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Optimizing Oil Palm Seedling Growth (*Elaeis guineensis* Jacq.) in the main nursery using NPK fertilizer and Mycorrhizal Biofertilizer

Gusmawartati[1], Arman Effendi AR[1,*], Erlida Ariani[1], Isna Rahma Dini[1]

Abstract

Oil palm (*Elaeis guineensis* Jacq.) is a valuable plantation commodity with promising development prospects. This research investigated the interaction between NPK fertilizer application and mycorrhizal biofertilizer on the growth of oil palm seedlings in the main nursery on Ultisol soil. The study was conducted using a factorial Completely Randomized Design (CRD). The first factor was NPK fertilizer 16:16:16 (P) with three levels: P1 = 33 g per plant, P2 = 40 g per plant, and P3 = 47 g per plant. The second factor was Mycorrhizal biofertilizer (M) with three levels: M0 = Control, M1 = 20 g per plant, and M2 = 40 g per plant. The parameters measured included plant height, corm diameter, leaf area, root volume, dry weight of seedlings, and percentage of roots infected with mycorrhiza. Statistical analysis was performed using variance analysis and an honest significant difference test at the 5% level using the SAS application. The results indicated that applying NPK fertilizer at a dose of 40 g per plant significantly increased plant height, corm diameter, leaf area, root volume, and dry weight of seedlings. Urea fertilizer at a dose of 3 g per plant also positively influenced plant height, corm diameter, leaf area, and dry weight of seedlings. Mycorrhizal biofertilizer at a dose of 20 g per plant resulted in increased plant height, corm diameter, leaf area, root volume, dry weight of seedlings, and percentage of roots infected with mycorrhiza. The combination of NPK fertilizer at a dose of 40 g and mycorrhizal biofertilizer at a dose of 20 g per plant showed significant improvements in plant height, corm diameter, leaf area, root volume, dry weight of seedlings, and percentage of roots infected with mycorrhiza.

Keywords: Biofertilizer, Compound NPK, Growth, Mycorrhiza, Oil Palm Seedlings

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) is a plant of high economic value as a source of vegetable oil. It plays a crucial role in national economic development by generating foreign exchange and improving people's welfare through job creation in Indonesia. Given the significance of oil palm plants, it is essential to consider strategies to effectively enhance both the quality and quantity of oil palm production. One critical aspect of agronomy that significantly impacts production is the nursery.

The nursery is a key factor in the success of oil palm cultivation in the field as it contributes to the growth and development of plants. According to Nurhadi et al. (2023), proper seed management in nurseries can produce high-quality seeds, resulting in healthy fruit and plant growth.

According to Jamidi et al. (2023), the nutrients nitrogen (N), phosphorus (P), and potassium (K) are the primary nutrients necessary to enhance the quality of oil palm (*Elaeis guineensis*) seedlings. Additional nutrients can be supplied through inorganic fertilizers, promoting rapid growth and resulting in seedlings of superior quality. Nitrogen, phosphorus, and potassium (NPK) fertilizer is one of the most prevalent inorganic fertilizers in plant cultivation. This formulation is rich in nitrogen, phosphorus, and potassium, facilitating robust plant development. Notably, NPK 16:16:16 fertilizer is a particularly effective option, offering a balanced blend of these crucial nutrients. Its high nitrogen, phosphorus, and potassium content makes it a highly suitable choice for enhancing plant growth and productivity (Aminullah et al., 2017).

The use of both inorganic and organic fertilizers remains prevalent due to the beneficial effects of organic fertilizers in enhancing the soil's physical, chemical, and biological fertility, particularly in marginal or low-fertility

*Correspondence: arman.effendi@lecturer.unri.ac.id
1) Universitas Riau - Kampus Bina Widya Km 12.5 Simpang Baru, Pekanbaru, Riau 28293, Indonesia

soils. Soil fertility, including soil biology, is crucial in supporting plant growth, as evidenced by the symbiotic relationship between plant roots and mycorrhizae facilitated by organic materials. This symbiosis enhances nutrient availability by improving nutrient solubility by associating plant roots with mycorrhizal fungal mycelium. Arbuscular mycorrhizal fungi (AMF) have been recognized for enhancing plant nutrient and water uptake. These fungi are widespread and commonly form symbiotic relationships with the roots of vascular plants, significantly contributing to plant growth and productivity (Nizar et al., 2023).

By utilizing the appropriate doses of organic and inorganic fertilizers, optimal growth of oil palm seedlings can be achieved. This study aims to investigate the impact of the interaction between NPK 16:16:16 fertilizer and mycorrhizal biofertilizer and determine the optimal dosage combination for promoting the growth of oil palm seedlings in the primary nursery on Ultisol soil medium.

2. Material and Methods

The research was conducted at the Experimental Garden of the Faculty of Agriculture, University of Riau, Bina Widya Campus, located in Pekanbaru. The following coordinates specify the geographical location of the campus: 0.510574° N latitude and 101.455422° E longitude. The research period spanned from June to November of 2023. The experimental design employed a factorial Completely Randomized Design (CRD), incorporating two factors: the initial application of NPK 16:16:16 (P) fertilizer at three levels (33 g, 40 g, and 47 g per plant) and the subsequent provision of mycorrhizal biofertilizer (M) at three levels (Control, 20 g, and 40 g per plant), administered every two weeks for four months, commencing at three months post-planting and continuing until seven months. The parameters that were observed included the following: plant height, tuber diameter, leaf area, volume, root length, dry weight of seedlings, and percentage of mycorrhizal infection. The collected data were subjected to statistical analysis using variance analysis. This analysis was then tested using the BNJ test at the 5% level, with the SAS application version 21.0.16 serving as the statistical software.

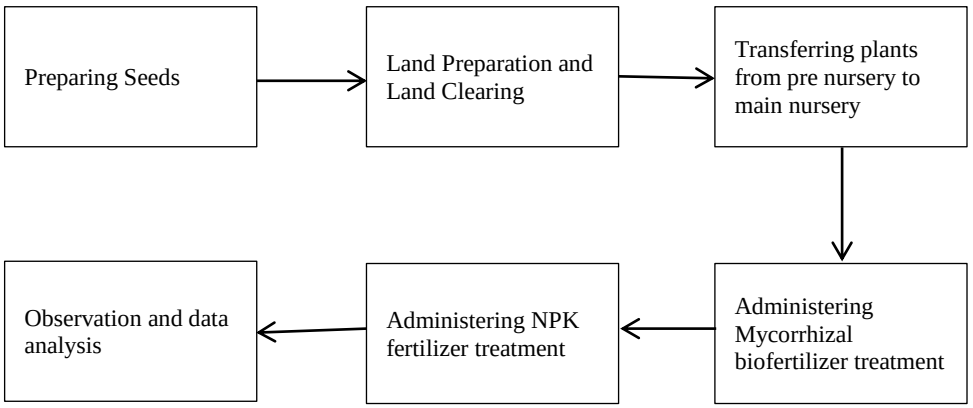

Figure 1. Research flow diagram

3. Results and Discussion

3.1. Increase in Plant Height

The findings of the data analysis of plant height increase parameters demonstrated that the interaction of NPK fertilizer and mycorrhizal biological fertilizer, as well as the single factor of NPK fertilizer and mycorrhizal biological fertilizer, influenced the increase in plant height of oil palm seedlings in the primary nursery. The results of the 5% BNJ further test on plant height increase are presented in Table 1.

Table 1. Height increase of oil palm seedlings aged 3-7 months

NPK fertilizer dosage (gr)	Mycorrhiza (g per plant)			Average
	0	2 0	4 0	
33	15.30 ± 0.20 c	15.4 2 ± 0.22 c	15.6 4 ± 0.19 b c	15.4 5 ± 0.21 b
40	15.75 ± 0.19 b c	1 8.26 ± 0.23 a	1 7.6 9 ± 0.21 ab	17.23 ± 0.22 a
47	15.3 3 ± 0.21 c	1 7.35 ± 0.10 ab	1 7.39 ± 0.18 a b	1 6.69 ± 0.22 a
Average	15.46 ± 0.22 b	1 7.01 ± 0.23 a	1 6.9 0 ± 0.24 a	

Notes: The numbers in the same row and column followed by the same lowercase letter are not significantly different according to the BNJ test at the 5% level.

Table 1 illustrates that the combination of applying NPK fertilizer at a rate of 40 g per plant with mycorrhiza at a rate of 20 g per plant yielded results that were not significantly different from the combination of NPK treatment at a rate of 40 g per plant with mycorrhiza at a rate of 40 g per plant, and NPK at a rate of 47 g per plant with mycorrhiza at rates of 20 g and 40 g per plant. However, these combinations significantly differed from the other in promoting plant height growth in oil palm seedlings in the main nursery. This result could be

attributed to the synergistic effect of applying NPK fertilizer at 40 g per plant with mycorrhiza at a rate of 20 g per plant, which enhances soil nutrient availability. Mycorrhizal fungi around the plant roots further support this, leading to significant plant height growth.

The availability of N, P, and K nutrients in the combinations of NPK fertilizer treatment at rates of 40 g per plant with mycorrhiza at rates of 20 g and 40 g per plant, as well as NPK fertilizer at a rate of 47 g per plant with mycorrhiza at rates of 20 g and 40 g per plant, are in balanced and sufficient conditions compared to other treatments. This balanced nutrient availability stimulates growth, particularly in increasing plant height in oil palm seedlings in the main nursery. NPK fertilizer, containing essential nutrients such as N, P, and K, supports seedling growth, with nitrogen playing a crucial role in promoting vegetative growth, including plant height.

According to Maroghi and Ekawati (2023), NPK fertilizer provides multiple macronutrients necessary for plant growth and development, including nitrogen, phosphorus, and potassium, each serving distinct functions. Nutrient absorption by plants through the roots is facilitated by mycorrhiza, which extends the nutrient absorption area through hyphal formation. The symbiotic relationship between mycorrhiza and plant roots optimizes nutrient absorption, enhancing growth. Additionally, mycorrhiza aids in improving root performance by increasing nutrient absorption, providing nutrients, and releasing nutrients bound to clay particles, thereby optimizing phosphorus absorption and promoting cell division, particularly in meristem development, influencing plant height growth.

Applying NPK fertilizer at doses of 40 g and 47 g per plant increased the height of oil palm seedlings significantly compared to 33 g per plant. This is likely due to the enhanced nutrient content in the soil resulting from the addition of NPK fertilizer, promoting optimal growth in oil palm seedlings. The application of NPK at a dose of 40 g per plant demonstrated notable growth improvement in seedlings, as the nutrient content in NPK increased sufficiently to support the growth of oil palm seedlings. However, the increase in NPK dosage to 47 g per plant did not show a significant difference, indicating that 40 g per plant was adequate for enhancing the height of oil palm seedlings in the main nursery. Consistent with Ramadhan & Nasrul (2022), the growth of oil palm plants is significantly influenced by the availability of nutrients N, P, and K, as NPK fertilizer application provides essential nutrients for the vegetative growth of oil palm seedlings. The N element is crucial in plant growth, particularly in vegetative stages, contributing to protein formation, chlorophyll synthesis, and other essential compounds that enhance plant growth. However, excessive use of inorganic fertilizers can negatively impact plant growth and development, as observed in the study by Rizal et al. (2022), where excessive NPK inorganic fertilizer usage leads to soil damage and hinders plant growth.

Applying mycorrhiza at doses of 20 g and 40 g per plant increased the height of oil palm seedlings compared to those without mycorrhiza. Mycorrhizal fungi are believed to infect the root cortex in mycorrhizal plants, establishing a mutually beneficial symbiosis that accelerates oil palm root growth. Mycorrhiza aids in water and nutrient absorption through external hyphae that spread throughout the planting medium, with finer hyphae than root hairs, enabling penetration into soil pores inaccessible to plant roots. This enhanced water availability facilitates nutrient absorption and boosts cell division and elongation, ultimately promoting the height growth of oil palm seedlings. In alignment with Sofian et al. (2022), mycorrhiza has been shown to enhance the growth of oil palm seedlings by assisting plant roots in water and nutrient uptake. According to Hidayati et al. (2015), external mycorrhizal hyphae extend beyond the roots, forming smaller and finer hyphal branches than root hairs, with a diameter of approximately 2 μm.

3.2. Increase in Tuber Diameter

The findings of the data analysis on the parameters for increasing the diameter of the tubers demonstrated that the interaction of NPK fertilizer and mycorrhizal biological fertilizer, as well as the single factors of NPK fertilizer and mycorrhizal biological fertilizer, exerted an effect on the increase—stump diameter of oil palm seedlings in the main nursery. The results of the 5% BNJ further test on the increase in stump diameter are presented in Table 2.

Table 2. Increase in diameter of oil palm seedlings aged 3-7 months

NPK fertilizer dosage (g)	Mycorrhiza (g per plant)			Average
	0	2 0	4 0	
33	1.69 ± 0.002 c	1.99 ± 0.003 bc	1.86 ± 0.001 bc	1.85 ± 0.001 b
40	1.93 ± 0.003 bc	2.37 ± 0.004 a	2.15 ± 0.002 ab	2 ,15 ± 0.003 a
47	1.98 ± 0.001 bc	2.03 ± 0.003 b	2.14 ± 0.003 ab	2 ,05 ± 0.001 a
Average	1.87 ± 0.003 b	2 ,13 ± 0.002 a	2 ,05 ± 0.002 a	

Notes: Numbers in the same row and column followed by the same lowercase letter are not significantly different according to the BNJ test at the 5% level.

Table 2 demonstrates that the combination of NPK fertilizer at a rate of 40 g per plant with mycorrhiza at a rate of 20 g per plant yielded results that were not significantly different from the combination of NPK treatment at 40 g per plant with mycorrhiza at 40 g per plant and NPK at 47 g per plant with mycorrhiza at 40 g per plant. However,

these combinations significantly differed from the other combinations in terms of increasing the diameter of oil palm seedling stems in the main nursery. This result could be attributed to the combination of NPK fertilizer at 40 g per plant with mycorrhiza at 20 g per plant, which provided sufficient plant nutrients to enhance the diameter of oil palm seedling stems in the main nursery. NPK fertilizer effectively improves soil fertility by containing essential nutrients such as nitrogen, phosphorus, and potassium, which play a crucial role in plant development. Mycorrhizal biofertilizer, containing mycorrhizal fungi, can enhance nutrient absorption when applied in the correct dosage, leading to optimal symbiosis and increased stem diameter growth. The size of the stem diameter is closely linked to the availability of nutrients required for metabolic processes like cell enlargement and division. Stems are vital organs for nutrient and water transport from the roots to other plant parts. According to Maroghi and Ekawati (2023), the uptake of NPK nutrients by roots and mycorrhizal support for enhanced nutrient absorption can contribute to increased stem size as the plant matures.

Applying NPK fertilizer at doses of 40 g and 47 g per plant increased the diameter of oil palm seedling tubers significantly compared to the 33 g dose. The 40 g dose of NPK resulted in noticeable growth enhancement in seedlings due to the sufficient availability of nutrients in the fertilizer. However, the difference in growth between the 40 g and 47 g doses was insignificant, indicating that 40 g per plant is adequate for promoting tuber diameter growth in oil palm seedlings at the main nursery. The nutrients in NPK fertilizer are crucial in stimulating seedling development by facilitating photosynthate accumulation through photosynthesis, particularly the N, P, and K present in NPK. According to Sitorus et al. (2021), administering nutrients at appropriate doses positively impacts plant growth, whereas insufficient doses may not yield significant results, and excessive doses can lead to toxicity.

Applying mycorrhizae at doses of 20 g and 40 g per plant also increased the diameter of oil palm seedling tubers compared to those without mycorrhiza. Mycorrhizal biofertilizer likely enhances the formation and spread of external hyphae in the soil, aiding plants in nutrient and water absorption. The availability of essential nutrients due to mycorrhizal association contributes to improved growth in oil palm seedlings. Mycorrhizal hyphae play a crucial role in facilitating the absorption of organic phosphorus elements by plant roots, leading to increased carbohydrate levels and efficient starch translocation to the stem, thereby influencing cell division and tuber formation in oil palm seedlings. In agreement with Kartika et al. (2016), plants inoculated with mycorrhiza exhibit larger tuber diameters due to enhanced nutrient absorption, particularly phosphorus, which supports cell division and reserves storage in stems and roots.

3.3. Increase in Leaf Area

The interaction of NPK fertilizer and mycorrhizal biofertilizer did not affect the increase in leaf area of oil palm seedlings, as demonstrated by the area increase data. However, applying NPK fertilizer in isolation or conjunction with mycorrhizal biofertilizer did elicit a significant effect on the augmentation of leaf area in oil palm seedlings. The results of the 5% BNJ further test on the increase in leaf area are presented in Table 3.

Table 3. Increase in leaf area of 3-7 month-old oil palm seedlings

NPK fertilizer dosage (g)	Mycorrhiza (g per plant)			Average
	0	2 0	4 0	
33	14.99 ± 0.80 a	15, 49 ± 0.70 a	16.50 ± 0.60 a	15.66 ± 0.66 b
40	1 5 .51 ± 0.83 a	17.73 ± 0.72 a	16.76 ± 0.62 a	16.67 ± 0.68 a
47	15.34 ± 0.87 a	16.70 ± 0.78 a	15.52 ± 0.62 a	15.85 ± 0.68 a b
Average	15.28 ± 0.85 b	16.64 ± 0.77 a	16.26 ± 0.66 a	

Notes: Numbers in the same row and column followed by the same lowercase letter are not significantly different according to the BNJ test at the 5% level.

Table 3 shows that the combination of NPK fertilizer and mycorrhizal biofertilizer did not significantly differ in increasing the leaf area of oil palm seedlings in the main nursery. This result is believed to be because, in addition to the effect of fertilizer application, the increase in the parameters of leaf area is also influenced by plant physiological processes. In line with the opinion of Nofrifaldi et al. (2023), a larger leaf area enhances the effectiveness of the leaf in absorbing light for the photosynthesis process, which is beneficial for the growth and development of plants. An optimal leaf area allows for the absorption of sufficient sunlight to support the photosynthesis process, which is related to leaf chlorophyll as the main element of plants for photosynthesis. According to Sukmawan and Riniarti (2022), chlorophyll is a photosynthetic pigment crucial for converting light energy into chemical energy, making the chlorophyll content of leaves an important physiological variable. Chlorophyll formation in the leaves influences the leaf area, with more chlorophyll leading to increased photosynthesis. This result aligns with the findings of Ariyanti et al. (2018), where leaf area reflects the extent of the area conducting photosynthesis so that a higher leaf area may increase photosynthesis. Therefore, a smooth photosynthesis process will directly impact the leaf surface area, which functions to capture sunlight.

Applying NPK fertilizer at 40 g and 47 g per plant increased leaf area in oil palm seedlings, with the 40 g dose

showing the most significant growth enhancement compared to the 33 g dose. The 47 g dose did not yield a significant difference, indicating that 40 g was sufficient for optimal leaf area in the main nursery. Adequate nutrient supply is essential for promoting plant metabolism, organ growth, and development. NPK fertilizer provides essential nitrogen (N) and phosphorus (P) elements crucial for leaf formation, facilitating cell division and enlargement, leading to faster leaf maturation and increased leaf count.

Application of mycorrhizae at rates of 20 g and 40 g per plant also increased the leaf area of oil palm seedlings compared to non-mycorrhizae plants. This improvement is attributed to mycorrhizal hyphae, which enhance water absorption and nutrient availability for photosynthesis. Improved photosynthesis increases energy production for cell division and enlargement, ultimately leading to expanded leaf area. Research by Leovini et al. (2014) supports the role of mycorrhizae in enhancing nutrient absorption, including both macro and micronutrients, to support increased leaf area.

3.4. Root Volume

An analysis of the root volume data revealed that the interaction of NPK fertilizer and mycorrhizal biofertilizer did not exert an effect on the root volume of oil palm seedlings. However, applying NPK fertilizer in isolation or in conjunction with mycorrhizal biofertilizer elicited a response in the root volume of oil palm seedlings. The results of the 5% BNJ further test on root volume are presented in Table 4.

Table 4. Root volume of 7-month-old oil palm seedlings

NPK fertilizer dosage (g)	Mycorrhiza (g per plant)			Average
	0	2 0	4 0	
33	33.83 ± 0.64 a	35.67 ± 0.60 a	36.17 ± 0.62 a	35.22 ± 0.64 b
40	35.17 ± 0.62 a	39.33 ± 0.61 a	39.17 ± 0.63 a	37.89 ± 0.62 a
47	37.17 ± 0.62 a	38.67 ± 0.64 a	37.22 ± 0.61 a	37.68 ± 0.68 a
Average	35.39 ± 0.61 b	37.89 ± 0.66 a	37.52 ± 0.64 a	

Notes: Numbers in the same row and column followed by the same lowercase letter are not significantly different according to the BNJ test at the 5% level.

The use of mycorrhizal biofertilizers did not lead to a significant increase in the root volume of oil palm seedlings in the main nursery. It is suspected that the combination of NPK and mycorrhizal biofertilizers at different doses has provided the necessary nutrients for the growth and development of oil palm seedling roots, but did not show significant effects on root volume in the main nursery. NPK compound fertilizers, particularly phosphorus, can promote plant root growth. Insufficient phosphorus can result in stunted root growth (Syamsuwirman et al., 2023). Moreover, mycorrhizal hyphae associated with plant roots release phosphatase enzymes that can make phosphorus bound by aluminum and iron available to plants. The availability of phosphorus is crucial for enhancing root growth through the proliferation of root hairs. Consistent with the findings of Satria et al. (2015), phosphorus can stimulate plant roots to improve nutrient absorption for plant growth. Adequate water and nitrogen availability can enhance photosynthesis rates, influencing root growth and development.

Applying NPK fertilizer at doses of 40 g and 47 g per plant increased the root volume of oil palm seedlings significantly compared to 33 g per plant. The application of 40 g of NPK per plant resulted in notable growth and development of seedlings, particularly in root volume. However, increasing the NPK dose to 47 g per plant did not show a significant difference, as 40 g per plant was sufficient to enhance the root volume of oil palm seedlings in the main nursery. The boost in root growth area was attributed to the potassium elements in the fertilizer, which promote root growth and enhance nutrient absorption. According to Setyawati et al. (2023), NPK is crucial in increasing plant root growth, facilitating better water and nutrient absorption, and improving plant resistance to water scarcity. Potassium elements are essential for photosynthesis enzymes, carbohydrate translocation, and CO_2 absorption in leaves. Ramadhan and Nasrul (2022) also emphasize the importance of macronutrients like N, P, and K in promoting vegetative growth, including root development, to ensure plants receive adequate nutrients and water for optimal growth.

Applying mycorrhizal doses at 20 g and 40 g per plant significantly increased the root volume of oil palm seedlings compared to those without mycorrhizal treatment. Mycorrhizal biofertilizers are believed to enhance water absorption and access to macro and micro elements beyond the reach of plant roots. Improved water absorption leads to the uptake of easily soluble nutrients through mass flow, increasing turgidity in guard cells and boosting photosynthesis rates. Enhanced photosynthesis facilitates the translocation of photosynthate for root growth, as Manurung et al. (2020) suggested. Furthermore, mycorrhizal hyphae can release bound phosphorus (P) into an available form for plants, as Lubis et al. (2019) noted. This yield increased P absorption promotes cell division, particularly in root organs, highlighting the role of mycorrhizae in enhancing nutrient uptake and root development.

3.5. Percentage of Mycorrhizal Infection

The findings of the data analysis concerning the percentage of roots infected with mycorrhiza revealed that the interaction of NPK fertilizer and mycorrhizal

biofertilizer, as well as the single factor of mycorrhizal biofertilizer, exerted an influence on the percentage of roots infected with mycorrhiza in oil palm seedlings. However, the single factor of NPK fertilizer demonstrated no effect on the percentage of roots infected with mycorrhiza in oil palm seedlings in the primary nursery.

The results of the 5% BNJ further test on the percentage of roots infected with mycorrhiza are presented in Table 5.

Table 5. Percentage of mycorrhizal infection in 7-month-old oil palm roots

NPK fertilizer dosage (g)	Mycorrhiza (% per plant)			Average
	0	2 0	4 0	
33	40.00 ± 0.69 cd	46.67 ± 0.60 bcd	50.00 ± 0.69 bcd	45.56 ± 0.61 a
40	33.33 ± 0.66 d	73.33 ± 0.61 a	53.33 ± 0.68 bc	53.33 ± 0.68 a
47	36.67 ± 0.69 cd	63.33 ± 0.62 ab	43.33 ± 0.67 cd	47.78 ± 0.69 a
Average	36.67 ± 0.67 c	61.11 ± 0.69 a	48.89 ± 0.65 b	

Notes: Numbers in the same row and column followed by the same lowercase letter are not significantly different according to the BNJ test at the 5% level.

The mycorrhizal colonization test confirmed the presence of endomycorrhizal type Mycorrhizal Vesicle Arbuscular (MVA) in the biofertilizer, with hyphae, arbuscules, and vesicles observed. Results from Table 5 indicated that the combination of 40 g NPK fertilizer and 20 g mycorrhizal application per plant was comparable to 4.7 g NPK and 2.0 g mycorrhizal per plant in terms of mycorrhizal infected roots in oil palm seedlings in the main nursery—factors such as planting medium condition and plant type influence mycorrhizal root infection. Loose, nutrient-rich media may reduce symbiosis, while low-nutrient conditions can increase mycorrhizal infection. This result aligns with previous research by Saputra et al. (2015), showing that soil type and nutrient content impact root infection rates.

The application of NPK fertilizer did not significantly affect the percentage of mycorrhizal infection in oil palm seedling roots, suggesting that nutrient availability in the soil may influence mycorrhizal development. Research by Syamsiyah et al. (2014) indicates that mycorrhizal fungi enhance N and P nutrient absorption in plants by promoting hyphal growth in roots, facilitating nutrient uptake. Infected roots exhibit increased nutrient absorption due to external hyphae extending beyond the roots, expanding the root's exploration area.

When administered at a rate of 20 g per plant, mycorrhizal inoculation increased the percentage of infected roots compared to higher doses and no inoculation. This finding demonstrates the beneficial symbiosis between mycorrhiza and oil palm seedling roots, with the 20 g dose showing the highest infection rate. Consistent with Eliyani et al.'s (2022) findings, the 20 g mycorrhiza treatment resulted in the highest root infection rate compared to the control group. Effective mycorrhizal inoculation relies on suitable media to maintain its natural properties, promoting hyphal growth within root tissues and enhancing nutrient absorption.

Microscopic examination of mycorrhizal-infected roots through staining revealed the presence of mycorrhizal structures such as hyphae, arbuscules, and vesicles. Roots containing any of these structures were considered mycorrhizal-infected. Colonization tests confirmed the presence of vesicular-arbuscular mycorrhizae (VAM) in the biofertilizer, with hyphae, arbuscules, and vesicles forming in oil palm seedling roots.

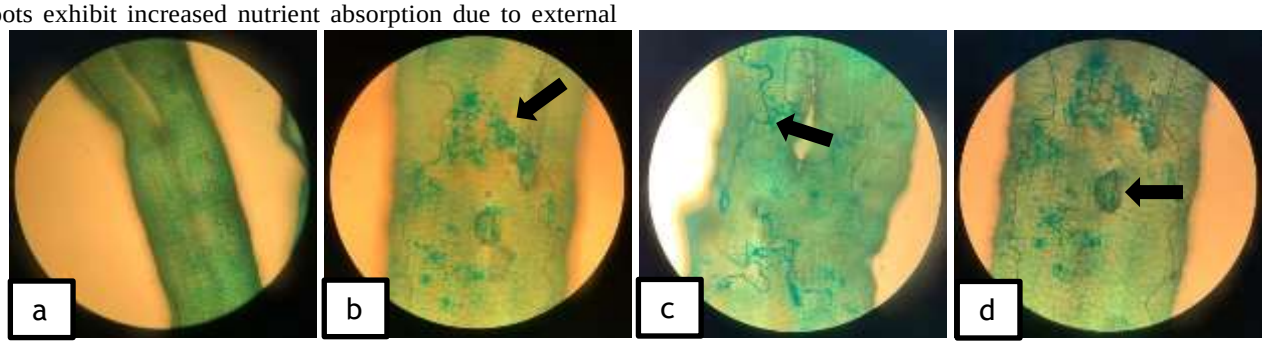

Figure 2. Roots of 7-month-old oil palm seedlings. (a) roots of oil palm seedlings without mycorrhizal infection; (b) hyphae; (c) arbuscules; (d) vesicles

Mycorrhizal hyphae play a pivotal role in enhancing the absorption of macro and micronutrients and water that are essential for plant growth. Two distinct types of MVA hyphae have been identified: external hyphae and internal hyphae, characterized by their fine and irregular thread-like morphology. According to Rini et al. (2021), external mycorrhizal hyphae extend from the root and penetrate the soil, enabling direct nutrient absorption and subsequent transfer to the root cell cortex. In contrast, internal hyphae are formed in the epidermis and cortex. The formation of

vesicles and arbuscules is a hallmark feature of the endomycorrhizal type of vesicular-arbuscular mycorrhiza (MVA). The arbuscular structure is comparable to tree branches, serving as a conduit for nutrient exchange between the fungus and its host. Conversely, vesiclesre are oval-shaped at the tips of hyphae within the host tissue and serve as storage organs (Basri, 2018).

3.6. Dry Weight of Seeds

The findings of the investigation into the dry weight parameter data for seedlings indicated that the interaction of NPK fertilizer and mycorrhizal biofertilizer, as well as the individual factor of NPK fertilizer and mycorrhizal biofertilizer, exerted an influence on the dry weight of oil palm seedlings in the primary nursery. The results of the 5% BNJ further test on the dry weight of seedlings are presented in Table 6.

Table 6 illustrates that the combination of applying NPK fertilizer at a rate of 40 g per plant with mycorrhiza at a rate of 20 g per plant yielded results that were not significantly different from the combination of NPK treatment at a rate of 33 g per plant with mycorrhiza at rates of 20 g and 40 g per plant, NPK at a rate of 40 g per plant with mycorrhiza at a rate of 40 g per plant, and NPK at a rate of 47 g per plant with mycorrhiza at rates of 0 g, 20 g, and 40 g per plant in terms of the dry weight parameters of oil palm seedlings in the main nursery. This suggests that the combination of NPK fertilizer at 40 g per plant with mycorrhiza at a rate of 20 g per plant provided sufficient nutrients to enhance the dry weight of oil palm seedlings.

Table 6. Dry weight of 7-month-old oil palm seedlings

NPK fertilizer dosage (g)	Mycorrhiza (g per plant)			Average
	0	2 0	4 0	
33	37.35 ± 0.40 b	40.11 ± 0.48 ab	40.12 ± 0.44 ab	39.19 ± 0.41 b
40	36.43 ± 0.43 b	46.67 ± 0.49 a	42.87 ± 0.43 ab	41.99 ± 0.40 a
47	40.58 ± 0.49 ab	42.54 ± 0.45 ab	41.18 ± 0.49 ab	41.43 ± 0.39 ab
Average	38.11 ± 0.45 b	43.11 ± 0.49 a	41.39 ± 0.50 a	

Notes: Numbers in the same row and column followed by the same lowercase letter are not significantly different according to the BNJ test at the 5% level.

The presence of N, P, and K nutrients in the combinations of NPK fertilizer treatment at rates of 33 g with mycorrhiza at rates of 20 g and 40 g per plant, NPK at a rate of 40 g with mycorrhiza at rates of 20 g and 40 g per plant, and NPK at a rate of 47 g with mycorrhiza at rates of 0 g, 20 g, and 40 g per plant was balanced and adequate compared to other treatments, promoting growth, particularly in the dry weight of oil palm seedlings. The proper administration and dosage of nutrients in NPK fertilizer stimulate vegetative growth, thereby influencing the dry weight of oil palm seedlings. According to Amri et al. (2018), plants' dry weight is influenced by plant height, number of leaf stalks, length of leaf stalks, and stem diameter. Additionally, the dry weight of seedlings is affected by the percentage of mycorrhiza infection in oil palm roots (Table 6), where higher infection levels indicate improved root, stem, and leaf growth, leading to increased seedling dry weight. Consistent with Istiqomah and Novanto (2023), mycorrhiza enhances water and nutrient uptake in polybags, resulting in higher root dry weight than plants without mycorrhiza.

The application of NPK fertilizer at 40 g and 47 g per plant led to increased dry weight in oil palm seedlings compared to the 33 g dose. The 40 g dose showed significant growth improvement, indicating optimal nutrient availability. However, the difference between 40 g and 47 g doses was insignificant, suggesting that 40 g was sufficient for optimal growth in the main nursery. Proper NPK dosage enhances nutrient availability, promoting better growth, as supported by Adnan et al. (2015)

Similarly, applying mycorrhizal doses of 20 g and 40 g per plant increased the dry weight of oil palm seedlings compared to no mycorrhizal treatment. Mycorrhizal biofertilizer likely boosts nutrient availability, stimulating root and crown growth. The symbiotic relationship between mycorrhizal and plant roots enhances root elongation and nutrient absorption, particularly phosphorus, which is crucial for root and root hair growth. This improved nutrient uptake leads to increased crown growth and seedling dry weight. Mycorrhizal infection aids in absorbing immobile nutrients like phosphorus, prioritizing root growth for metabolic processes (Malik et al., 2017). Mycorrhiza is vital in enhancing growth, root stimulation, and nutrient absorption, as Riduan et al. (2017) noted. Additionally, mycorrhiza can enhance soil structure, further boosting plant root dry weight. (Wicaksono et al., 2014).

4. Conclusion

In this study, combining 40 g per plant of NPK fertilizer with 20 g per plant of mycorrhizal biofertilizer positively impacted the growth of oil palm seedlings. It resulted in increased plant height, tuber diameter, dry weight of seedlings, and the percentage of roots infected with mycorrhizae. The optimal application of NPK fertilizer at 40 g per plant improved plant height, tuber diameter, leaf area, root volume, and dry weight of seedlings. Similarly, the best application of mycorrhizal biofertilizer at 20 g per plant enhanced plant height, tuber diameter, leaf area, root volume, dry weight of seedlings, and the percentage of roots infected with mycorrhizae in oil palm seedlings of the D x P PPKS 540 variety aged 3-7 months in the main nursery.

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