RESPONSE OF RUBBER (*Hevea brasiliensis* Mull. Arg) AT THE IMMATURE STAGE GROWTH TO VARIATIONS IN FERTILIZER APPLICATION

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ABSTRACT

Rubber (*Hevea brasiliensis*) is a commodity that plays a vital role in the Indonesian economy, although its productivity still lags behind that of competing countries. One factor contributing to low productivity is suboptimal cultivation practices, particularly during the nursery or immature plant phase. Proper fertilization is a key factor in producing high-quality seedlings. This study aimed to analyze the growth response of rubber seedlings to various combinations of inorganic fertilizer, biofertilizer, and liquid organic fertilizers (LOF), and to determine the most effective application rates. The experiment was conducted at the Ciparanje Experimental Field, Universitas Padjadjaran, from March to June 2025. A Randomized Complete Block Design (RCBD) was employed using nine-month-old rubber seedlings of clone PB 260, which were subjected to eight different fertilization treatments. Observed parameters included plant height, stem circumference, number of compound leaves, chlorophyll content, and leaf area. The results after three months of treatment showed that the application of the biofertilizer at 30 g per plant, combined with LOF at 6 $mL.L^{-1}$ produced the highest stem circumference growth and significantly increased plant height. Meanwhile, the treatment with biofertilizer at 10 g per plant combined with LOF at 6 $mL.L^{-1}$ resulted in the highest leaf area (638.8 cm^2), which was statistically significant. The recommended dose of inorganic NPKMg fertilizer at 10 g per plant produced the best results for the number of compound leaves (10 leaves). It can be concluded that an integrated fertilization approach, particularly the combination of biofertilizer and LOF, is highly effective in supporting the vegetative growth of rubber seedlings, although the optimal dosage varies depending on the targeted growth parameters.

Keywords: Biofertilizer; *Hevea brasiliensis*; Integrated Fertilization; Liquid Organic Fertilizer; Rubber.

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INTRODUCTION

The rubber commodity (*Hevea brasiliensis* Mull. Arg) makes a substantial contribution to the national economy, both as a source of foreign exchange and through the creation of employment opportunities for millions of smallholder farmers (Direktorat Jenderal Perkebunan, 2022). Since its introduction to the Dutch East Indies in 1864 and its widespread diffusion across various regions in the early 20th century, rubber has underpinned agrarian economic systems and interregional trade networks (Utama et al., 2020; Hidayat & Seprina, 2022).

Low productivity remains a major challenge for the sector. National rubber productivity, which averages only 1.0 t ha^{-1} $year^{-1}$, places Indonesia below competing countries such as India, Thailand, and Vietnam, despite Indonesian smallholders controlling approximately 85% of the total rubber plantation area (Santoso, 2018). Inappropriate cultivation techniques, particularly during the nursery phase, are among the main causes and directly affect plant quality and yield.

Seedling quality is determined by various factors, including genetic characteristics, physiological condition, and crop management practices, especially proper fertilization (Syafaah et al., 2015). Enhanced vegetative growth during the immature plant phase—such as plant height, stem diameter, and leaf number—serves as an important indicator of successful early-phase cultivation (Hakim, 2016; Purwati, 2013).

The application of inorganic NPKMg fertilizer supplies essential macronutrients, including nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg), which support key physiological processes such as chlorophyll formation, photosynthate transport, and latex production (Taiz & Zeiger, 2010; White & Karley, 2010). Meanwhile, biofertilizers improve soil fertility and enhance plant nutrient availability by facilitating nutrient supply through beneficial microorganisms and their metabolic products (Hettiarachchi et al., 2025). In addition, liquid organic fertilizer (LOF) is a liquid extract obtained from the fermentation of plant- and animal-derived organic materials and contains bioactive compounds that can further enhance soil fertility and nutrient uptake efficiency (Bahri et al., 2025).

Biofertilizers and LOF contain Bacillus sp. bacteria, which help increase nutrient absorption, produce plant growth regulators, and reduce the risk of fungal diseases in tapping fields. Bacillus sp. bacteria can produce phytohormones that can directly and indirectly support plant growth. Indirectly, bacterial phytohormones inhibit pathogen activity in plants, while direct phytohormones can enhance plant growth and facilitate the absorption of certain nutrients (Septiani, 2019).

An integrated fertilization approach combining inorganic, biological, and liquid organic fertilizers offers a sustainable solution to improve seedling quality and rubber productivity. Research evaluating seedling growth responses to variations in fertilizer type and dosage is, therefore, an important step toward developing more efficient and competitive rubber cultivation systems. This study aims to determine the optimal fertilizer type and dosage for rubber plant growth.

MATERIALS AND METHODS

The materials used in this experiment were nine-month-old rubber seedlings derived from seeds of clone PB 260. The tools used included a measuring tape, a ruler, a vernier caliper, a watering can, a measuring board, stationery, and documentation equipment.

The experiment was conducted at the Ciparanje Experimental Field, Faculty of Agriculture, Universitas Padjadjaran, Jatinangor, at an altitude of approximately ±750 m above sea level, with rainfall type C according to the Schmidt–Ferguson classification. The soils of the mid-altitude Jatinangor area belong to the Inceptisol soil order. Based on the research conducted by Setiawati et al. (2022), Inceptisol soils in Jatinangor exhibit the following chemical properties: a soil pH of 6.71 (neutral), 1.67% organic carbon (low), 0.18% total nitrogen (low), 40.90 mg/100 g total phosphorus (moderate), 2.79 ppm available phosphorus (very low), and 61.14 mg/100 g total potassium (very high). The soil has a cation exchange capacity (CEC) of 21.51 cmol kg^{-1} (moderate) and a base saturation of 63.69% (high), with a clayey texture. The experiment was carried out from March to June, 2025. The experimental design used was a Randomized Complete Block Design (RCBD) with eight treatments replicated six times. Data were analyzed using smartstatXL software, and significant differences between treatment means were further tested using Duncan's Multiple Range Test (DMRT) at a 5% significance level. The fertilization treatments were as follows:

A= NPKMg fertilizer at 10 g per plant (recommended dose)
B= NPKMg fertilizer at 7.5 g per plant
C= NPKMg fertilizer at 5 g per plant

D= NPKMg fertilizer at 2.5 g per plant
E= Biofertilizer at 10 g per plant + liquid organic fertilizer (LOF) at 6 $mL.L^{-1}$
F = Biofertilizer at 20 g per plant + LOF at 6 $mL.L^{-1}$
G= Biofertilizer at 30 g per plant + LOF at 6 $mL.L^{-1}$
H = Biofertilizer at 40 g per plant + LOF at 6 $mL.L^{-1}$

The experiment involved fertilizer application: NPKMg and the biofertilizer Bioneensis were buried at approximately 5 cm depth in a circular pattern around the plant, while Nasa liquid organic fertilizer was sprayed onto the leaves and stems. Fertilizer application was carried out twice, at 0 weeks after treatment (WAT) and 7 WAT. Observations were conducted from 0 WAT to 12 WAT. The parameters observed during the experiment included plant height, stem circumference, number of compound leaves, chlorophyll content, and leaf area.

1. Plant height: Plant height was measured from the base of the stem to the V-shaped growing point.
2. Stem circumference: Stem circumference was measured by first recording the stem diameter with a vernier caliper and then converting it to the circumference of a circle ($2\pi r$).
3. Number of compound leaves: The number of compound leaves was calculated by counting each additional leaf with the leaves fully opened.
4. Chlorophyll content: Chlorophyll measurements were conducted on the second and third leaves located at the base, middle, and tip of the leaf using a YIS-A type chlorophyll meter.
5. Leaf area: Leaf area was calculated on all fully opened leaves with observation intervals of every two weeks. Leaf area measurements were performed using ImageJ software.

RESULTS AND DISCUSSION

Results

The results showed that the treatments didn’t affect plant height and number of leaves (Table 1-2). However, combining liquid organic fertilizer (LOF) with biofertilizer increased chlorophyll content index, stem circumference, and leaf area (Table 3-5).

Table 1. The effect of providing inorganic fertilizer and biofertilizer on the height of rubber plants in the immature phase

Treatments	Plant Height (cm)		
	1 MAT	2 MAT	3 MAT
NPKMg fertilizer at 10 g per plant (recommended dose)	43.48 a	47.27 a	47.83 a
NPKMg fertilizer at 7.5 g per plant	35.50 a	39.62 a	47.30 a
NPKMg fertilizer at 5 g per plant	38.52 a	47.27 a	44.23 a
NPKMg fertilizer at 2.5 g per plant	32.23 a	36.53 a	39.00 a
Biofertilizer 10 g per plant + LOF at 6 $mL.L^{-1}$	34.11 a	35.66 a	40.37 a
Biofertilizer 20 g per plant + LOF at 6 $mL.L^{-1}$	38.21 a	39.52 a	30.60 a
Biofertilizer 30 g per plant + LOF at 6 $mL.L^{-1}$	33.73 a	38.75 a	49.86 a
Biofertilizer 40 g per plant + LOF at 6 $mL.L^{-1}$	23.34 a	24.39 a	36.70a

Notes:
Numbers followed by the same letter in the same column indicate no significant difference according to Duncan's Multiple Range Test at a significance level of 0.05. MAT was month(s) after treatment.

Discussion

According to Ataribaba et al. (2021), biological fertilizer is a material containing microorganisms that is applied to the soil as an inoculant to support the supply of specific nutrients for plants. Biofertilizer is a formulation containing nitrogen-fixing, phosphate-solubilizing, and IAA-producing microorganisms that promote plant growth. promoting bacteria (Situmorang et al., 2024). Liquid organic fertilizer helps fulfill plant nutritional requirements, including macro- and micronutrients, plant growth regulators, and soil microorganisms (Satria et al., 2021).

Inorganic fertilizers such as NPKMg produce stable growth, while biofertilizers are effective at certain doses. However, excessively high doses can reduce plant growth. Therefore, the appropriate type and dosage of fertilizer are crucial for supporting optimal plant growth.

Table 2. The effect of providing inorganic fertilizer and biofertilizer on the number of rubber leaves

Treatments	Number of leaves		
	1 MAT	2 MAT	3 MAT
NPKMg fertilizer at 10 g per plant (recommended dose)	7.6 a	9.7 a	10.0 a
NPKMg fertilizer at 7.5 g per plant	5.8 a	7.4 a	9.0 a
NPKMg fertilizer at 5 g per plant	6.0 a	7.0 a	7.0 a
NPKMg fertilizer at 2.5 g per plant	5.4 a	6.2 a	8.3 a
Biofertilizer 10 g per plant + LOF at 6 $mL.L^{-1}$	4.5 a	6.8 a	7.2 a
Biofertilizer 20 g per plant + LOF at 6 $mL.L^{-1}$	4.5 a	6.9 a	5.7 a
Biofertilizer 30 g per plant + LOF at 6 $mL.L^{-1}$	6.6 a	7.8 a	8.3 a
Biofertilizer 40 g per plant + LOF at 6 $mL.L^{-1}$	8.6 a	9.0 a	9.2 a

Notes:
Numbers followed by the same letter in the same column indicate no significant difference according to Duncan's Multiple Range Test at a significance level of 0.05. MAT was month(s) after treatment.

Table 3 indicated that although inorganic fertilizers and low doses of biofertilizer provided reasonably good growth, their effectiveness was still lower than that of the 30 g per plant biofertilizer combined with LOF. This finding is consistent with Purwati's (2013) finding that applying liquid organic fertilizer at a concentration of 9 mL L^{-1} can increase rubber plant stem diameter. Therefore, it can be concluded that the application of biofertilizer at 30 g per plant, combined with LOF at 6 $mL.L^{-1}$, was the best treatment for enhancing stem diameter growth by up to 3 MAT compared with the other treatments.

NPKMg fertilizer at a dose of 10 g per plant (recommended dose) showed the highest increase in chlorophyll content at 3 months after treatment (MAT), reaching a value of 87.15. This indicates that applying inorganic fertilizer at an optimal dose can significantly support chlorophyll synthesis, most likely by providing adequate nitrogen (N) and magnesium (Mg), which are key components of the chlorophyll molecule (Mengel & Kirkby, 2001).

Table 3. The effect of providing inorganic fertilizer and biofertilizer on the rubber stem circumference

Treatments	Number of leaves		
	1 MAT	2 MAT	3 MAT
NPKMg fertilizer at 10 g per plant (recommended dose)	1.8 a	2.0 a	2.2 b
NPKMg fertilizer at 7.5 g per plant	1.8 a	2.1 a	2.2 b
NPKMg fertilizer at 5 g per plant	1.7 a	2.0 a	2.0 b
NPKMg fertilizer at 2.5 g per plant	1.9 a	2.1 a	2.2 b
Biofertilizer 10 g per plant + LOF at 6 $mL.L^{-1}$	1.6 a	1.8 a	1.8 b
Biofertilizer 20 g per plant + LOF at 6 $mL.L^{-1}$	1.5 a	1.7 a	2.0 b
Biofertilizer 30 g per plant + LOF at 6 $mL.L^{-1}$	0.7 b	1.8 a	3.0 a
Biofertilizer 40 g per plant + LOF at 6 $mL.L^{-1}$	1.9 a	2.2 a	2.3 b

Notes:
Numbers followed by the same letter in the same column indicate no significant difference according to Duncan's Multiple Range Test at a significance level of 0.05. MAT was month(s) after treatment.

At lower doses (7.5 g, 5 g, and 2.5 g), although chlorophyll content continued to increase from month to month, the values at 3 MAT were significantly lower than those obtained with the recommended dose. For example, at 2.5 g per plant, chlorophyll content reached only 37.36, indicating that suboptimal fertilization reduces photosynthetic efficiency. This phenomenon is consistent with previous studies showing that deficiencies of Mg and N lead to chlorosis and reduced chlorophyll production (Römheld & Kirby, 2010).

Table 4. The effect of providing inorganic fertilizer and biofertilizer on the chlorophyll content index

Treatments	Chlorophyll content index		
	1 MAT	2 MAT	3 MAT
NPKMg fertilizer at 10 g per plant (recommended dose)	43.40 a	45.71 a	87.15 c
NPKMg fertilizer at 7.5 g per plant	45.54 a	43.42 a	53.06 c
NPKMg fertilizer at 5 g per plant	45.54 a	47.02 a	51.73 c
NPKMg fertilizer at 2.5 g per plant	44.92 a	46.50 a	37.36 c
Biofertilizer 10 g per plant + LOF at 6 $mL.L^{-1}$	43.61 a	36.62 b	52.00 a
Biofertilizer 20 g per plant + LOF at 6 $mL.L^{-1}$	44.96 a	40.15 ab	44.94 bc
Biofertilizer 30 g per plant + LOF at 6 $mL.L^{-1}$	43.07 a	39.78 ab	48.40 ab
Biofertilizer 40 g per plant + LOF at 6 $mL.L^{-1}$	40.84 a	46.69 a	36.35 c

Notes:
Numbers followed by the same letter in the same column indicate no significant difference according to Duncan's Multiple Range Test at a significance level of 0.05. MAT was month(s) after treatment.

Based on the dose–response curve, the effectiveness of biofertilizer appears to be non-linear. This finding supports the results of Bhardwaj et al. (2014), who reported that the success of biofertilizers is highly dependent on rhizosphere conditions, the presence of native microorganisms, and application concentration. In contrast, inorganic fertilizers provide a more direct and consistent response in increasing chlorophyll content, in line with classical agronomic literature (Brady & Weil, 2008). The reduced effectiveness observed at biofertilizer doses of 30–40 g per plant may also be explained by the "overcolonization" hypothesis, which posits that excessive microbial populations disrupt the rhizosphere ecosystem, leading to nutrient competition among microbial species and between microbes and plant roots (Kloepper & Ryu, 2006).

Table 5. The effect of providing inorganic fertilizer and biofertilizer on the leaf area

Treatments	Leaf Area (cm^2)		
	1 MAT	2 MAT	3 MAT
NPKMg fertilizer at 10 g per plant (recommended dose)	146.7 ab	154.9 b	354.4 c
NPKMg fertilizer at 7.5 g per plant	170.2 ab	158.4 b	317.5 c
NPKMg fertilizer at 5 g per plant	152.3 ab	157.2 b	301.0 c
NPKMg fertilizer at 2.5 g per plant	153.4 ab	175.2 b	321.9 c
Biofertilizer 10 g per plant + LOF at 6 $mL.L^{-1}$	63.9 c	384.5 a	638.5 a
Biofertilizer 20 g per plant + LOF at 6 $mL.L^{-1}$	175.2 a	367.4 a	370.2 bc
Biofertilizer 30 g per plant + LOF at 6 $mL.L^{-1}$	43.07 a	39.78 ab	48.40 ab
Biofertilizer 40 g per plant + LOF at 6 $mL.L^{-1}$	40.84 a	46.69 a	36.35 c

Notes:
Numbers followed by the same letter in the same column indicate no significant difference according to Duncan's Multiple Range Test at a significance level of 0.05. MAT was month(s) after treatment.

Furthermore, high chlorophyll content is not only closely correlated with photosynthetic capacity but also with biomass productivity, as stated by Lichtenthaler et al. (2007). Therefore, treatments that produce higher chlorophyll values have greater potential to enhance vegetative growth.

At 3 MAT, the biofertilizer treatment at 10 g per plant combined with LOF at 6 $mL.L^{-1}$

produced the highest leaf area (638.8 cm²) and was statistically significantly different from the other treatments. This indicates that the combination of biofertilizer and LOF at a low dose was highly effective in promoting leaf growth in rubber plants. This effectiveness can be attributed to the role of microorganisms contained in the biofertilizer, such as nitrogen-fixing, phosphate-solubilizing, and IAA-producing microbes, as well as plant growth regulators in the LOF that accelerate cell expansion and leaf tissue development.

Treatments with moderate doses of biofertilizer at 20 g per plant combined with LOF, also resulted in relatively high leaf area values (370.2 cm²), although they were not statistically significantly different from the inorganic fertilizer treatments. In contrast, higher doses of biofertilizer (30–40 g per plant) did not result in a significant increase in leaf area and even tended to decline compared with lower doses. The treatment at 30 g per plant produced a leaf area of 501.4 cm², while the 40 g per plant dose reached only 315.9 cm². This reduction is likely due to microbial saturation or antagonistic interactions among microbial populations that reduce nutrient uptake efficiency.

In the inorganic fertilizer treatments (NPKMg and NPK), leaf area also increased consistently. The highest value was observed in the NPK treatment at 2.5 g per plant, with a leaf area of 321.9 cm², followed by NPKMg at 7.5 g per plant (317.5 cm²). However, the increase was slower and more stable compared with that observed in the biofertilizer treatments. This suggests that inorganic fertilizers can support leaf growth consistently but are less effective than optimal biofertilizer treatments at significantly increasing leaf area.

Overall, it can be concluded that the combination of biofertilizer at 10 g per plant with LOF at 6 mL.L⁻¹ was the best treatment for enhancing leaf area in PB 260 rubber plants during the immature phase. Excessively high fertilizer doses tended to reduce physiological efficiency. Therefore, an integrated fertilization approach with appropriate dosage is essential for supporting optimal vegetative growth.

CONCLUSION

Fertilization exerted differential effects on the vegetative growth of rubber (Hevea brasiliensis) seedlings of clone PB 260 during the immature plant phase. The combination of biofertilizer and liquid organic fertilizer (LOF) effectively enhanced plant height, stem girth, and leaf area, with optimal application rates varying across growth parameters. Biofertilizer applied at a rate of 30 g per plant in combination with LOF at 6 mL.L⁻¹ produced the greatest increases in plant height and stem girth, whereas biofertilizer at 10 g per plant combined with LOF at 6 mL.L⁻¹ resulted in the highest leaf area. Inorganic NPKMg fertilization at the recommended rate of 10 g per plant yielded the best performance in terms of compound leaf number and chlorophyll content. Overall, an integrated fertilization strategy has the potential to improve rubber seedling quality; however, its effectiveness is strongly dependent on the appropriate selection of fertilizer type and application rate.

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