

Banana-Waste-Based Liquid Organic Fertilizer Improves Soil Fertility and Nutrient Availability in Floating Cultivation of Shrub Pepper

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Abstract

Shrub pepper (*Piper albi* Linn) is a nutrient-demanding plant that requires additional fertilization to achieve optimal growth, especially in floating cultivation systems where nutrient availability is limited. Liquid organic fertilizer (LOF) derived from banana waste offers a sustainable alternative to enhance soil fertility and plant performance. This study aimed to evaluate the effects of banana-waste-based LOF on soil organic carbon, total nitrogen in soil and plant tissue, and the vegetative growth of shrub pepper (*Piper albi* Linn). The experiment was arranged in a randomized block design with two treatments: P0 (0 mL plant⁻¹) and P1 (50 mL plant⁻¹), applied weekly throughout the experimental period. The application of LOF significantly increased soil organic carbon and total nitrogen compared with the control. The P1 resulted in the highest soil organic carbon and nitrogen and enhanced nitrogen uptake. Furthermore, LOF application increased vegetative growth, particularly leaf number, indicating a positive response to increased nutrient availability. In conclusion, banana-waste-based LOF efficiently provides essential nutrients and improves soil fertility in floating cultivation systems. The findings highlight its potential as an environmentally friendly soil amendment to support sustainable production of shrub pepper (*Piper albi* Linn) and reduce reliance on chemical fertilizers.

1. Introduction

Shrub pepper (*Piper albi* Linn) is a promising form of pepper cultivation that can be developed widely in Indonesia (Karmawati et al., 2020). This plant offers several advantages, including the absence of a need for supporting poles, ease of maintenance, and suitability for limited land or alternative farming systems (Sitinjak et al., 2024). However, national pepper productivity remains suboptimal due to land degradation, pest infestations, and inefficient fertilization management (Anjarsari et al., 2024). The use of chemical fertilizers, although effective in the short term, often leads to declining soil quality and harmful chemical residues that threaten the environment (Zhou et al., 2025). Therefore, the development of sustainable fertilization technologies is essential to maintain soil fertility (Al-Shammary et al., 2024) and ensure the long-term productivity of shrub pepper cultivation.

Liquid organic fertilizer (LOF) is considered one of the most promising alternatives to reduce dependence on chemical fertilizers in modern agriculture (Allouzi et al., 2022). This fertilizer provides nutrients in readily available forms (Haryadi et al., 2015), enhances soil microbial activity (Wu et al., 2024), and improves soil physical and chemical characteristics more efficiently than many solid amendments (Napoleon et al., 2023). Previous studies have shown that LOF derived from agricultural residues, such as vegetables, fruits, and livestock manure can enhance the growth and productivity of horticultural and plantation crops (Liu et al., 2024). Banana waste is an abundant tropical resource with a balanced macro and micronutrient content (Hendrawani et al., 2021), making it suitable as a feedstock for LOF production. Utilizing this waste not only provides an organic nutrient source but also contributes to sustainable agricultural waste management (Muniappan et al., 2023).

The floating cultivation system is an agricultural innovation that utilizes wetlands and tidal lands by providing continuous water supply from beneath the planting medium (Ghosh et al., 2024). This system efficiently manages

water resources but often faces limitations in nutrient availability, which can restrict plant growth (Rianti et al., 2019). To overcome this constraint, integrating floating cultivation with LOF could be a potential strategy to balance water and nutrient availability. This combination can create a more resilient and sustainable production environment for shrub pepper cultivation in wetland conditions.

Previous research has primarily focused on solid organic fertilizers, such as compost and vermicompost, to improve soil fertility and plant growth (Blouin et al., 2019; Vega and Sanabria, 2023). However, limited scientific evidence exists regarding the application of banana waste, based on LOF for shrub pepper cultivation in floating systems. This knowledge gap indicates the need for further research to determine the effectiveness of LOF in enhancing soil nutrient dynamics and the vegetative growth of shrub pepper in such environments.

This study aims to evaluate the effects of banana waste, based LOF on soil organic carbon, total soil and plant nitrogen, and vegetative growth of shrub pepper cultivated in a floating system. The results are expected to provide a scientific foundation for sustainable nutrient management and to support environmentally friendly production of shrub pepper in wetland ecosystems.

2. Research Methods

2.1. Research Area Description

The research was conducted from October 2020 to January 2021 at the experimental floating pond of the Department of Soil Science, Faculty of Agriculture, Universitas Sriwijaya, Indralaya, South Sumatra, Indonesia. The study was carried out as a field experiment under floating cultivation conditions. The experimental pond was established within the faculty's experimental area and specifically designed to simulate floating cultivation practices. The site is located at an elevation of 10–20 meters above sea level and is characterized by flat to slightly undulating topography (slope < 5%). The region has a tropical climate with an average annual rainfall of 2,500–3,000 mm and a mean temperature ranging from 26 to 28 °C.

2.2. Research Implementation

The study was conducted using a floating cultivation system in an experimental pond measuring 8 m × 6 m, lined with a plastic sheet at the bottom to prevent water leakage. The pond was filled with water, and bamboo rafts equipped with flotation devices were placed on the surface to hold polybags, maintaining stability and ensuring each polybag was submerged to approximately 5 cm. Polybags (30 cm in diameter × 45 cm in height), each containing 7.5 kg of rawa lebak soil collected from the Experimental Field, Faculty of Agriculture, Universitas Sriwijaya, South Sumatra, Indonesia (3°13'20.4" S 104°38'52.7" E), were arranged on the rafts. Uniform and healthy shrub pepper (*Piper albi* Linn) seedlings, aged 3 months, were transplanted into each polybag.

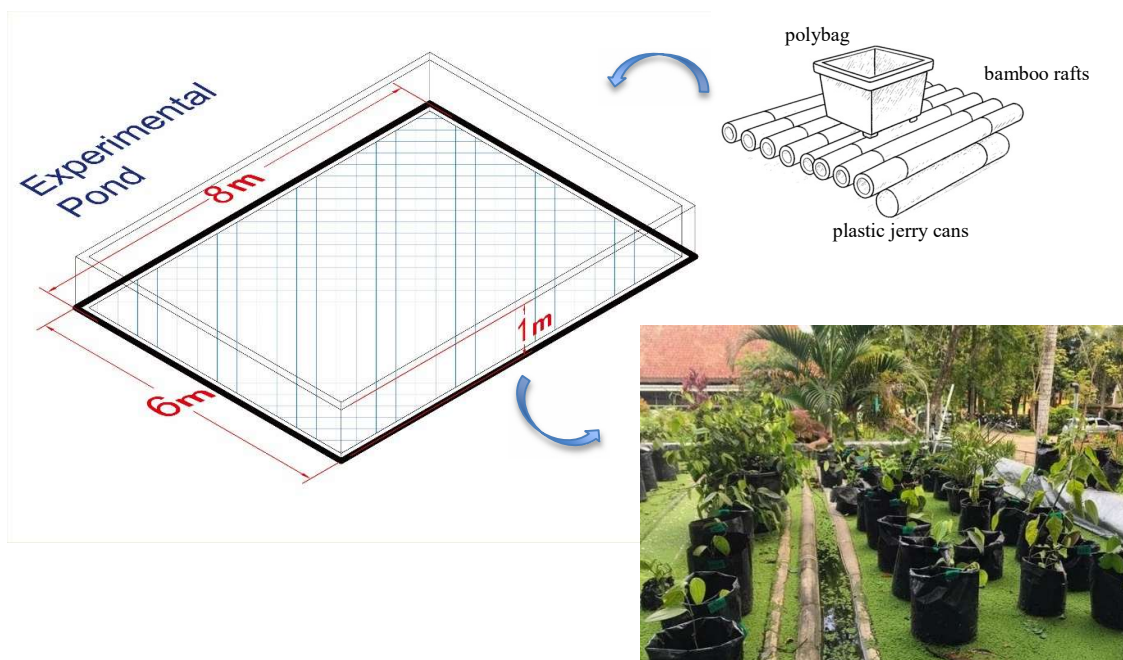


Figure 1. Sketch of the experimental pond showing the floating cultivation system used for shrub pepper (*Piper albi* Linn)

The LOF used in this study was produced from banana peel waste, sugar palm sap (nira aren), Effective Microorganisms (EM4), and water. The mixture was combined at a ratio of 3:1:0.1:10 (banana peel waste: sugar palm sap: EM4: water) and fermented anaerobically for 7-10 days at room temperature (27-30 °C) until the color darkened and a distinct fermentation odor developed, indicating the decomposition process was complete. The fermented solution was then filtered and stored in sealed plastic containers prior to application.

The chemical characteristics of the LOF (Table 1) suggest its potential as a balanced organic amendment, providing both nutrient elements and carbon sources that stimulate soil microbial processes and sustain nutrient cycling in floating cultivation conditions.

Table 1. Chemical composition of the LOF used in the experiment

Parameter	Unit	Value	Analysis Method
pH (H ₂ O)	-	4.21	Electrometric
Available phosphorus	cmol(+)kg ⁻¹	0.01	Bray I (Bray-P)
Organic Carbon	%	34.91	Walkley and Black
Organic Matter	%	60.18	Calculated from organic carbon
Total Nitrogen	%	1.54	Kjeldahl
Exchangeable K	%	0.06	
Exchangeable Ca	%	0.0012	NH ₄ OAc (1 N, pH 7.0)
Exchangeable Mg	%	0.0018	

Fertilizer was applied weekly, starting one week after transplanting, by pouring the solution near the base of each plant. Routine maintenance included manual weeding and pest monitoring. Irrigation was not applied because the lower portion of each polybag was partially submerged in pond water (up to 5 cm), allowing continuous water absorption into the growing medium through capillary action. This passive irrigation mechanism maintained adequate and stable moisture conditions in the root zone throughout the growing period. The experiment followed a Randomized Block Design (RBD) with one factor, LOF, at two levels: P0 (0 mL plant⁻¹) and P1 (50 mL plant⁻¹), each replicated three times. Blocks were assigned based on raft position to minimize environmental variation. Soil samples were collected at the end of the experiment to analyze total nitrogen (N-total) and soil organic carbon using the Kjeldahl and Walkley-Black methods, respectively, while plant tissue analysis assessed nutrient uptake. Plant growth was monitored weekly by measuring height and counting the number of leaves.

2.3. Data Analysis

Data from soil (total nitrogen and organic carbon), plant tissue (nutrient uptake), and growth parameters (height and number of leaves) were analyzed to evaluate the effects of LOF on soil quality and plant development. Statistical analysis was performed using an ANOVA, and significant differences among treatments were further examined with the Least Significant Difference (LSD) test at the 5% significance level.

3. Results and Discussion

3.1. Soil Organic Carbon

The application of LOF derived from banana waste significantly increased soil organic carbon compared with the control treatment (Table 2). The treatment with 50 mL plant⁻¹ resulted in the highest organic carbon concentration (1.58%), representing an increase of approximately 30% over the control (1.21%). These results indicate that the consistent application of LOF provided an abundant source of decomposable carbon, supporting microbial activity and enhancing humification processes. The organic acids, carbohydrates, and lignocellulosic residues in banana waste act as primary substrates for soil microorganisms, accelerating the formation of humic and fulvic substances that stabilize soil organic matter.

Table 2. Effect of LOF on soil organic carbon (%)

Treatment	Soil Organic Carbon (%)	Improvement Over Control (%)
0 mL plant ⁻¹	1.21 ± 0.03	-
50 mL plant ⁻¹	1.58 ± 0.05	+30.6
Mean ± SE	1.40 ± 0.04	-

Note: Different letters indicate significant differences according to the LSD test ($p < 0.05$)

The enhancement of soil organic carbon also implies improvements in soil structure and aeration, which are crucial in floating cultivation where the media are periodically submerged. In such conditions, nutrient leaching and anaerobic decomposition are common, yet the consistent carbon input from LOF might have stimulated

microbial respiration and stabilized organic molecules. This phenomenon aligns with studies by Kok et al. (2023) and Luo et al. (2023), which reported that organic amendments derived from fermented plant residues promote carbon stabilization through microbial polymerization processes.

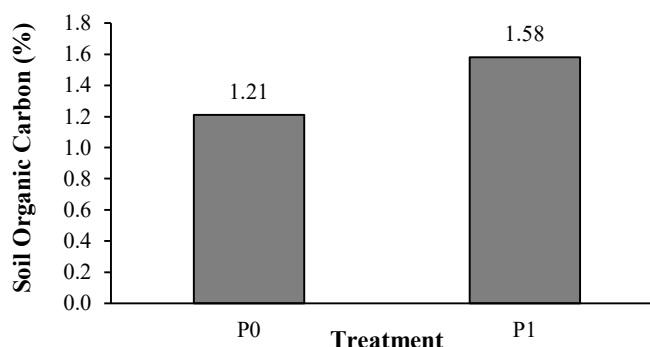


Figure 2. Changes in soil organic carbon under different LOF treatments in floating cultivation of shrub pepper (*Piper albi* Linn).

3.2. Soil and Plant Nitrogen

The application of LOF significantly increased total nitrogen in both soil and plant tissues (Table 3). The treatment of 50 mL plant⁻¹ resulted in soil nitrogen content of 0.19% and plant nitrogen content of 1.42%, both higher than the control. This improvement reflects efficient nitrogen mineralization from the organic compounds in banana waste, including amino acids and protein residues, which are readily decomposed by soil microbes.

Table 3. Effect of LOF on total nitrogen (%) in soil and plants

Treatment	Total N in Soil (%)	Total N in Plant (%)
0 mL plant ⁻¹	0.12 ± 0.01	1.16 ± 0.02
50 mL plant ⁻¹	0.19 ± 0.02	1.42 ± 0.03
Mean ± SE	0.16 ± 0.02	1.29 ± 0.03

The increase in nitrogen content suggests active microbial transformation of organic nitrogen to inorganic forms, such as ammonium (NH₄⁺) and nitrate (NO₃⁻). In floating cultivation, where the root zone remains moist, microbial nitrification and denitrification processes can coexist, but the presence of organic substrates reduces gaseous N losses by promoting microbial immobilization. This mechanism ensures synchronized nutrient release and plant uptake, enhancing nitrogen use efficiency. The improved N concentration in plant tissues is directly linked to better chlorophyll synthesis and higher photosynthetic capacity, leading to vigorous vegetative growth (Guo et al., 2024).

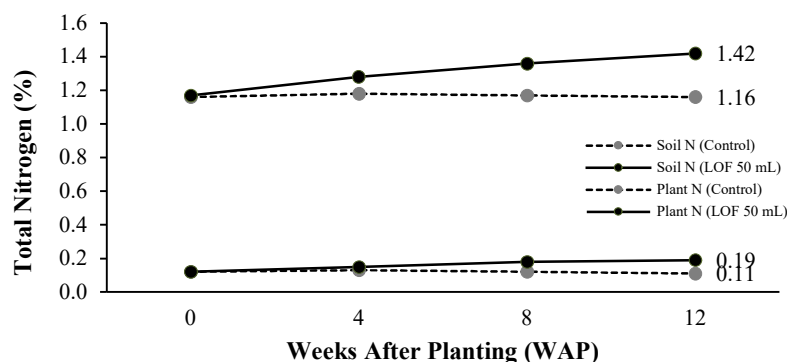


Figure 3. Trends of soil and plant nitrogen content as affected by LOF application in floating cultivation of shrub pepper (*Piper albi* Linn).

3.3. Growth of shrub Pepper (*Piper albi* Linn)

The vegetative growth of shrub pepper (*Piper albi* Linn) responded positively to LOF application (Table 4). Plants treated with 50 mL of fertilizer plant⁻¹ produced an average of 33.8 leaves, 39.7% higher than the control (24.2 leaves plant⁻¹). This increase is likely associated with improved nitrogen availability, enhanced root activity, and

the potential presence of natural growth regulators, such as auxins and cytokinins, produced during banana waste fermentation.

Table 4. Effect of LOF on vegetative growth of shrub pepper (*Piper albi* Linn)

Treatment	Leaf Number (leaves plant ⁻¹)	Relative Increase (%)
0 mL plant ⁻¹	24.2 ± 1.3	-
50 mL plant ⁻¹	33.8 ± 1.6	+39.7
Mean ± SE	29.0 ± 1.5	-

Note: Different letters indicate significant differences according to the LSD test ($p < 0.05$)

The enhanced leaf development under LOF treatment reflects the fertilizer's contribution to nutrient availability and hormonal stimulation. The organic compounds likely improved soil porosity and water retention, thereby facilitating nutrient diffusion and root uptake (Xuan et al., 2023). Moreover, the floating cultivation system maintained a consistent water supply and oxygen diffusion at the root interface (Puspitahati et al., 2024), reducing physiological stress and supporting steady plant metabolism (Topali et al., 2024). This interaction demonstrates the adaptability of shrub pepper (*Piper albi* Linn) to water-based systems when nutrient management is optimized through organic inputs.

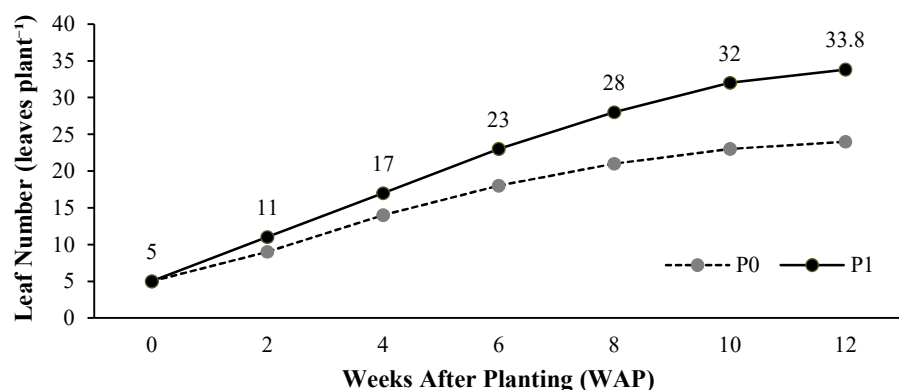


Figure 4. Weekly leaf number progression of shrub pepper (*Piper albi* Linn) under control and LOF treatments in the floating cultivation system.

Visual observations were conducted to support the quantitative growth data by documenting morphological development and plant health responses of shrub pepper (*Piper albi* Linn.) under the floating cultivation system. The observations showed active vegetative development and various plant health responses during the experimental period, including shoot growth and flower stalk development in several plants. In addition, leaf disease symptoms and permanent leaf wilting were recorded in some individuals.

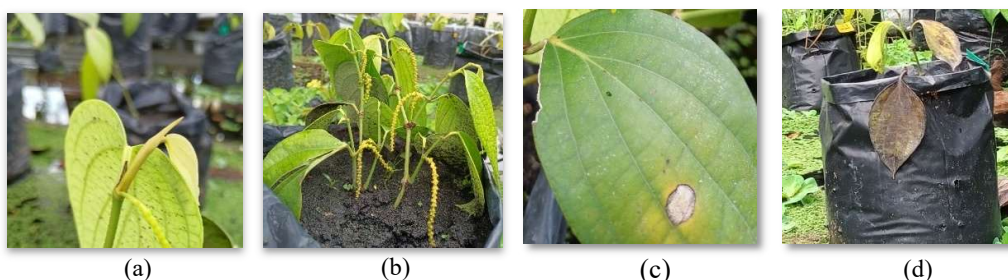


Figure 5. Visual observations of shrub pepper (*Piper albi* Linn.) grown under a floating cultivation system: (a) shoot growth, (b) flower stalk development, (c) leaf disease symptoms, and (d) permanent leaf wilting.

3.4. Integrated Discussion

The integration of organic fertilization and floating cultivation systems offers a sustainable approach to improving soil productivity in waterlogged environments. The application of banana-waste-based LOF significantly increased soil organic carbon and total nitrogen, which in turn supported greater nutrient uptake and enhanced vegetative growth of shrub pepper (*Piper albi* Linn). These findings indicate that organic amendments not only supply

essential macronutrients but also stimulate microbial activity and enzymatic processes (Luo et al., 2018) that maintain soil fertility under flooded conditions.

Compared with conventional solid organic fertilizers, liquid formulations offer faster nutrient release and better distribution throughout the growth medium, facilitating more efficient nutrient diffusion and root absorption. In floating cultivation systems, continuous water–soil contact further promotes microbial-mediated nutrient mineralization. Consequently, the combined use of LOF and floating systems improves soil and plant interactions and may enhance nutrient use efficiency.

From a sustainability perspective, the use of banana waste as a feedstock for liquid fertilizer contributes to circular resource management by transforming agricultural residues into valuable organic inputs. This practice minimizes environmental waste while reducing reliance on synthetic fertilizers. However, the present study was conducted over a single growing season; thus, the long-term persistence of soil fertility improvements and their effects on yield stability remain to be evaluated. Future studies should investigate the integration of biochar or microbial inoculants with LOF to enhance nutrient retention, carbon sequestration, and soil biochemical stability in wetland agricultural systems.

Overall, the responses of shrub pepper (*Piper albi* Linn) cultivated under the floating system indicate that the application of banana-waste-based LOF improved plant performance under waterlogged conditions. Improvements in soil organic carbon and nitrogen availability were consistently accompanied by enhanced vegetative development, while plants without organic fertilization tended to exhibit reduced vigor. These integrated responses demonstrate the effectiveness of LOF in supporting soil-plant interactions and improving plant resilience in floating cultivation systems.

4. Conclusion

The application of banana-waste-based LOF effectively improved soil fertility and nutrient availability in the floating cultivation system. Enhanced soil organic carbon and nitrogen levels were accompanied by increased plant nitrogen uptake and vegetative growth of shrub pepper (*Piper albi* Linn). These findings confirm that LOF can function as a sustainable soil amendment that supports nutrient cycling and soil productivity in waterlogged environments. The use of banana waste as a raw material also promotes resource efficiency and reduces dependence on chemical fertilizers. Further long-term studies are recommended to evaluate nutrient dynamics, yield stability, and soil biochemical balance under repeated applications.

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