4. Balai Penelitian Tanah. 2009. Petunjuk Teknik. Analisis kimia tanah, tanaman, air dan pupuk. Balai Penelitian Tanah. Bogor. Indonesia, 234.

5. Balai Penelitian Tanah. 2010. Mengenal *Calopogonium mucunoides* Sumber Pupuk Hijau dan Bahan Organik. Bogor. Indonesia, 32(4), 9–10.
6. Begum N., Cheng Qin., Ahangar M.A., Raza S., Khan M.I., Ashraf M., Ahmed N., Zhang L. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Front. Plant Sci., 10. https://doi.org/10.3389/fpls.2019.01068
7. Charisma A., Yuni S.R., Isnawati. 2012. Pengaruh Kombinasi Kompos Trichoderma dan Mikoriza Vesikular Arbuskular (MVA) terhadap Pertumbuhan Tanaman Kedelai (*Glycine max* (L.) Merill) pada Media Tanam Tanah Kapur. Lantera Bio, 1(3), 111–116.
8. Chen Y., Li D., Li D., Wu X., Zheng Y. 2011. Assessment for soil improvement benefit of land rehabilitation in dump areas. Mathematical and Computer Modeling, 54(3–4), 1204–1212. https://doi.org/10.1016/j.mcm.2010.11.054
9. Dewi A. 2007. Peran, Prospek dan Kendala dalam Pemanfaatan Endomikoriza. Jurusan Budidaya Pertanian, Program Studi Agronomi, Fakultas Pertanian Universitas Pajajaran, Jatinangor, Bandung.
10. Gandahi A.W., Hanafi M.M. 2014. Bio-composting Oil Palm Waste for Improvement of Soil Fertility. Editors: Dinesh K. Maheshwari. Publisher: © Springer International Publishing Switzerland, 209–243. https://doi.org/10.1007/978–3-319–08004–8
11. Ghaida S.H., Wasis B., Budi S.W. 2020. Application of Arbuscular Mycorrhizal Fungi and Soil Ameliorant on the Growth of *Leucaena leucocephala* in Limestone Post-mining Soil Media. Journal of Tropical Forest Management, 26(3), 282–290.
12. Ghose M.K. 2004. Effect of opencast mining on soil fertility. Journal of Scientific and Industrial Research, 63, 1006–1009. https://doi.org/10.1002/tqem.20150
13. Goltapeth E.M., Danesh Y.Z., Prasad R., Varma A. 2008. Mycorrhizal fungi: what we know and what should we know/. In: Varma A., Editor. Mychorriza: State of the Art, Genetic and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics. India (IN). Springer.
14. Hakim N., Nyakpa Y., Lubis A., Nugroho S., Saul M., Diha M.A., Hong G.B., Bailey H.H. 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung. Lampung.
15. Hakim N. 2006. Pengelolaan Kesuburan Tanah Masam dengan Teknologi Pengapuran Terpadu. Padang. Universitas Andalas Press, 204.
16. Hastuti P.H, Rohmiyati S.M. 2020. Application of Empty Fruit Bunches Compost and Types of P Fertilizer on the Growth and Phosphorus Uptake in Oil Palm Seedlings. Agrotechnology Research Journal, 4(2), 59–64.
17. Husna F.D., Arif T.A. 2021. Arbuscular mycorrhizal fungi to enhance the growth of tropical endangered species Pterocarpus indicus and Pericopsis mooniana in post gold mine field in Southeast Sulawesi, Indonesia. Biodiversitas Journal of Biological Diversity, 22(9). https://doi.org/10.13057/biodiv/d220930
18. Islami T., Utomo W.H. 1995. Hubungan Tanah, Air dan Tanaman. Semarang: IKIP Semarang
19. Kumar, B.M. 2013. Mining waste contaminated lands: an uphill battle for improving crop productivity. J Degrad Min Lands Manag, 1, 43–50.
20. Mahyudin R.P., Firmansyah M., Purwanti M.A., Najmina D. 2020. Bioremediation of Iron on Diamond Post Mining Soil Using Compost Made from Cow Manure and Traditional Market Organic Waste. Journal of Ecological Engineering, 21(5), 221–228. https://doi.org/10.12911/22998993/122566
21. Musfal. 2010. Potensi cendawan mikoriza arbuskula untuk meningkatkan hasil tanaman jagung. Jurnal Penelitian dan Pengembangan Pertanian, 29(4), 154–158. http://dx.doi.org/10.21082/jp3.v29n4.2010.p154–158
22. Nakajima K., Nansai K., Matsubae K., Tomita M., Takayanagi W., Nagasaka T. 2017. Global land-use change hidden behind nickel consumption. Science of the Total Environment, 586, 730–737. http://dx.doi.org/10.1016/j.scitotenv.2017.02.049.
23. Nakhone L.N., Tabatabai M.A. 2008. Nitrogen mineralization of leguminous crops in soils. J. Plant Nut. Soil S., 171, 231–241.
24. Ningtyas V.A., Lia Y.A. 2010. Utilization of Oil Palm Empty Fruit Bunches Leftover Red Mushroom Media (*Volvarella volvaceae*) as Organic Fertilizer with Addition of EM-4 Effective Microorganism Activator. Essay. Faculty of Chemical Engineering. Surabaya Institute of Technology, Surabaya.
25. Noli Z.A., Netty W.S., Sari E.M. 2011. Exploration of Indigenous Arbuscular Mycorrhizal Fungi (CMA) Associated with Begonia resecta in Biological Education and Research Forest (HPPB). Proceedings of the National Biology Seminar: Increasing the Role of Biology in Realizing the National Achievement with Global Reach. Department of Biology, FMIPA, University of North Sumatra, Medan.
26. Prayogo C., Ihsan M. 2018. Utilization of LCC (legume cover crop) and bokashi fertilizer for the efficiency of Fe and Mn uptake of former coal mine land. Journal of Degraded and Mining Lands Management, 6(1). http://dx.doi.org/10.15243/jdmlm.2018.061.152
27. Puspitasari D., Indah K., Anton H. 2012. Exploration of Indigenous Vesicular Arbuscular Mycorrhiza (VAM) in Corn Field of Sampang Madura. Science Journal. Arts and ITS Surabaya, 1(2).
28. Riniarti D., Kusumastuty A., Utoyo B. 2012. Effect of Organic Matter, P Fertilizer, and Phosphate

Solubilizing Bacteria on Oil Palm Plant Performance on Ultisols. Journal of Applied Agricultural Research, 12(3), 187–195.

29. Rosmimi. 2000. Organic Fertilizer. Faculty of Agriculture, University of Riau. Lectures. Pekanbaru.
30. Samsi N., Pata'dungan Y.S., Tah A.R. 2017. Isolation and Morphological Identification of Arbuscular Mycorrhizal Fungi Spores in Root Areas of Several Horticultural Crops in Sidera Village Agricultural Land. Agrotechnical Journal, 5(2).
31. Sarrantonio M., Gallandt E.R. 2003. The Role of Cover Crops in North American Cropping Systems. Journal of Crop Production, 8(1), 53–74. https://doi.org/10.1300/J144v08n01_04
32. Sembiring S. 2008. Chemical and Physical Properties of Soil in the Former Bauxite Mine Area on Bintan Island, Riau. Aek Nauli Forestry Research Institute. North Sumatra, 5(2), 123–134.
33. Suherman C. 2007. Effect of Mixture of Subsoil and Compost as a Planting Media on the Growth of Oil Palm (*Elaeis guineensis Jacq*) Cultivars Sungai Pancur 2 (SP 2) in Early Nurseries. Padjadjaran University Thesis. Bandung.
34. Suncayaningsih R.P., Suharno. 2013. Arbuscular Mycorrhizal Fungi: Potential of Heavy Metal Mycorrhiza remeditation Technology in Mining Land Rehabilitation. Journal of Biotechnology, 10(1), 31–42.
35. Sutanto A., Prasetyo A.E., Fahroidayanti A.F., Lubis, Dongoran A.P. 2005. Viability of *Trichoderma koningii* Fungus Bioactivator on Oil Palm Blank Mark Media. Journal of Oil Palm Bunches Research, 13(1), 25–33.
36. Tan K.H. 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Croup. Boca Raton. London. New York, 362.
37. Umaternate G.R, Abidjulid J., Wuntu A.D. 2014. Test of Olsen and Bray Methods in Analyzing Available Phosphate Content in Rice Field Soil in Konarom Barat Village, Dumoga Utara District. Journal of Mathematics and Natural Sciences, Sam Ratulangi University, 3(1), 6–10. https://doi.org/10.35799/jm.3.1.2014.3898
38. Zaeni A., Alwahab, Hasmawati, Hade S., Irnawati P.E., Susilowati. 2021. Utilization of Compost as ameliorant in a Nickel post mining soil. Journal of Physics: Conference Series. IOP Publishing, 1899–012031. https://doi.org/10.1088/1742–6596/1899/1/012031