ISRG Journal of Agriculture and Veterinary Sciences (ISRGJAVS)

ISRG PUBLISHERS

Abbreviated Key Title: ISRG. J. Agri.Vet.Sci.

ISSN: 3048-8869 (Online)

Journal homepage: https://isrgpublishers.com/gjavs/

Volume – III Issue - III (May-June) 2026

Frequency: Bimonthly

"The Effectiveness of Mycorrhiza (Mycovir) in Improving the Adaptation of Root Systems of Pre-Nursery Oil Palm Seedlings in Marginal Environments".

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| **Received:** 09.05.2026 | **Accepted:** 14.05.2026 | **Published:** 16.05.2026

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Abstract

This study evaluated the effectiveness of mycorrhizal biofertilizer (Mycovir) in enhancing the adaptive growth of oil palm (Elaeis guineensis Jacq.) seedlings under marginal environmental conditions. Marginal conditions were simulated using nutrient-poor ultisol soil and low-quality swamp water as irrigation sources. A completely randomized design with five Mycovir dosage levels (0, 5, 10, 15, and 20 g/polybag) and five replications was applied. Results showed that mycorrhizal application had no significant effect on shoot growth parameters, but significantly increased root length. The highest root length (33.89 cm) was recorded at the 15 g/polybag treatment, indicating that mycorrhizae mainly support root development as an adaptive response under stress conditions. Therefore, 15 g/polybag was identified as the optimum dose for improving oil palm seedling adaptation during the pre-nursery stage.

Keywords: marginal environment; mycorrhiza; oil palm;; root system; ultisol soil

INTRODUCTION

Oil palm is a strategic commodity with a significant contribution to the national and global economy. However, increased productivity depends not only on genetic factors and field management but also on the quality of the seedlings from the early stages of cultivation (Woittiez et al., 2021; Darras et al., 2022). Therefore, the nursery phase is a critical stage that determines the success of plant growth in subsequent stages.

In this context, the early pre-nursery phase plays a crucial role because it is the phase where the root system is formed. The root system in this phase serves as the primary foundation for

determining the plant's nutrient uptake capacity and adaptability in subsequent stages, particularly in increasing the efficiency of soil resource exploration and response to environmental stresses (Lim et al., 2022; Freschet et al., 2021; Lynch, 2022).

Nevertheless, a fundamental problem in oil palm nurseries remains the low efficiency of nutrient uptake, particularly phosphorus, which directly impacts the quality of the resulting seedlings. This condition indicates limitations in the physiological function of roots in exploring soil resources, particularly in soils with low nutrient availability and limited phosphorus mobility (Chen et al., 2022; Liu et al., 2020).

This problem becomes even more complex when linked to environmental conditions. In Jambi Province, the majority of land is dominated by marginal land with Ultisol or Red-Yellow Podzolic (PMK) soil types, as well as swamps (Jambi Province in Figures, 2025). Furthermore, cultivation systems generally utilize swamp water as an irrigation source, which has relatively low chemical quality and potentially limits optimal plant growth.

In general, marginal land is characterized by low fertility, high acidity, and various physical and chemical constraints that limit agricultural productivity. These conditions are also related to the complexity of interactions between soil, plants, and microorganisms, which directly affect nutrient uptake efficiency and the stability of agricultural systems (Compant et al., 2021; Hart et al., 2023; Trivedi et al., 2021). Thus, optimizing the use of marginal environments presents both a challenge and an opportunity in developing sustainable cultivation systems.

In practice, conventional approaches involving increased inorganic fertilizer inputs often fail to provide optimal solutions and even potentially lead to nutrient inefficiency and environmental degradation. Therefore, more adaptive alternative approaches are needed, one of which is the use of biological agents such as mycorrhizae, which are known to increase nutrient use efficiency and plant resilience to suboptimal conditions (Rouphael & Colla, 2022; Calvo et al., 2022).

Mycorrhizae operate through a mutualistic symbiotic mechanism with host plants, enabling the expansion of the root absorption zone through the formation of an external hyphal network. However, the effectiveness of mycorrhizae is not universal and is strongly influenced by complex interactions between plants, soil, and other microorganisms in the soil, including microbiome dynamics and environmental conditions (Trivedi et al., 2021; Bender et al., 2022; Sánchez-Castro et al., 2022; Lehmann & Rillig, 2021).

Although the potential of mycorrhizae has been widely reported, most research on plantation crops has been conducted under relatively optimal environmental conditions. Consequently, understanding of mycorrhizal effectiveness in marginal environments remains limited. This indicates a research gap, particularly regarding the ability of mycorrhizae to support plant growth under complex and unstable environmental stress conditions (Hart et al., 2023; Bender et al., 2022).

These conditions are relevant to the study site, where nutrient-poor PMK soil is used in combination with swamp water with high iron content and low water quality. This combination of conditions has the potential to affect the symbiotic interaction between mycorrhizae and plants, primarily through root physiological disturbances and changes in soil nutrient availability (Bender et al., 2022; Sánchez-Castro et al., 2022).

Furthermore, previous research has generally focused on canopy growth parameters, while the response of the root system, the primary target of mycorrhizal activity, has not been comprehensively analyzed. However, the root system is the primary organ that first responds to interactions with soil microorganisms and plays a crucial role in determining nutrient uptake efficiency (Lynch, 2022; Freschet et al., 2021).

Based on this description, this study aims to evaluate the effectiveness of mycorrhizae (Mycovir) in enhancing the growth of oil palm seedlings under environmental conditions.

MATERIALS AND METHODS

Research Location

This research was conducted at the Experimental Garden of the Faculty of Agriculture, Science, and Technology, Graha Karya Muara Bulian University, Batang Hari Regency, Jambi Province, from August to October 2025. The research site was located at an elevation of approximately 22 meters above sea level with Ultisol or Red-Yellow Podzolic (PMK) soil type.

In general, Ultisol soil is classified as marginal land with low fertility, limited organic matter content, and a relatively low cation exchange capacity (CEC). This soil is also characterized by low base saturation and a high prevalence of iron (Fe) and aluminum (Al) oxides, which have the potential to bind nutrients, particularly phosphorus, making them less available to plants (Chen et al., 2022; Hart et al., 2023).

Furthermore, the relatively high soil acidity and unstable soil structure can limit root system development and reduce nutrient uptake efficiency. These conditions often lead to low productivity in Ultisol soils if not managed properly, particularly through soil amelioration and increased biological activity (Compant et al., 2021; Liu et al., 2020).

Nevertheless, field measurements indicate that the soil pH at the study site ranges from 6.5 to 6.7, indicating conditions relatively close to neutral. Functionally, however, the limited chemical and biological properties of Ultisol soils still impact nutrient availability and soil-plant interactions, particularly during the early stages of seedling growth. Therefore, biological approaches such as the use of mycorrhizae are relevant for increasing nutrient uptake efficiency under these conditions (Bender et al., 2022; Sánchez-Castro et al., 2022).

Tools and Materials

The tools used in this study included buckets, a two-wheeled cart, a hoe, a measuring tape, a soil sieve, an analytical balance, a vernier caliper, a ruler, a watering can, shade netting, 10 x 15 cm polybags, a sprayer, a camera, and stationery.

The materials used consisted of PMK soil as a planting medium, dolomite, and rock phosphate, with a composition of 500 g of soil, 5 g of dolomite, and 10 g of rock phosphate per polybag. The addition of dolomite and natural phosphate aimed to improve soil pH and increase nutrient availability, particularly phosphorus, which is generally strongly bound in acidic soils (Liu et al., 2020; Chen et al., 2022).

The biological agent used was a commercial mycorrhizal agent (Mycovir), which is known to increase root absorption area through the formation of external hyphae and improve plant nutrient utilization efficiency (Bender et al., 2022; Sánchez-Castro et al., 2022).

DOI: 10.5281/zenodo.20230557

The water used for irrigation came from swamp water, which is generally of low quality, with a relatively high dissolved iron (Fe) content, potential turbidity, and high organic matter content. The seedlings used were DXP Yangambi oil palm seedlings, commonly used in nursery systems due to their good growth potential (Darras et al., 2022).

Swamp Water Characteristics

The water characteristics used in this study were based on previous research in the same area, as direct laboratory analysis had not yet been conducted. In general, swamp water in the Batanghari region has relatively low quality, indicated by an acidic pH (around 5.2–5.3) and a high organic matter content, reflected in high BOD and COD values (Sari et al., 2018).

Furthermore, high total suspended solids (TSS) values indicate high levels of water turbidity, potentially affecting root growth. Reductive aquatic environments also increase the solubility of metals, particularly iron (Fe), which can cause plant physiological disorders, including toxicity and impaired nutrient uptake (Sánchez-Castro et al., 2022; Bender et al., 2022).

In line with this, several studies have shown that the water quality of the Batanghari River is classified as moderately polluted and does not fully meet standards as a raw water source (Putra & Siregar, 2017). This indicates that the use of swamp water as an irrigation source has the potential to be a limiting factor in plant growth.

However, a limitation of this study lies in the lack of direct laboratory analysis data on the quality of the swamp water used. Therefore, interpretation of the research results must take this limitation into account and serve as a basis for further research.

Research Stages

The study began with the preparation of a planting medium consisting of a mixture of PMK soil, dolomite, and rock phosphate, placed in polybags. Next, a single application of mycorrhizal (Mycovir) was carried out directly into the planting medium according to the treatment dosage to ensure initial interaction between the inoculum and the plant's root system (Bender et al., 2022).

Germinated oil palm seedlings were planted at a depth of 2–3 cm in polybags. Plant maintenance included watering with swamp water twice daily, follow-up fertilization with NPK 15-15-15 fertilizer at 60 days after planting, and mechanical and chemical control of plant pests as needed.

Observations were conducted from 4 to 12 weeks after planting at one-week intervals. Observed variables included plant height, stem diameter, leaf number, leaf length, and root length. These parameters were chosen because they represent indicators of vegetative growth and the plant's physiological response to environmental conditions (Freschet et al., 2021; Lynch, 2022).

Root length measurements were performed at the end of the observation period by carefully uprooting the plants to maintain the integrity of the root structure.

Experimental Design

This study used a Randomized Block Design (RBD) with one treatment factor, the mycorrhizal dose (Mycovir), consisting of five levels: 0 g (P0), 5 g (P1), 10 g (P2), 15 g (P3), and 20 g/polybag (P4).

Each treatment was replicated five times, resulting in 25 experimental units with a total of 100 plants. Each experimental unit consisted of four plants, with two plants selected as observation samples through a lottery method to minimize bias.

The spacing between plants within each experimental unit was 10 cm, while the spacing between individual experimental units was 60 cm. The use of RBD aims to control environmental variability that cannot be directly controlled, thereby increasing the accuracy and validity of the research results (Dutta et al., 2022).

Analysis Method

Observation data were analyzed using analysis of variance (ANOVA) to determine the effect of treatments on plant growth parameters. This method is used to statistically test differences between treatments under controlled experimental conditions (Dutta et al., 2022).

If the analysis results indicate a significant effect, a Duncan Multiple Range Test (DMRT) at the 5% level is used to further examine differences between treatments.

The experimental approach used in this study was to test the causal relationship between mycorrhizal dosage and plant growth responses under controlled, simulated marginal environmental conditions.

The experimental layout and layout of the test plant polybags are presented in Appendix Figures 1 and 2.

The ANOVA was chosen to minimize uncontrolled environmental variability, thereby increasing the internal validity of the study (Dutta et al., 2022).

RESULTS AND DISCUSSION

Crown Growth

Oil palm seedling crown growth was observed using plant height, stem diameter, leaf number, and leaf length. In general, all parameters showed a relatively uniform pattern of increase across all Mycovir treatments.

Table 1. Average crown growth of oil palm seedlings across various Mycovir treatments (12 week after planting)

Treatment	**Height (cm)**	**Diameter (cm)**	**Number of Leaves**	**Leaf Length (cm)**
P0	23.56	0.48	4.80	18.79
P1	24.19	0.49	4.80	18.87
P2	22.99	0.50	4.80	18.22
P3	23.64	0.43	4.70	19.00
P4	23.04	0.45	4.80	18.49

Description: The results of the analysis of variance show that all canopy growth parameters are not significantly different at the 5% level ($p > 0.05$).

The average canopy growth of oil palm seedlings at the end of the observation period (12 weeks after planting) showed that all parameters were relatively uniform across treatments (Table 1). This indicates that under marginal environmental conditions, canopy growth response is not significantly influenced by mycorrhizal application.

DOI: 10.5281/zenodo.20230557

The analysis showed that mycorrhizal application did not significantly affect all canopy growth parameters ($p > 0.05$). The mean values for plant height, stem diameter, number of leaves, and leaf length were relatively uniform across treatments, with values ranging closely.

Data presentation as mean ± standard error indicates that variation between replicates was relatively low, so differences between treatments were not statistically significant.

Table 2 Results of DMRT further tests on the growth parameters of oil palm seedling canopies.

Perlakuan	**Tinggi (cm)**	**Diameter (cm)**	**Jumlah Daun (helai)**	**Panjang Daun (cm)**	**Keterangan**
P0	23.50	0.47	4.70	18.50	a
P1	24.19	0.48	4.80	18.80	a
P2	22.99	0.50	4.70	18.22	a
P3	23.70	0.43	4.75	19.00	a
P4	23.10	0.46	4.72	18.60	a

The DMRT test results (Table 2) confirmed these findings, with all treatments showing the same letter notation. Therefore, it can be concluded that Mycovir administration did not significantly affect canopy growth at the 5% test level. This can be visualized in the canopy growth graph (Figure 1) as follows:

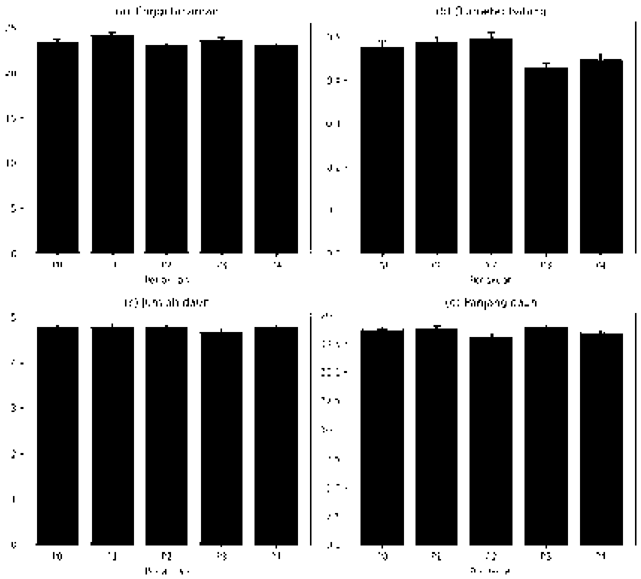

Figure 1. Effect of Mycovir dosage on oil palm seedling canopy growth at 12 weeks after planting: (a) plant height, (b) stem diameter, (c) number of leaves, and (d) leaf length. Error bars indicate ± standard error (SE).

Figure 3 shows the response of oil palm seedling canopy growth to various Mycovir dosages, including plant height (a), stem diameter (b), number of leaves (c), and leaf length (d). In general, all parameters showed a relatively uniform pattern across treatments with no significant differences.

The average values for each parameter tended to be close to each other, indicating that mycorrhizal application did not significantly affect canopy growth during the pre-nursery stage. This is consistent with the results of the analysis of variance and further tests, which showed no significant differences between treatments.

The relatively small error bars for all parameters indicate low variation between replicates, resulting in good data consistency. This condition confirms that the canopy growth response is more influenced by marginal environmental factors than by mycorrhizal treatment.

Root System Growth

The results of observations on root system growth are shown in Table 3 below:

Table 3. Observation data on root length of oil palm seedlings in various Mycovir treatments (cm)

Treatment	**Replication I**	**Replication II**	**Replication III**	**Replication IV**	**Replication V**	**Total**	**Average**
P0	29.05	29.00	30.30	28.60	28.80	145.75	29.15
P1	27.45	26.55	30.00	25.85	25.75	135.60	27.12
P2	29.90	35.90	29.95	29.25	29.80	154.80	30.96
P3	35.50	28.85	34.55	35.30	35.25	169.45	33.89
P4	30.35	26.55	22.50	23.40	23.25	126.05	25.21
Total	152.25	146.85	147.30	142.40	142.85	731.65	29.27

In contrast to crown growth, root length parameters showed a significant response to Mycovir application (Table 3). The 15 g/polybag dose resulted in the highest root length, followed by the 10 g/polybag dose, while the 20 g/polybag dose showed the lowest value.

DOI: 10.5281/zenodo.20230557

Table 4. Results of DMRT follow-up tests on oil palm seedling root length.

Treatment	Mean (cm)	SD	SE	CV (%)	Notasi
P0	29.15	0.67	0.30	2.29	b
P1	27.12	1.75	0.78	6.44	ab
P2	30.96	2.78	1.24	8.97	a
P3	33.89	2.84	1.27	8.38	a
P4	25.21	3.27	1.46	12.96	c

Note: Numbers followed by the same letter in the same column indicate no significant difference based on the DMRT test at the 5% level.

The DMRT test results (Table 4) indicate significant differences between treatments, confirming that mycorrhizae play a significant role in increasing root system growth.

This is supported by the analysis of variance (Table 5), where only root length showed a highly significant effect.

Table 5. Summary of analysis of variance results of the effect of Mycovir on oil palm seedling growth parameters.

Parameter	Fhitung	Keterangan
Tinggi tanaman	0.35	tn
Diameter batang	2.09	tn
Jumlah daun	0.14	tn
Panjang daun	0.27	tn
Panjang akar	8.47	**

Note: tn = not real; ** = very real

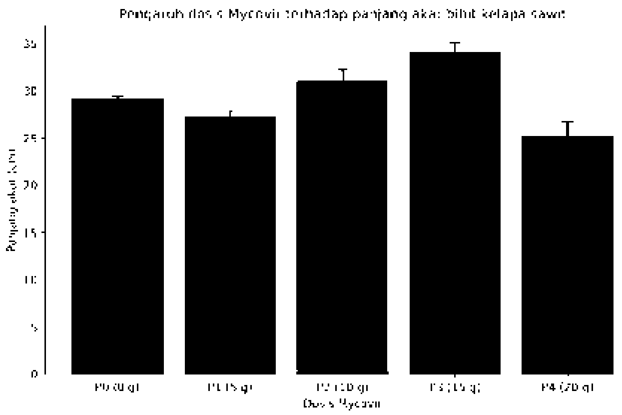

Figure 2. Effect of Mycovir dosage on root length of oil palm seedlings at the pre-nursery stage. Error bars indicate ± standard error (SE).

Figure 2 shows differences in the root length response of oil palm seedlings to various Mycovir dosages. The 15 g/polybag (P3) dosage treatment produced the highest root length, followed by the 10 g/polybag (P2) dosage treatment, while the 20 g/polybag (P4) dosage showed the lowest value.

The graph pattern demonstrates a nonlinear relationship between mycorrhizal dosage and root growth. Increasing the dosage to a certain level can increase growth, but at excessively high doses, the plant's response decreases. The relatively small error bars indicate low variation between replicates, resulting in fairly consistent results.

These results indicate that mycorrhizal fungi play an effective role in increasing root system growth as a form of plant adaptation to marginal environmental conditions.

Overall, the results of this study demonstrate a differentiation in response between the shoot and root systems. Mycorrhiza did not have a significant effect on crown growth, but had a significant effect on root growth, with an optimum dose of 15 g/polybag.

The differences in response between the canopy and root systems indicate that mycorrhizal effectiveness is contextual and influenced by environmental conditions. In marginal environments with high Fe content in soil and swamp water, canopy growth tends to be inhibited due to physiological stress.

Excess Fe in the growing medium can trigger the formation of reactive oxygen species (ROS), which disrupt photosynthesis and plant metabolism, thus limiting the growth of the upper part of the plant (Briat et al., 2015; Kobayashi & Nishizawa, 2012).

This explains why mycorrhizae did not show a significant effect on canopy parameters.

These findings indicate that plant responses to mycorrhizal application in marginal conditions depend not only on the presence of the symbiont but are also significantly influenced by the level of environmental stress the plant faces. Under certain conditions, such as high Fe content in the growing medium, plants tend to experience physiological disturbances that can limit the effectiveness of the symbiotic relationship. This indicates that the success of mycorrhizal inoculation in the field is not always linear with increasing dosage but is instead influenced by a complex set of environmental factors.

Conversely, the increase in root length indicates that mycorrhizae continue to function as an adaptive agent by increasing root exploration capacity. The external hyphal network of mycorrhizae expands the nutrient absorption zone, particularly for phosphorus, thereby increasing nutrient uptake efficiency.

The optimum response at a dose of 15 g/polybag indicates a non-linear relationship between mycorrhizal dose and plant growth. Too high a dose can increase the plant's carbon requirements to support mycorrhizal activity, thereby reducing energy allocation for growth.

The finding that root growth responded significantly to mycorrhizal application suggests that the primary role of mycorrhizae in these conditions is more directed at increasing root exploration capacity than at increasing shoot growth.

Thus, mycorrhizae in this study act as a root-oriented adaptation mechanism, particularly in marginal environmental conditions.

Conceptual Model of Plant Adaptation

The results of this study lead to the following model:

Mycorrhiza → Marginal Environment (FMK Soil + Swamp Water: high Fe, low nutrients) → Root System Adaptation → Increased

DOI: 10.5281/zenodo.20230557

Nutrient Uptake Efficiency → Plant Physiological Regulation → Seedling Growth

To further understand this model, see the visualization shown in Figure 3.

This model (Figure 3) shows that the effectiveness of Mycovir is contextual and acts as a biological mediator in enhancing plant adaptation through the root system. Increased root adaptive capacity has implications for nutrient uptake efficiency and plant physiological regulation, while shoot growth does not show a significant response (Lynch, 2022; Freschet et al., 2021).

Figure 3. Ecophysiological Model of Oil Palm Seedling Response to Mycorrhiza under Marginal Environmental Conditions in the Pre-nursery Stage

CONCLUSION

The application of mycorrhizal biofertilizer (Mycovir) demonstrated its potential as a biological strategy to improve the adaptive capacity of oil palm seedlings grown under marginal environmental conditions, particularly through stimulation of root system development. The findings suggest that root-oriented adaptation plays a more important role than shoot growth during the early pre-nursery stage when seedlings are exposed to nutrient limitations and low-quality irrigation water. The optimum dosage of 15 g/polybag can therefore be considered a practical recommendation for supporting early root establishment in suboptimal nursery environments.

Beyond its agronomic relevance, this study highlights the importance of integrating biological approaches into sustainable oil palm nursery management on marginal lands, especially in regions dominated by Ultisol soils and swamp ecosystems. However, the study was limited by the absence of direct laboratory analysis of swamp water quality and the short observation period restricted to the pre-nursery stage. Future studies should include detailed soil and water chemical analyses, evaluate mycorrhizal colonization rates, and extend observations to later growth phases to better understand the long-term effectiveness and physiological mechanisms of mycorrhizal adaptation in palm oil cultivation.

APPENDIX

ACKNOWLEDGMENT

We would like to express our deepest gratitude to the Serentak Bak Regam Muara Bulian Education Foundation, the Rector of Graha Karya Muara Bulian University, the Head of LPPM Graha Karya Muara Bulian University, the Head of the Field Laboratory Unit / Head of the Experimental Garden of the Faculty of Agriculture, Science and Technology, and colleagues for their support and assistance before, during and after the implementation of this research.

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