DOI :https://doi.org/10.36378/juatika.v6i3.3822
JUATIKA
JURNAL AGRONOMI TANAMAN TROPIKA
VOL. 6 NO. 3 September 2024
eissn 2656-1727
pissn 2684-785X
Hal : 894 – 903

Application of FMA on Soil Chemical Properties in Oil Palm (*Elaeis guineensis* Jacq.) plants

Asri Cahyati Zebua*, Zulfarina, Wawan
Universitas Riau
Kampus Bina Widya KM. 12,5, Simpang Baru, Tampan Distric, Pekanbaru City, Riau 28293, Indonesia
email: asri.cz1234@gmail.com

ABSTRACT

Oil palm (*Elaeis guineensis* Jacq.) is a significant agricultural commodity in tropical regions, particularly Indonesia. The increasing demand for palm oil has prompted the expansion of agricultural land, including the utilization of marginal lands such as Dystrudepts soil, typically characterized by low fertility and a deficiency in phosphate, a critical nutrient for plant growth. One potential solution to address these limitations is the application of Arbuscular Mycorrhizal Fungi (AMF), which have been shown to enhance water availability, improve fertilizer efficiency, facilitate nutrient absorption, and increase the populations of soil microorganisms. This study aims to evaluate the alterations in the chemical properties of Dystrudepts soil following the application of Arbuscular Mycorrhizal Fungi. The research was conducted in Petapahan Village, Tapung District. The experimental treatments comprised four levels of AMF application: a control group without AMF and three treatment groups receiving AMF at doses of 150 g/plant, 300 g/plant, and 450 g/plant. Each treatment was replicated five times, resulting in 20 experimental units containing one plant. The study employed a non-factorial RAL methodology. Data were subjected to analysis of variance, followed by Duncan's Multiple Range Test (DMRT) at a 5% significance level. The findings indicated that the application of AMF significantly affected the soil's pH, organic carbon content (C-Organic), available phosphorus (P-available), and cation exchange capacity (CEC). Notably, a dose of 300 g per plant emerged as the most effective in enhancing the chemical properties of the soil associated with oil palm cultivation.

Keywords: Arbuscular Mycorrhizal Fungi, Dystrudepts, Oil Palm, Soil Chemistry

1. INTRODUCTION

Oil palm cultivation is prevalent across various regions in Indonesia, notably in North Sumatra, West Sumatra, South Sumatra, Jambi, Lampung, West Kalimantan, East Kalimantan, Central Kalimantan, and Riau (Nora & Mual, 2018). According to the Riau Province Central Statistics Agency (2023), the total area dedicated to oil palm plantations in Riau Province expanded from 2,860,832 hectares in 2021 to 2,999,743 hectares in 2022. This plantation area is comprised of 35.88% managed by large private enterprises, 2.57% by large state-owned enterprises, and 61.55% by community-managed plantations. The growth in oil palm plantation area in Riau has led to the utilization of marginal lands, including sandy soils classified as Dystrudepts.

Dystrudepts represent a category of acidic mineral soils extensively utilized for oil palm cultivation. The application of Dystrudepts for agricultural purposes presents numerous challenges, particularly concerning the soil's physical, chemical, and biological characteristics. A significant issue related to its physical properties is the high porosity of the soil, which facilitates the rapid evaporation of water from both irrigation and precipitation. Consequently, the availability of water and moisture in these sandy soils is notably low, which is critical since humidity plays a vital role in plant development (Aprilia & Sukur, 2022). Research conducted by Tewu et al. (2016) on sandy soils revealed that the organic carbon content ranged from 2.07% to 2.32%, indicating medium levels, while the total nitrogen content was between 0.14% and 0.18%, classified as low. Additionally, the available phosphorus content was found to be between 11.48 ppm and 14.33 ppm, also low, and potassium levels ranged from 12.20 ppm to 15.49 ppm, which is similarly low. Biological property issues include soil biota's low diversity, population, and activity.

One potential solution to address the challenges associated with Dystrudepts soil, thereby enhancing water availability, improving fertilizer efficiency, facilitating nutrient uptake by plants, and increasing the rhizosphere microorganisms population, is mycorrhizal biological agents' application.

Mycorrhiza refers to the symbiotic relationship established between fungi and plants, which specifically colonizes the root cortex of plants during their active growth phases. This association is categorized into three primary types: endomycorrhiza, ectomycorrhiza, and ectomycorrhiza. Ectomycorrhizal fungi are predominantly classified within the Ascomycetes and Basidiomycetes groups. In contrast, endomycorrhiza is typically associated with the Glomales order (Zygomycetes), further divided into the Glominae and Gigasporinae suborders (Brundrett et al., 1996).

Plants that engage in symbiosis with mycorrhizal fungi exhibit enhanced root systems due to mycorrhizal hyphae, which significantly increase their capacity to absorb water and nutrients, particularly phosphorus. Phosphorus (P) is frequently a limiting nutrient for plant growth, with its primary source being non-renewable rock deposits. The parent rock particularly rich in phosphorus is apatite, where phosphorus is predominantly found in Ca3 (PO4)2 (Mukhlis, 2014).

The application of Arbuscular Mycorrhizal Fungi (AMF) has been previously investigated using annual plants as indicators to evaluate their effectiveness. A study by Putri et al. (2024) focused on the response of two shallot varieties to the application of local AMF, while Rastono and Firgiyanto (2024) examined the growth and yield responses of cayenne pepper to the introduction of Phosphate Solubilizing Bacteria (BPF) and AMF in Alfisol soil located in Tuban Regency. Beyond annual plants, AMF has also been utilized in the pre-nursery phase of oil palm cultivation (Yuliatri, 2023). Consequently, researchers have explored the alterations in the chemical properties of Dystrudepts soil associated with oil palm plants following the application of AMF.

2. MATERIAL AND METHOD

The research was conducted in Petapahan Village, Tapung District, Kampar Regency, Riau Province. This location is at coordinates 0 ° 35' 39.612" N and 101 ° 0' 12.5568" E. The research was conducted on a 7-year-old Topaz 2 variety smallholder oil palm plantation with sandy soil (Dystrudepts).

The research was conducted for 6 months (October 2023 - April 2024). Soil and root analysis was carried out at the Central Plantation Services Laboratory, Jalan Soekarno Hatta No. 488, Pekanbaru, Riau.

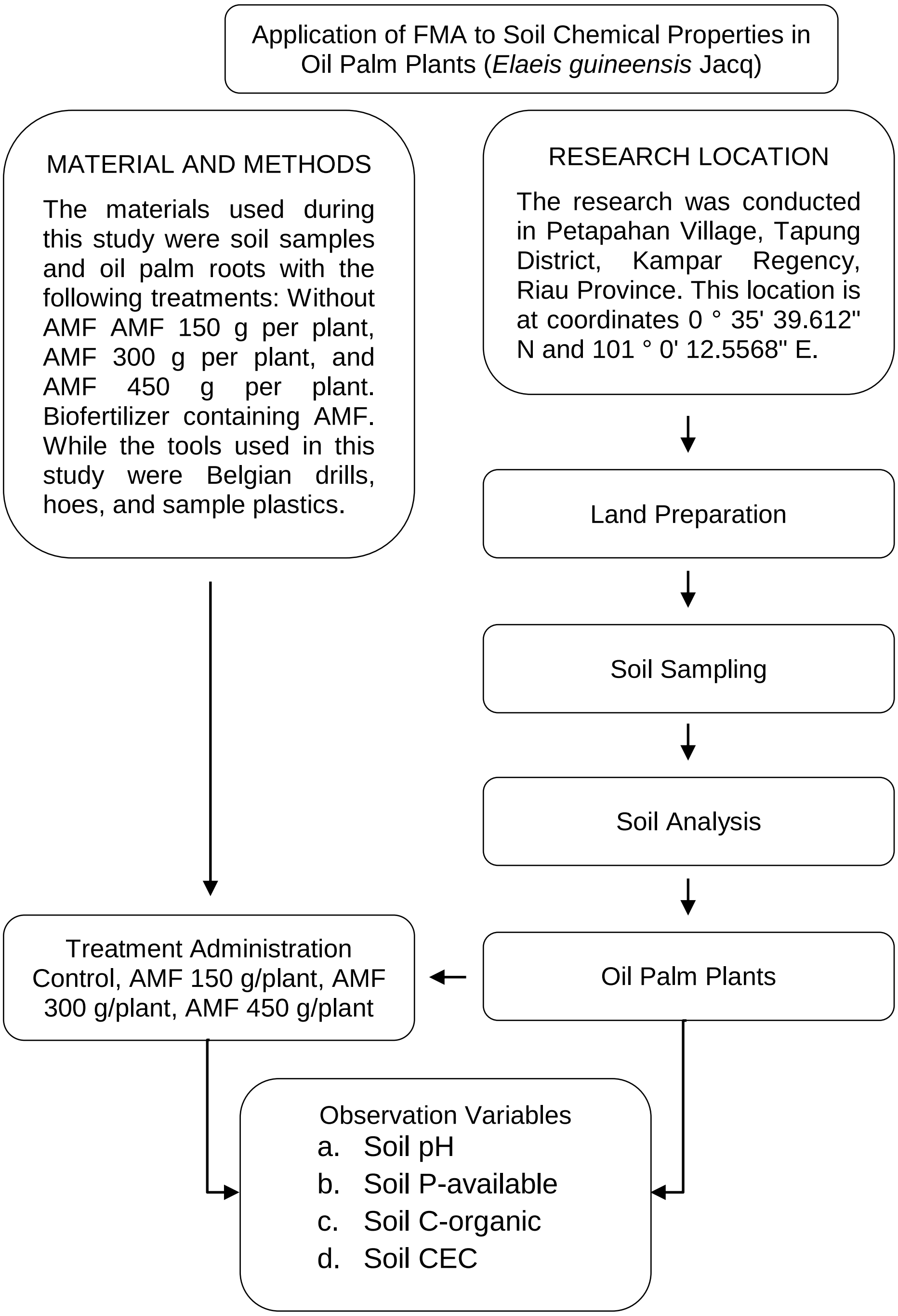

Figure 1. Research Flow Diagram

The materials used during this study were soil and root samples from oil palm plants with the following treatments: Without AMF, AMF 150 g per plant, AMF

300 g per plant and AMF 450 g per plant. Biofertilizer containing AMF The tools used in this study were Belgian drills, hoes, and sample plastics.

This research constitutes a field experiment employing a non-factorial utterly randomized design (CRD) for allocating treatments. The experimental treatments included four distinct levels of arbuscular mycorrhizal fungi (AMF) application: no AMF, 150 g of AMF per plant, 300 g of AMF per plant, and 450 g of AMF per plant. Each treatment was replicated five times, resulting in a total of 20 experimental units, with each unit comprising a single plant. Consequently, the overall number of plants utilized in this study was 20. The data collected were subjected to statistical analysis through variance analysis. To assess the differences among the treatments, subsequent analysis was performed using the Duncan New Multiple Range Test (DNMRT) at a significance threshold of 5%. Data processing was conducted using Excel and the SAS 9.0 software.

Soil sampling was executed around the oil palm plants, focusing on a 0 to 30 cm depth. Each sampling location underwent three repetitions, and the samples were then combined for laboratory analysis of soil chemistry. Soil samples were collected using a Belgian drill. The parameters analyzed included pH (measured electrometrically), organic carbon (determined by the Walkley and Black Method), available phosphorus (assessed using the P-Bray Method 1), and cation exchange capacity (CEC) of the soil. A flow diagram illustrating the research methodology is presented in Figure 1.

3. RESULT AND DISCUSSION

3.1 Soil Chemical Properties Before Application of Arbuscular Mycorrhizal Fungi (FMA)

Soil chemical properties (initial) before FMA application are presented in Table 1.

Table 1. Soil chemical properties (initial) of oil palm plants before FMA application

Parameter	Depth (0 – 30cm)	
	Value	Criteria*
pH	5,16	Acidic
C-Organic (%)	1,95	Low
P availability (mg.100 g^{-1})	20,81	Low
CEC (me.100 g^{-1})	2.78	Higly Low

Notes: * = Soil Chemical Properties Criteria (Balai Penelitian Tanah, 2009);

Table 1 shows the results of the analysis of soil chemical properties (initial) on Dystrudepts soil used in this study has an acidic pH. CEC content included very low criteria, and C-organic content and P-available content included low criteria.

3.2. Soil Chemical Properties 6 months after FMA application

3.2.1 Soil pH

The results of the variance analysis showed that the application of FMA had no significant effect on soil pH. presented in Table 2.

Table 2. pH of Dystrudepts soil at 0-30 cm depth 6 months after application of Arbuscular Mycorrhizal Fungi (FMA)

FMA Dosage (g per plant)	pH
0	5.55 ± 0.12 ^{m}
150	5.43 ± 0.12 ^{am}
300	5.66 ± 0.08 ^{m}
450	5.54 ± 0.10 ^{m}

Notes: Numbers followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at the 5% level; am = slightly acidic, m = acidic. Criteria for Soil Chemical Properties (Balai Penelitian Tanah, 2009).

In general, the application of arbuscular mycorrhizal fungi (AMF) increased soil pH compared to measurements taken prior to AMF application. This indicates that AMF contributes to alterations in the chemical properties of the soil, specifically by elevating soil pH, albeit to a modest extent. This finding aligns with the research conducted by Herawati et al. (2020), which suggests that the metabolic activities of AMF lead to the production and release of organic compounds that facilitate the binding of metal cations responsible for soil acidity, thereby increasing pH. Tan (1998) further supports this notion, asserting that organic compounds can effectively bind cations within the adsorption complex, leading to enhanced base saturation and a subsequent rise in soil pH.

Applying a 300 g AMF dose per plant emerged as the most effective treatment, achieving a soil pH of 5.66. In contrast, AMF doses of 150 g and 450 g per plant also resulted in increased soil pH, yet these values remained lower than that observed with the 300 g dose. This phenomenon may be attributed to the heightened competition for root colonization among oil palm plants at higher AMF doses. Barea et al. (2005) noted that administering AMF in optimal quantities can enhance the microbial population within the soil, leading to increased competition among microorganisms. Smith (2009) also highlighted that while nearly all agricultural plants can form associations with AMF, the benefits derived from such symbiosis can vary significantly.

3.2.2. P-availability

The results of the variance analysis showed that the provision of FMA had a significant effect on soil available P. The results of further tests on soil available P using DNMRT at the 5% level are presented in Table 3.

Table 3. P-available soil Dystrudepts at a depth of 0-30 cm 6 months after application of Arbuscular Mycorrhizal Fungi (AMF)

FMA dosage (g per plant)	P Availability (mg.100 g^{-1})
0	46.75 ± 0.46 a^{t}
150	31.54 ± 0.57 c^{s}
300	29.04 ± 1.03 c^{s}
450	35.97 ± 1.35 b^{s}

Notes: Numbers followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at the 5% level; s = medium, t = high. Soil Chemical Properties Criteria (Balai Penelitian Tanah, 2009).

Based on the observation, the dose of FMA at 150 g per plant was not significantly different from the dose of 300 g per plant but significantly different from the dose of no FMA and 450 g per plant. Table 3 shows that the highest P-available average is without FMA application at 46,754 mg.100 g-1. Before FMA application. This shows that phosphate in the soil is mostly bound in insoluble form and cannot be absorbed by plants. After applying FMA, the phosphatase enzyme produced by mycorrhiza can dissolve phosphate, making phosphate more available to plants. The decrease in available P in the treatment with FMA application is thought to be caused by plants' faster phosphate absorption. This is in line with the literature of Vázquez et al. (2000) stating that phosphatase activity was higher in the rhizosphere of FMA-colonised plants than in non-mycorrhizal plants (166% increase). According to Mukhlis (2014), the phosphatase enzyme can break the covalent bond between phosphorus (P) with Al3+, Fe3+, Ca2+, and clay ions with P, making phosphorus available to plants. According to Parniske (2008), the decrease in available P in the soil is thought to be because mycorrhiza has increased the absorption of P for the fungus' own metabolism and to be translocated to the host plant.

Mycorrhizal hyphae expand the absorption area of the roots, allowing the plant to absorb more phosphorus from the soil that is normally not reached by the roots alone. Therefore, when mycorrhizae are applied to the soil plants can absorb phosphorus more effectively, causing a decrease in available phosphorus levels in the soil through the help of mycorrhizal hyphae (Nasution, et al., 2014). This is in line with the research of Hazra et al. (2019) which states that the treatment without FMA application on pepper plants P-available is higher than the application of FMA 20 g per plant this is due to the uptake of phosphorus by mycorrhizal hyphae. According to Smith (2009), plants can increase phosphorus uptake if the roots are symbiotic with mycorrhizae. Furthermore, Farzaneh et al. (2011) stated that mycorrhizal inoculation can help the absorption of nutrients such as P, K, Mg, Fe, Mn, Zn and Cu in bean plants.

Plants infected with mycorrhizae have other mechanisms that help increase the absorption of more nutrients than uninfected plants. According to Lǚ et al. (2019) mycorrhizal plants can produce different root exudate compositions. These root exudates can increase the population of beneficial microbes in the rhizosphere region. Furthermore, Vázquez et al. (2000) stated that these microbes play a role in plants' providing nutrients and increasing the absorption of nutrients, such as phosphate-solubilizing bacteria and nitrogen-fixing bacteria.

3.2.3. C-Organic

The results of the variance analysis showed that the provision of FMA had a significant effect on soil organic C. The results of further tests on soil organic C using DNMRT at 5% are presented in Table 4.

Table 4. C-organic soil Dystrudepts at a depth of 0-30 cm 6 months after application of Arbuscular Mycorrhizal Fungi (AMF)

FMA dosage (g per plant)	C-Organic (%)
0	1.73 ± 0.04c^{r}
150	2.37 ± 0.12b^{s}
300	2.75 ± 0.17a^{s}
450	2.57 ± 0.05ab^{s}

Notes: Numbers followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at the 5% level; r = low. Soil Chemical Properties Criteria (Balai Penelitian Tanah, 2009).

From Table 4 it can be seen that the administration of Arbuscular Mycorrhizal Fungi (AMF) 6 months after application with doses of 150 g, 300 g and 450 g per plant has a higher C-organic content than without AMF administration. The administration of AMF at 300 g per plant was not significantly different from that of a dose of 450 g per plant. The administration of AMF at a dose of 150 g per plant was not significantly different from the dose of 450 g per plant but was significantly different from without AMF application. The highest C-organic was the administration of AMF at a dose of 300 g per plant.

Based on the results of observations, it is known that the metabolic activity of AMF can increase the C-organic content of the soil. This activity includes forming organic compounds that bind metal cations that cause soil acidity, so the pH increases (Table 1) and the C-organic content also increases. This is following the results of Suwarniati's research (2014), which stated that the administration of AMF caused the highest average percentage of C-organics and was significantly different from the control.

Additionally, the hyphae of AMF can contribute to the increase in C-organic when they die and decompose. The organic components of the AMF body serve as an additional carbon source for the soil. This finding is in accordance with the literature of Suwarniati (2014), who stated that AMF contributes to the increase of soil organic carbon (C-organic) and nitrogen (N-organic). The increase in C-organic is due to the presence of hyphae in the fungi themselves and the organic components of their bodies, which also serve as a source of C. AMF produce enzymes that facilitate their access to C, N, and P from organic material sources in the soil.

Mycorrhiza can facilitate the proliferation of other microorganisms in the soil involved in the decomposition of organic matter, which ultimately increases in soil C-organic. Table 8 illustrates that the provision of AMF at a rate of 300 g per plant results in the highest total bacterial population. This finding follows the literature of Nasution et al. (2014), which states that soil aggregates wrapped by external AMF hyphae can increase plant water availability. This more humid and stable environment also supports the growth of other microorganisms, increasing metabolic activity and enzyme production, thereby increasing organic C.

3.2.4. CEC (Cation Exchange Capacity)

The results of the variance analysis showed that the provision of FMA had a significant effect on the soil CEC. The results of further tests on the soil CEC using DNMRT at the 5% level are presented in Table 5.

Table 5. Dystrudepts soil KTK at a depth of 0-30 cm 6 months after application of Arbuscular Mycorrhizal Fungi (AMF)

FMA dosage (g per plant)	CEC (me.100 g^{-1})
0	2.42 ± 0.09 c^{sr}
150	2.63 ± 0.14 bc^{sr}
300	3.57 ± 0.24 a^{sr}
450	3.07± 0.05 b^{sr}

Notes: Numbers followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at the 5% level; sr = very low. Soil Chemical Properties Criteria (Balai Penelitian Tanah, 2009).

Table 5 shows that the administration of AMF to Dystrudepts soil with doses of 150 g, 300 g and 450 g is higher than without administration of AMF. The highest CEC is the administration of AMF with a dose of 300 g per plant of 3,578 me.100 g-1. The lowest CEC is found in soil without AMF application of 2.42 me.100 g-1. The administration of AMF 300 g per plant is significantly different from without administration of AMF, doses of 150 g and 450 g per plant, but the administration of AMF 150 g per plant is not significantly different from the administration of AMF with a dose of 450 g per plant.

Based on observations made on the administration of AMF, the CEC increased (Table 5). This is suspected because AMF activity can accelerate the soil decomposition process of organic matter.

According to (Mukhlis, 2014), organic materials' decomposition forms humus colloids through the humification process. Humus is a decomposed organic material with a high ability to hold and release cations. This compound functions as a negative colloid that can attract and store cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}) in the soil, thereby increasing the CEC.

This study showed that the application of AMF significantly increased the content of C-organic (Table 4) and CEC in the soil (Table 5). This increase occurred because AMF helped increase the amount of organic matter in the soil by adding root biomass and decomposed plant residues. Organic matter is rich in carboxyl (-COOH) and hydroxyl (-OH) groups; these organic colloids function as cation binders (eg K+, Ca2+, Mg2+), which increase the soil CEC. This follows the literature stating that the increase in CEC occurs because the presence of AMF helps the decomposition process, so the availability of nutrients increases, which also causes an increase in the cation exchange capacity in the soil. The content of organic matter can increase the soil CEC

The administration of AMF can affect changes in the soil's physical, chemical and biological properties. AMF can improve soil particle aggregation, improve soil structure, and create more pore space to accommodate cations so that the CEC increases. This follows the literature Tisdall & Oades (1979) stated that AMF affects the physical properties of the soil such as soil aggregation, the percentage of soil aggregates with a size of >2 mm is higher in plants inoculated with AMF than without AMF. According to Fall et al. (2022), the external hyphae of AMF produce a slimy substance called glomalin or glycoprotein which binds soil particles, thereby increasing soil stability. Syamsiyah et al. (2014) showed that mycorrhizal treatment could increase easily extractable glomalin-related soil protein by 20%.

4. CONCLUSION

The application of Arbuscular Mycorrhizal Fungi (AMF) at a dose of 300 g per plant proved the most effective treatment in increasing soil pH from 5.16 to 5.66, increasing soil organic carbon (C-organic) from 1.95% to 2.758%, and increasing soil CEC from 2.78 me.100 g-1 to 3.578 me.100 g-1. In contrast, the provision of AMF 300 g per plant resulted in the lowest observed increase in available P, compared to other treatments. Without the provision of AMF, this is attributed to the faster phosphate absorption by plants, which is thought to result from the application of AMF 300 g per plant. It can therefore be concluded that the provision of arbuscular mycorrhizal fungi at a dose of 300 g per plant in oil palm plants has the potential to increase pH, available P, organic C, CEC, and root infection.

ACKNOWLEDGMENT

The author would like to express his gratitude to the Central Plantation Services Laboratory in Pekanbaru, which provided the facilities and full support necessary to complete this research project.

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