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Interaksi Pupuk Organik Cair GDM dan Pupuk NPK 16-16-16 terhadap Pertumbuhan Bibit Kakao (*Theobroma cacao* L.) pada Tanah Podsolik Merah Kuning

Interaction between GDM Liquid Organic Fertilizer and NPK 16-16-16 on the Growth of Cacao (*Theobroma cacao* L.) Seedlings Grown on Red-Yellow Podzolic Soil

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ABSTRACT

Background: Cacao (*Theobroma cacao* L.) is an economically important plantation crop in Indonesia, but its growth is constrained by seedling quality and the acidic, nutrient-poor conditions of Red-Yellow Podzolic (RYP) soil. Therefore, appropriate fertilization is essential to support seedling growth. **Objective:** This study aimed to evaluate the interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16 fertilizer, as well as their individual effects, on the vegetative growth of cacao seedlings. **Methods:** The experiment was arranged in a 4 x 4 factorial Completely Randomized Design with three replications using four GDM LOF concentrations and four NPK 16-16-16 application rates. Plant height, leaf number, stem diameter, root length, root volume, fresh weight, and dry weight were measured and analyzed using analysis of variance followed by Tukey's Honestly Significant Difference test at the 5% level. **Results:** The results showed that the interaction between GDM LOF and NPK 16-16-16 significantly affected all growth parameters except root length, which was influenced only by the individual effects of each treatment. The combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16 consistently resulted in the best overall growth performance of cacao seedlings. **Conclusions:** Overall, combined organic and inorganic fertilization improved cacao seedling growth on RYP soil, indicating that GDM LOF and NPK 16-16-16 can serve as an effective and cost-efficient fertilization strategy.

Keywords: *Cacao seedlings; GDM liquid organic fertilizer; NPK 16-16-16; RYP soil; vegetative growth*

ABSTRAK

Pendahuluan: Kakao (*Theobroma cacao* L.) merupakan tanaman perkebunan penting di Indonesia, tetapi pertumbuhannya terkendala oleh kualitas bibit dan kondisi tanah Podsolik Merah-Kuning (PMK) yang masam serta miskin hara. Oleh karena itu, pemupukan yang tepat diperlukan untuk mendukung pertumbuhan bibit. **Tujuan**: Penelitian ini bertujuan untuk mengevaluasi interaksi antara pupuk organik cair (POC) GDM dan pupuk NPK 16-16-16, serta pengaruh masing-masing perlakuan terhadap pertumbuhan vegetatif bibit kakao. **Metode**: Penelitian ini menggunakan Rancangan Acak Lengkap (RAL) faktorial 4 x 4 dengan tiga ulangan, yang terdiri atas empat konsentrasi POC GDM dan empat dosis pupuk NPK 16-16-16. Parameter yang diamati meliputi tinggi tanaman, jumlah daun, diameter batang, panjang akar, volume akar, bobot segar, dan bobot kering. Analisis data menggunakan analisis ragam dan dilanjutkan dengan uji Beda Nyata Jujur (BNJ) Tukey pada taraf 5%. **Hasil**: Hasil penelitian menunjukkan bahwa interaksi antara POC GDM dan pupuk NPK 16-16-16 berpengaruh nyata terhadap seluruh parameter pertumbuhan, kecuali panjang akar yang hanya dipengaruhi oleh pengaruh tunggal masing-masing perlakuan. Kombinasi POC GDM dengan konsentrasi 25 mL L^{-1} dan pupuk NPK 16-16-16 dengan dosis 12 g $polybag^{-1}$ secara konsisten menghasilkan pertumbuhan bibit kakao terbaik secara keseluruhan. **Kesimpulan**: Secara keseluruhan, kombinasi pupuk organik dan anorganik meningkatkan pertumbuhan bibit kakao pada tanah PMK, sehingga GDM LOF dan NPK 16-16-16 berpotensi menjadi strategi pemupukan yang efektif dan ekonomis.

Kata kunci: *Bibit kakao; pupuk organik cair GDM; NPK 16-16-16; tanah PMK; pertumbuhan vegetatif*

BACKGROUND

Cacao (*Theobroma cacao* Linnaeus) is one of Indonesia's most valuable plantation commodities, contributing substantially to rural livelihoods, agro-industrial development, and national export earnings. As one of the world's largest cacao-producing countries, Indonesia cultivates more than 1.4 million hectares of cacao plantations, with an annual production of approximately 641,360 tons (Badan Pusat Statistik Indonesia, 2026). Despite this considerable production area, national productivity remains relatively low, averaging only about 710-723 kg ha^{-1} year^{-1} (Kementerian Pertanian Republik Indonesia, 2026), which is far below the crop's estimated genetic potential of 2,000 kg ha^{-1} year^{-1}(Aminullah et al., 2017). This substantial yield gap suggests that improvements in cultivation practices are still needed across different stages of production, beginning with the nursery phase. The quality of planting materials established during early growth directly influences field establishment, crop vigor, and ultimately plantation productivity. Consequently, producing healthy and vigorous seedlings has become an essential component of sustainable cacao production systems.

The challenge is also evident in Riau Province, where cacao production has shown a declining trend in recent years. According to Badan Pusat Statistik Provinsi Riau (2026), total cacao production decreased from 1,038 tons in 2023 to 800 tons in 2025, representing a decline of approximately 22.93%. Although fluctuations in production may result from several interacting factors, including plantation management, pest and disease pressure, and climatic conditions, inadequate seedling quality remains one of the underlying constraints affecting long-term productivity. Seedlings with poorly developed root systems or limited vegetative growth often exhibit lower survival rates after transplanting and require longer periods to establish under field conditions. Improving seedling performance is therefore expected to enhance plantation establishment and contribute to more stable cacao production.

The success of cacao seedling production is strongly influenced by the physical, chemical, and biological characteristics of the growing medium. In many parts of Riau Province, nurseries commonly utilize Red-Yellow Podzolic (RYP) soil because of its wide availability. However, this soil presents several limitations for nursery production. RYP soil is generally acidic, contains relatively low organic matter, and exhibits limited nutrient availability due to the high fixation of phosphorus by aluminium (Al) and iron (Fe). These conditions restrict nutrient uptake, inhibit root development, and reduce overall plant growth. Previous studies have also shown that acidic soils with poor biological activity often limit the efficiency of applied fertilizers because a considerable proportion of nutrients becomes unavailable for plant absorption (Abdillah et al., 2020; Syaputra & Elfis, 2022). Consequently, improving nutrient availability while simultaneously enhancing soil biological properties has become an important strategy for optimizing cacao seedling growth on this type of soil.

Balanced fertilization is widely recognized as one of the most effective approaches for overcoming nutrient limitations during the nursery stage. Among inorganic fertilizers, NPK 16-16-16 is frequently recommended because it provides nitrogen, phosphorus, and potassium in balanced proportions that support vegetative development. Nitrogen promotes chlorophyll formation and leaf expansion, phosphorus plays a central role in energy transfer and root development, while potassium regulates enzyme activity, photosynthesis, and assimilate translocation. Appropriate application of these nutrients allows seedlings to develop stronger stems, larger leaf areas, and more vigorous root systems, thereby improving their readiness for field planting.

Several studies have demonstrated the benefits of NPK fertilization for cacao seedlings. Thedi (2022) reported that combining an appropriate growing medium with suitable NPK application significantly enhanced seedling growth, with 10 g polybag^{-1} producing the greatest plant height, leaf number, stem diameter and root volume. Likewise, Setiawan (2023) found that an application rate of 12 g plant^{-1} of NPK 16-16-16 resulted in superior vegetative growth compared with lower and higher fertilizer rates. More recently, Barus et al. (2025) confirmed that balanced NPK fertilization effectively stimulates vegetative development by supplying essential macronutrients in forms readily available for plant uptake (Kusmiati et al. 2026). These findings highlight the importance of determining the optimum fertilizer dosage rather than assuming that increasing fertilizer rates will always improve plant growth.

Besides inorganic fertilizers, the use of liquid organic fertilizers has attracted increasing attention because of their ability to improve both nutrient availability and soil biological activity. Unlike inorganic fertilizers that primarily function as nutrient sources, liquid organic fertilizers may also introduce beneficial microorganisms capable of accelerating organic matter decomposition, improving nutrient cycling, and increasing microbial diversity in the rhizosphere. GDM liquid organic fertilizer is one such product, containing beneficial microorganisms such as *Bacillus* spp., *Pseudomonas* spp., and *Azotobacter* spp., in addition to essential macro- and micronutrients.

These microorganisms contribute to nutrient mineralization, biological nitrogen fixation, and the production of growth-promoting compounds, thereby creating a more favorable environment for root development and nutrient uptake. Such plant growth-promoting rhizobacteria act through complementary direct and indirect mechanisms, including phosphate and potassium solubilization, siderophore-mediated iron acquisition, and phytohormone synthesis, which together enlarge the root absorptive surface and increase the pool of nutrients available for uptake (Khoso et al., 2024). Because these microbial mechanisms operate mainly on nutrient availability and root function rather than on total nutrient supply, GDM LOF is expected to be most effective when combined with a readily available nutrient source such as NPK fertilizer, rather than when applied alone.

Similar synergy between organic and inorganic inputs has also been reported for cacao grown under other marginal soil conditions, where combined fertilization consistently outperformed either input applied singly in supporting seedling establishment and nutrient uptake (Dogbatse et al., 2021; Prasatyio et al., 2025; Mahdalena et al., 2025). However, most previous studies on GDM LOF and NPK fertilization of cacao seedlings have evaluated each input separately or tested only a limited number of application rates, so that the interactive dose-response pattern between the two fertilizers on Red-Yellow Podzolic soil remains poorly quantified.

This study therefore examined a full 4 x 4 factorial combination of GDM LOF concentrations and NPK 16-16-16 rates to identify the fertilizer combination that most effectively overcomes the nutrient constraints of Red-Yellow Podzolic soil and to determine whether the two fertilizer sources act synergistically or independently across the range of vegetative growth parameters. Specifically, it was hypothesized that GDM LOF and NPK 16-16-16 would interact synergistically, so that their combined application would produce greater seedling growth than either fertilizer applied alone at an equivalent rate.

METHODS

Study Site and Experimental Materials

The experiment was conducted at the Experimental Garden of the Faculty of Agriculture, Universitas Islam Riau, Pekanbaru, Indonesia, from January to April 2026. The study evaluated the effects of GDM liquid organic fertilizer (LOF), NPK 16-16-16 fertilizer, and their interaction on the growth of cacao (*Theobroma cacao* L.) seedlings grown on Red-Yellow Podzolic (RYP) soil.

The experiment used BL-50 cacao seeds and RYP topsoil collected from Tenayan Raya District, Pekanbaru, with an initial soil pH of approximately 5.5. Before use, the soil was amended with dolomite to increase the pH to about 6.5 and mixed with rice husk charcoal to improve its physical properties. Because this liming and biochar amendment was applied uniformly to all treatments before transplanting, the growth responses reported below reflect the performance of GDM LOF and NPK 16-16-16 on a lime- and biochar-amended RYP substrate rather than on unamended, naturally acidic RYP soil; this pre-treatment is a standard nursery practice for this soil type and is discussed further where relevant to the interpretation of individual results.

The organic fertilizer used was GDM liquid organic fertilizer, containing 1.16% N, 2.13% P, 1.99% K, and beneficial microorganisms (*Bacillus* spp., *Pseudomonas* spp., and *Azotobacter* spp.). The inorganic fertilizer was NPK Mutiara 16-16-16, containing 16% N, 16% P_2O_5, and 16% K_2O. Other materials included dolomite and pesticides (Dithane M-45, Furadan 3GR, Decis 25 EC, and Amistar Top). Standard nursery equipment, including 25 x 30 cm polybags, a digital caliper, digital balance, graduated cylinder, measuring tape, watering can, hand sprayer, and a 50% shade net, was used throughout the study.

Experimental Design

The experiment was arranged in a 4 x 4 factorial Completely Randomized Design (CRD) with three replications. The first factor consisted of four concentrations of GDM liquid organic fertilizer: 0 (G0), 12.5 (G1), 25 (G2), and 37.5 mL L^{-1} (G3). The second factor consisted of four application rates of NPK 16-16-16 fertilizer: 0 (N0), 6 (N1), 12 (N2), and 18 g $polybag^{-1}$ (N3). Sixteen treatment combinations were obtained, resulting in 48 experimental units. Each unit consisted of four seedlings, with two plants selected for observation, giving a total of 192 seedlings.

Seedling Establishment and Fertilizer Application

Uniform cacao seeds were soaked in a Dithane M-45 solution (0.2 g L^{-1}) for 15 min before sowing. Seedlings were transplanted into polybags five days after germination and maintained under a 50% shade net. Polybags were arranged at a spacing of 20 x 20 cm within experimental units and 40 cm between units.

GDM liquid organic fertilizer was applied as a soil drench at 250 mL $polybag^{-1}$ every 14 days from 14 to 84 days after planting (DAP). NPK 16-16-16 fertilizer was applied in three equal splits at 35, 49, and 63 DAP by placing the fertilizer approximately 5 cm from the stem at a depth of 3 cm. Routine nursery management, including irrigation, weeding, and pest and disease control, was carried out uniformly for all treatments following standard nursery practices.

Observation Variables

Plant height, leaf number, stem diameter, root length, root volume, fresh weight, and dry weight were recorded. Plant height and leaf number were measured at 30, 60, and 90 DAP, whereas the remaining parameters were determined at 90 DAP. Root volume was determined using the water displacement method, in which the cleaned root system was submerged in a graduated cylinder filled with a known volume of water and the increase in water volume was recorded as the root volume. Dry weight was measured after oven-drying the samples at 60^{o}C until a constant weight was reached.

Statistical Analysis

The data were analyzed using analysis of variance (ANOVA). For each observed variable, the values recorded from the two measured plants within each experimental unit were averaged prior to analysis, so that each of the 48 experimental units contributed a single observation and the error degrees of freedom in the ANOVA were based on these 48 units. When significant treatment effects were detected, mean comparisons were performed using Tukey’s Honestly Significant Difference (HSD) test at the 5% significance level.

RESULTS AND DISCUSSION

Plant Height

Analysis of variance indicated that both the interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16, as well as the individual effects of each fertilizer, significantly influenced cacao seedling height at 90 days after planting (DAP) (Table 1).

The combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16 (G2N2) produced the tallest seedlings (39.25 cm), significantly outperforming most other treatments, while the unfertilized control (G0N0) recorded the lowest plant height (24.17 cm). These results indicate that combining organic and inorganic fertilizers provided a more balanced nutrient supply, creating favorable conditions for vegetative growth. Nitrogen, phosphorus, and potassium supplied by NPK fertilizer support chlorophyll formation, energy transfer, and cell expansion, whereas the beneficial microorganisms contained in GDM LOF improve nutrient availability through organic matter decomposition and biological nitrogen fixation (Meutia et al., 2021; Wulandari, 2023).

The plant height obtained in this study was higher than that reported by Sari et al. (2024). In the present study, the tallest cacao seedlings reached 39.25 cm at 90 DAP under the combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16, whereas Sari et al. (2024) reported a maximum plant height of 36.73 cm for cacao seedlings grown on Red-Yellow Podzolic soil. This finding suggests that the combination of GDM LOF and NPK 16-16-16 was effective in promoting seedling growth under Red-Yellow Podzolic soil conditions. However, increasing the NPK application rate from 12 to 18 g $polybag^{-1}$ at the 25 mL L^{-1} GDM LOF level did not significantly increase plant height, as indicated by the values of 39.25 and 37.58 cm, respectively. This finding indicates that the nutrient requirements of the seedlings were likely met at 12 g polybag^{-1}, while the higher fertilizer rate did not provide additional benefits to plant growth because nutrient uptake had reached an optimum level (Lestari et al., 2016).

Table 1. Mean plant height of cacao seedlings at 90 DAP under GDM LOF and NPK 16-16-16 treatments (cm).

GDM LOF (mL L^{-1})	N0 (0 g)	N1 (6 g)	N2 (12 g)	N3 (18 g)	Mean
G0 (0)	24.17 h	24.45 h	27.38 g	28.82 g	26.20 c
G1 (12.5)	28.18 g	29.88 fg	31.83 ef	32.47 def	30.59 b
G2 (25)	31.90 ef	34.63 cd	39.25 a	37.58 ab	35.84 a
G3 (37.5)	33.97 cde	35.03 bcd	36.15 bc	36.43 bc	35.40 a
Mean	29.55 c	31.00 b	33.65 a	33.83 a	
CV = 2.82%		HSD G & N = 1.00		HSD GN = 2.75	

*Values followed by the same lowercase letter are not significantly different at the 5% HSD level.

Leaf Number

Analysis of variance showed that both the interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16, as well as the individual effects of each fertilizer, significantly influenced the number of cacao seedling leaves at 90 days after planting (DAP). The mean leaf numbers for each treatment are presented in Table 2.

Table 2. Mean leaf number of cacao seedlings at 90 DAP under GDM LOF and NPK 16-16-16 treatments (leaves).

GDM LOF (mL L^{-1})	N0 (0 g)	N1 (6 g)	N2 (12 g)	N3 (18 g)	Mean
G0 (0)	16.50 c	17.00 bc	17.00 bc	17.33 bc	16.96 b
G1 (12.5)	17.33 bc	17.33 bc	17.67 bc	17.83 bc	17.54 b
G2 (25)	18.00 bc	18.17 bc	22.00 a	21.50 a	19.92 a
G3 (37.5)	18.33 bc	19.00 abc	19.50 abc	19.67 ab	19.13 a
Mean	17.54 b	17.88 b	19.04 a	19.08 a	
CV = 5.67%		HSD G & N = 1.16		HSD GN = 3.17	

*Values followed by the same lowercase letter are not significantly different at the 5% HSD level

The combination of 25 mL L^{-1} GDM LOF and 12 g polybag^{-1} NPK 16-16-16 (G2N2) produced the highest leaf number (22 leaves), whereas the unfertilized control (G0N0) recorded the lowest value (16.50 leaves). This result indicates that integrating organic and inorganic fertilizers created a more balanced nutrient supply, thereby supporting leaf initiation and expansion during the vegetative stage. Nitrogen supplied by NPK fertilizer promotes chlorophyll synthesis and cell division, while potassium enhances photosynthetic efficiency through stomatal regulation and assimilate translocation (Hasibuan et al., 2022). In addition, the beneficial microorganisms present in GDM LOF improve nutrient availability by accelerating organic matter decomposition and nutrient mineralization, creating more favorable conditions for leaf development (Meutia et al., 2021). These findings are consistent with those of Singgo et al. (2025), who reported that the application of liquid organic fertilizer improved the vegetative growth of cacao seedlings by enhancing nutrient availability and supporting leaf formation under nursery conditions.

Although increasing the NPK rate from 12 to 18 g polybag^{-1} maintained relatively high leaf numbers, the difference was not statistically significant. This suggests that the nutrient requirement for leaf development had already been fulfilled at 12 g polybag^{-1}, and further fertilizer application did not provide additional benefits. Overall, the combined application of GDM LOF and NPK 16-16-16 proved effective in promoting leaf development and improving the vegetative growth of cacao seedlings cultivated on Red-Yellow Podzolic soil.

Stem Diameter

Analysis of variance revealed that both the interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16, as well as the individual effects of each fertilizer, significantly affected the stem diameter of cacao seedlings at 90 days after planting (DAP). The mean stem diameter for each treatment is presented in Table 3

Table 3. Mean stem diameter of cacao seedlings at 90 DAP under GDM LOF and NPK 16-16-16 treatments (mm).

GDM LOF (mL L^{-1})	N0 (0 g)	N1 (6 g)	N2 (12 g)	N3 (18 g)	Mean
G0 (0)	5.01 j	5.22 ij	5.32 hij	5.43 ghi	5.25 c
G1 (12.5)	5.32 ij	5.54 f-i	5.72 fgh	5.81 fg	5.59 b
G2 (25)	5.92 f	6.60 e	8.99 a	7.95 b	7.36 a
G3 (37.5)	6.95 de	7.11 d	7.33 cd	7.56 c	7.24 a
Mean	5.80 d	6.12 c	6.84a	6.69 b	
CV = 2.04%		HSD G & N = 0.14		HSD GN = 0.39	

*Values followed by the same lowercase letter are not significantly different at the 5% HSD level.

The combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16 (G2N2) produced the largest stem diameter (8.99 mm), while the control (G0N0) recorded the smallest (5.01 mm). This indicates that combined organic-inorganic fertilization supplied sufficient nutrients to support cambial activity and stem thickening. Nitrogen and phosphorus contribute to protein synthesis, cell division, and energy transfer, all of which drive secondary stem growth (Shrivastav et al., 2020), while GDM LOF enhances soil biological activity and nutrient uptake efficiency, supporting stronger vegetative development (Meutia et al., 2021).

The stem diameter obtained in the present study was higher than that reported by Meutia et al. (2021) using GDM LOF alone. However, direct comparison with the value reported by Sari et al. (2024) should be interpreted cautiously because differences in fertilizer type, application rate, soil condition, and seedling age may affect stem diameter.

Increasing the NPK rate from 12 to 18 g $polybag^{-1}$ did not further increase stem diameter, suggesting the optimum requirement was already met at 12 g $polybag^{-1}$; higher rates may lower nutrient use efficiency due to nutrient imbalance or increased root-zone osmotic pressure (Lestari et al., 2016). Overall, balanced GDM LOF-NPK fertilization proved effective for stem development and vigorous seedling growth.

Root Length

Analysis of variance showed that the interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16 did not significantly affect root length at 90 days after planting (DAP). However, the individual effects of both fertilizers were significant (Table 4). The absence of a significant interaction indicates that GDM LOF and NPK 16-16-16 influenced root elongation independently. The highest mean root length was recorded with 37.5 mL L^{-1} GDM LOF (G3), reaching 36.07 cm, although it was not significantly different from 25 mL L^{-1} (G2). Likewise, the application of 18 g $polybag^{-1}$ NPK (N3) produced the longest roots but showed no significant difference from 12 g $polybag^{-1}$ (N2), suggesting that the lower rate was sufficient to meet the nutrient requirement for root growth.

Table 4. Mean root length of cacao seedlings at 90 DAP under GDM LOF and NPK 16-16-16 treatments (cm).

GDM LOF (mL L^{-1})	N0 (0 g)	N1 (6 g)	N2 (12 g)	N3 (18 g)	Mean
G0 (0)	23.75	26.85	28.93	31.05	27.65 b
G1 (12.5)	25.80	29.08	31.00	34.82	30.18 b
G2 (25)	26.62	33.07	40.87	37.84	34.60 a
G3 (37.5)	28.58	35.25	40.30	40.13	36.07 a
Mean	26.19 c	31.06 b	35.28 a	35.96 a	
CV = 7.25%		HSD G & N = 2.58			

*Values followed by the same lowercase letter are not significantly different at the 5% HSD level.

Improved root development may result from nutrients and beneficial microorganisms in GDM LOF, which enhance soil fertility and stimulate root elongation (Grover et al., 2021). Phosphorus supplied by NPK also supports root meristem development and cell division, thereby promoting root growth (Niu et al., 2013). Root lengths in this study were comparable to those reported by Meutia et al. (2021) and considerably higher than the 23.20 cm reported by Singgo et al. (2025), indicating favorable root development under combined GDM LOF and NPK fertilization.

The lack of interaction between fertilizers may be related to the characteristics of Red-Yellow Podzolic soil. Because the growing medium was limed with dolomite to increase pH from 5.5 to about 6.5 before transplanting, exchangeable Al^{3+} was likely largely precipitated before the trial began, making persistent Al toxicity a less likely explanation. A more plausible explanation is that root elongation in confined polybags is mainly limited by physical factors, such as substrate bulk density, pore structure, and restricted rooting volume, which may constrain root length independently of nutrient supply and cause root growth to respond primarily to the individual effects of each fertilizer (Situmeang & Sukmadewi, 2025; Syaputra & Elfis, 2022).

Root Volume

Analysis of variance showed that both the interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16, as well as the individual effects of each fertilizer, significantly affected the root volume of cacao seedlings at 90 days after planting (Table 5).

The combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16 (G2N2) produced the largest root volume (11.83 cm^3), while the control treatment (G0N0) recorded the lowest value (3.00 cm^3). This result indicates that the combined application of organic and inorganic fertilizers promoted the development of a more extensive root system, thereby increasing the plant's capacity to absorb water and nutrients. Based on mechanisms reported elsewhere in the literature, the organic matter and beneficial microorganisms in GDM LOF are thought to improve soil aggregation, porosity, and nutrient availability, while reducing phosphorus fixation by aluminium and iron in Red-Yellow Podzolic soil; however, soil aggregation, porosity, and exchangeable Al/Fe were not directly measured in the present trial, so this remains a plausible explanation for the observed root volume response rather than a confirmed mechanism (Niu et al., 2013; Yupanqui et al., 2026).

The root volume observed in the present study was substantially higher than the 5.37 cm^3 reported by Meutia et al. (2021) using GDM LOF alone, indicating that the addition of NPK 16-16-16 enhanced the effectiveness of liquid organic fertilizer in stimulating root growth. Similar findings were reported by Singgo et al. (2025), who observed that the application of liquid organic fertilizer improved root development by creating a more favorable growing medium and increasing nutrient availability for cacao seedlings.

The relatively high coefficient of variation for this variable (16.91%) likely reflects the sensitivity of the water-displacement method to how thoroughly roots were cleaned and drained, so part of the variability among replicates may stem from measurement handling rather than treatment effects alone. Overall, integrating GDM LOF with balanced NPK fertilization effectively promoted root system development, supporting vigorous vegetative growth.

Table 5. Mean root volume of cacao seedlings at 90 DAP under GDM LOF and NPK 16-16-16 treatments (cm^3).

GDM LOF ($mL\ L^{-1}$)	N0 (0 g)	N1 (6 g)	N2 (12 g)	N3 (18 g)	Mean
G0 (0)	3.00 g	3.67 fg	4.50 fg	5.00 efg	4.04 c
G1 (12.5)	4.33 fg	5.00 efg	6.00 d-g	8.33 b-e	5.92 b
G2 (25)	5.67 efg	6.00 d-g	11.83 a	11.33 ab	8.71 a
G3 (37.5)	7.00 c-f	7.00 c-f	9.33 a-d	10.00 abc	8.33 a
Mean	5.00 b	5.42 b	7.92 a	8.67 a	
CV = 16.91%		HSD G & N = 1.26		HSD GN = 3.47	

*Values followed by the same lowercase letter are not significantly different at the 5% HSD level.

Fresh Weight

Analysis of variance showed that both the interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16, as well as the individual effects of each fertilizer, significantly affected the fresh weight of cacao seedlings at 90 days after planting (DAP). The mean fresh weights are presented in Table 6. The highest fresh weight (59.29 g) was obtained from the combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16 (G2N2), whereas the control treatment (G0N0) recorded the lowest value (26.48 g). Fresh weight reflects the accumulation of plant biomass and water content, both of which are closely related to nutrient availability and photosynthetic activity.

Table 6. Mean fresh weight of cacao seedlings at 90 DAP under GDM LOF and NPK 16-16-16 treatments (g).

GDM LOF (mL L^{-1})	N0 (0 g)	N1 (6 g)	N2 (12 g)	N3 (18 g)	Mean
G0 (0)	26.48 k	31.54 j	34.31 i	36.55 h	32.22 d
G1 (12.5)	30.94 j	40.66 g	40.05 g	44.55 f	39.05 c
G2 (25)	36.34 h	48.81 e	59.29 a	58.40 ab	50.71 a
G3 (37.5)	35.87 hi	50.87 d	56.32 bc	56.53 bc	49.90 a
Mean	32.41 d	42.97 c	47.49 b	49.01 a	
CV = 1.52%		HSD G & N = 0.72		HSD GN = 1.99	

*Values followed by the same lowercase letter are not significantly different at the 5% HSD level.

The balanced supply of nitrogen, phosphorus, and potassium from NPK fertilizer, together with the beneficial microorganisms and organic compounds in GDM LOF, likely enhanced nutrient uptake, photosynthesis, and water retention in the growing medium, resulting in greater biomass accumulation (Kornelius et al., 2025; Sugiarto et al., 2024; Alta et al., 2025). The fresh weight obtained in this study was more than twice that reported by Meutia et al. (2021) when GDM LOF was applied as a single fertilizer source, indicating that the addition of NPK 16-16-16 substantially improved seedling growth. Similar findings were reported by Lainawa & Rahmi (2024), who found that liquid organic fertilizer enhanced cacao seedling growth by improving nutrient availability through microbial activity. Overall, these results demonstrate that the integration of GDM LOF with balanced NPK fertilization provides a synergistic effect on biomass production and contributes to the development of healthier and more vigorous cacao seedlings.

Dry Weight

Analysis of variance showed that both the interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16, as well as the individual effects of each fertilizer, significantly affected the dry weight of cacao seedlings at 90 days after planting (DAP). The mean dry weights for each treatment are presented in Table 7.

Table 7. Mean dry weight of cacao seedlings at 90 DAP under GDM LOF and NPK 16-16-16 treatments (g).

GDM LOF (mL L^{-1})	N0 (0 g)	N1 (6 g)	N2 (12 g)	N3 (18 g)	Mean
G0 (0)	4.08 k	7.22 j	9.75 ghi	10.29 fgh	7.84 c
G1 (12.5)	8.54 i	11.34 def	9.61 hi	12.12 d	10.40 b
G2 (25)	11.01 d-g	11.63 de	17.06 a	15.04 bc	13.68 a
G3 (37.5)	10.77 e-h	13.95 c	14.79 bc	15.23 b	13.68 a
Mean	8.60 c	11.03 b	12.80 a	13.17 a	
CV = 3.17%		HSD G & N = 0.47		HSD GN = 1.29	

*Values followed by the same lowercase letter are not significantly different at the 5% HSD level.

The combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16 (G2N2) produced the highest dry weight (17.06 g), while the control treatment (G0N0) resulted in the lowest value (4.08 g). Dry weight is considered a reliable indicator of plant growth because it reflects the accumulation of photosynthetic products rather than plant water content. The balanced supply of nitrogen, phosphorus, and potassium, together with the soil biological activity that GDM LOF is thought to promote, likely enhanced nutrient uptake and photosynthetic efficiency, leading to greater biomass accumulation (Kornelius et al., 2025; Stefanie et al., 2022). As soil biological activity and post-harvest nutrient status were not directly assayed in this trial, these effects are inferred from the observed growth response rather than from direct soil measurements.

The dry weight obtained in this study was considerably higher than the 8.70 g reported by Meutia et al. (2021) using GDM LOF alone, indicating that the addition of NPK 16-16-16 further improved plant growth. This finding is also consistent with Bertham et al. (2022), who emphasized that combining organic and inorganic fertilizers is an effective strategy for improving soil fertility and supporting plant biomass production. Overall, the results confirm that the combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16 is the most effective treatment for producing vigorous cacao seedlings on Red-Yellow Podzolic soil. A comparable synergistic pattern was reported by Hartawan et al. (2024), who found that a 25% liquid organic fertilizer plus 75% NPK combination increased cacao seedling dry weight, stem diameter, and root dry weight by 45.70%, 42.13%, and 95.54%, respectively, relative to the unfertilized control, and concluded that liquid organic fertilizer could substitute up to 25% of the recommended NPK rate without compromising seedling quality. Taken together with the present findings, this supports the general principle that a moderate share of the nutrient supply can be shifted from inorganic to organic sources in cacao nurseries without sacrificing, and in some parameters even improving, seedling vigor, offering a practical pathway toward reducing dependence on inorganic fertilizer in nursery management.

CONCLUSION

The interaction between GDM liquid organic fertilizer (LOF) and NPK 16-16-16 significantly improved plant height, leaf number, stem diameter, root volume, fresh weight, and dry weight of cacao seedlings, while root length responded only to the individual effects of each fertilizer. The combination of 25 mL L^{-1} GDM LOF and 12 g $polybag^{-1}$ NPK 16-16-16 consistently resulted in the best overall growth performance of cacao seedlings under the conditions of this study. As soil nutrient status and microbial activity were not directly measured, the improved nutrient availability and biological activity underlying this response remain inferred rather than confirmed. Since these findings come from a single nursery trial, further studies across additional seasons and field conditions are needed before broader recommendation, including evaluating GDM LOF as a partial NPK substitute.

REFERENCES

Abdillah, M. H., Abdillah, M. H., & Aldi, M. 2020. Aplikasi Limbah Padat Karet Remah Pada Tanah Podsolik Merah Kuning Terhadap Ketersediaan Hara Makro Dan Perbaikan Sifat Fisika Tanah. EnviroScienteae, 16(2): 264– 275. https://doi.org/10.20527/es.v16i2.9658

Alta, E. P., Desrihastuti, Sabli, T. E., & Ulpah, S. 2025. Pengaruh POC Kulit Nanas dan NPK Organik terhadap Pertumbuhan Bibit Kakao (Theobroma cacao L.). Dinamika Pertanian, 41(3). https://doi.org/10.25299/dp.2025.vol41(3).27156

Aminullah, Moh. F. S., Panggeso, J., & Rosmini, R. 2017. Uji Ketahanan Beberapa Klon Kakao (*Theobromae cacao* L.) Terhadap Penyakit Busuk Buah (*Phytophthorah palmivora* butl). Agrotekbis : Jurnal Ilmu Pertanian (e-Journal). https://jurnal.faperta.untad.ac.id/index.php/agrotekbis/id/article/view/177

Badan Pusat Statistik Indonesia. 2026. Luas Areal Tanaman Perkebunan Menurut Provinsi dan Jenis Tanaman - Tabel Statistik - Badan Pusat Statistik Indonesia. https://www.bps.go.id/id/statistics-table/2/MjU2NSMy/luas-areal-tanaman-perkebunan-menurut-provinsi-dan-jenis-tanaman--ribu-hektar-.html

Badan Pusat Statistik Provinsi Riau. 2026. Produksi Perkebunan Rakyat Menurut Jenis Tanaman di Provinsi Riau (ribu ton), 2025 - Tabel Statistik - Badan Pusat Statistik Provinsi Riau. https://riau.bps.go.id/id/statistics-table/3/Y0hOWWFGZHpPVkpUVjF

KUlowVjBhMUI1Wm1aWFp6MDkjMw==/produksi-perkebunan-rakyat-menurut-jenis-tanaman-di-provinsi-riau--ribu-ton---2019.html?year=2025

Barus, E. V. S., Evizal, R., Solikhin, S., & Sugiatno, S. 2025. Pengaruh Konsentrasi Pupuk Npk (16:16:16) Dan Asap Cair Kocor Terhadap Pertumbuhan Bibit Kakao (*Theobroma cacao* L.). Jurnal Agrotek Kultura, 1(1): 1– 12. https://doi.org/10.23960/JAK.V1I1.11117

Bertham, Y. H., M., B. G., & Utami, K. 2022. Peningkatan Pengetahuan Masyarakat Dalam Pemberian Pupuk Organik Dan Anorganik Untuk Produktivitas Tanaman. JMM (Jurnal Masyarakat Mandiri), 6(4): 2961– 2972. https://doi.org/10.31764/JMM.V6I4.9322

Dogbatse, J. A., Arthur, A., Awudzi, G. K., Quaye, A. K., Konlan, S., & Amaning, A. A. 2021. Effects of Organic and Inorganic Fertilizers on Growth and Nutrient Uptake by Young Cacao (*Theobroma cacao* L.). International Journal of Agronomy, 2021: 1– 10. https://doi.org/10.1155/2021/5516928

Grover, M., Bodhankar, S., Sharma, A., Sharma, P., Singh, J., & Nain, L. 2021. PGPR Mediated Alterations in Root Traits: Way Toward Sustainable Crop Production. Frontiers in Sustainable Food Systems, 4, 618230. https://doi.org/10.3389/FSUFS.2020.618230/FULL

Hartawan, R., Hayata, & Manullang, S. F. 2024. Best Combination of Liquid Organic Fertilizer with NPK Fertilizer for Cocoa Seedling Growth (*Theobroma cacao* L.). Jurnal Agronomi Tanaman Tropika (JUATIKA), 6(3): 723– 734. https://doi.org/10.36378/juatika.v6i3.3682

Hasibuan, H. G., Jamidi, J., Hafifah, H., Rafli, M., & Handayani, R. S. 2022. Respon Pertumbuhan Bibit Kakao (*Theobroma Cacao* L.) Akibat Pemberian Pupuk Organik Cair Lamtoro dan Pupuk Fosfor. Jurnal Ilmiah Mahasiswa Agroekoteknologi, 1(3): 68– 72. https://doi.org/10.29103/JIMATEK.V1I3.9757

Kementerian Pertanian Republik Indonesia. 2026. Laporan Kinerja Direktorat Jenderal Perkebunan *2025*. https://ditjenbun.pertanian.go.id/template/uploads/2026/03/LAKIN-DITJENBUN-2025.pdf

Khoso, M. A., Wagan, S., Alam, I., Hussain, A., Ali, Q., Saha, S., Poudel, T. R., Manghwar, H., & Liu, F. 2024. Impact of Plant Growth-Promoting Rhizobacteria (PGPR) on Plant Nutrition and Root Characteristics: Current Perspective. Plant Stress, 11: 100341. https://doi.org/10.1016/j.stress.2023.100341

Kornelius, A., Fathillah, S., & Sundari, S. 2025. Pengaruh Pupuk Organik Cair Nanas dan NPK Mutiara terhadap Pertumbuhan Bibit Kakao. Agroekotek View, 8(1), 71– 76. https://doi.org/10.20527/AGTVIEW.V8I1.14853

Kusmiati, K., Sutrisno, E., Yamesa Away, S. F., & Chairunnisa, P. 2026. Vegetative Response of Cocoa Seedlings (Theobroma cacao L.) to Nitrophenol Compound Concentration and NPK Fertilizer Dose. Jurnal Agronomi Tanaman Tropika (JUATIKA), 8(2). https://doi.org/10.36378/juatika.v8i2.5469

Lainawa, W., & Rahmi, R. 2024. Pengaruh Konsentrasi Pupuk Organik Cair Bioboost Terhadap Pertumbuhan Bibit Tanaman Kakao (Theobroma Cacao L.). Agrotekbis : Jurnal Ilmu Pertanian (e-Journal). https://jurnal.faperta.untad.ac.id/index.php/agrotekbis/id/article/view/2105

Lestari, S. A. D. A. D., Melati, M., Heni, P 2016. Penentuan Dosis Optimum Pemupukan N, P, dan K pada Tanaman Kacang Bogor [Vigna subterranea (L.) Verdcourt] Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), 43(3): 193–200. https://doi.org/10.24831/JAI.V43I3.11244

Mahdalena, S., Patricia, S., Aprilani, P., & Wati, A. 2025. The Effect of Cocoa Fruit Skin Waste POC and NPK Fertilizer on the Growth of Cocoa Seedlings (*Theobroma cacao* L.). Agrifarm Jurnal Ilmu Pertanian, 14(1): 24– 29.

https://doi.org/10.24903/ajip.v14i1.3662

Meutia, R. I., Nurahmi, E., & Jumini, J. 2021. Pengaruh Komposisi Media Tanam dan Konsentrasi Pupuk Organik Cair GDM terhadap Pertumbuhan Bibit Kakao (Theobroma cacao L.). Jurnal Ilmiah Mahasiswa Pertanian, 6(4): 72– 80. https://doi.org/10.17969/JIMFP.V6I4.18711

Niu, Y. F., Chai, R. S., Jin, G. L., Wang, H., Tang, C. X., & Zhang, Y. S. 2013. Responses of root architecture development to low phosphorus availability: a review. Annals of Botany, 112(2): 391– 408. https://doi.org/10.1093/AOB/MCS285

Prasatyio, A. E., Gusniwati, G., Fathia, N. M. E., & Neliyati, N. 2025. Optimization of Cacao Seedling Growth (Theobroma cacao L.) through the Interaction of Asystasia gangetica Compost Fertilizer and NPK Fertilizer. Biospecies, 18(2), 79– 85. https://doi.org/10.22437/biospecies.v18i2.44581

Sari, V. I., Rizal, M., & Susi, N. 2024. Perbedaan Pertumbuhan Bibit Kakao (*Theobroma cacao* L) Akibat Pemberian Pupuk Organik Cair Paitan dengan pupuk NPK Pada Tanah Gambut Dan Podzolid Merah Kuning. Jurnal Agrotela, 5(2): 71– 78. https://journal.unilak.ac.id/index.php/Agrotela/article/view/17933

Setiawan, A. 2023. Respon Pertumbuhan Bibit Tanaman Kakao (*Theobroma cacao* L.) Dengan Pemberian POC Kulit Pisang dan Pupuk NPK 16:16:16. Jurnal Ilmiah Mahasiswa Pertanian [JIMTANI], 3(1): 1– 13. https://jurnalmahasiswa.umsu.ac.id/index.php/jimtani/article/view/2205

Shrivastav, P., Prasad, M., Singh, T. B., Yadav, A., Goyal, D., Ali, A., & Dantu, P. K. 2020. Role of nutrients in plant growth and development. Contaminants in Agriculture: Sources, Impacts and Management, 43– 59. https://doi.org/10.1007/978-3-030-41552-5_2/SAVE-RESEARCH

Singgo, S., Fathurrahman, F., & Barus, H. (2025). Pengaruh Media Tanam Dan Pemberian Pupuk Organik Cair Terhadap Pertumbuhan Bibit Kakao (*Theobroma Cacao* L.). Agrotekbis : Jurnal Ilmu Pertanian (e-Journal). https://jurnal.faperta.untad.ac.id/index.php/agrotekbis/id/article/view/2429

Situmeang, I. Y. P., & Sukmadewi, D. K. T. 2025. *Pengelolaan Kesuburan Tanah Dan Pemupukan*. Scopindo Media Pustaka.

Stefanie, Y. S., Billy Wally, I., & Studi Agroteknologi-Fakultas Pertanian Kehutanan dan Kelautan Universitas Ottow Geissler Papua, P. 2022. Pengaruh Pemberian Beberapa Jenis Pupuk Organik Cair Terhadap Pertumbuhan Bibit Tanaman Kakao. Jurnal Indonesia Sosial Teknologi, 3(05): 562– 573. https://doi.org/10.59141/JIST.V3I05.421

Sugiarto, S., Lapanjang, I. M., & Madauna, I. s. 2024. Pengaruh Pemberian Pupuk Organik Padat Dan Cair Terhadap Pertumbuhan Bibit Kakao (*Theobroma cacao* L). Agrotekbis : Jurnal Ilmu Pertanian (e-Journal). https://jurnal.faperta.untad.ac.id/index.php/agrotekbis/id/article/view/2144

Syaputra, R., & Elfis, E. 2022. Pengaruh Media Tanah PMK dan POC Ares Pisang pada Pre-Nursery Tanaman Akasia (Acacia mangium Willd.). Jurnal Agroteknologi, Agribisnis, Dan Akuakultur, 2(2): 136– 145. https://doi.org/10.25299/JAAA.2022.11198

Thedi, M. 2022. Pengaruh Komposisi Media Tanam dan Dosis Pupuk NPK terhadap Pertumbuhan Bibit Kakao (*Theobroma cacao* L.). [Master' s thesis]. Universitas Syiah Kuala.

Wulandari, D. 2023. Pengaruh Kompos Daun Bambu Dan Tsp Terhadap Pertumbuhan Serta Produksi Kacang Hijau (*Vigna Radiata* L.) Pada Tanah PMK. https://repository.uir.ac.id/25700/

Yupanqui, H. A. H., Reátegui, P. T., Bazan, M. C. F., Chávez Matías, J. J., Paredes-Espinosa, R., Mishra, A. K., & Ocaña-Reyes, J. A. 2026. Soil Amendment Enhances Soil Regeneration and Cocoa Seedling Growth. Applied and Environmental Soil Science, *2026*(1): 8889637.

https://doi.org/10.1155/AESS/888963
7

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