

Growth Response of Water Spinach to Liquid Organic Fertilizer from Fruit Waste

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Abstract: Farmers' continuous reliance on chemical fertilizers can degrade soil quality over time, while abundant fruit waste remains underutilized. This study aimed to determine the effect of liquid organic fertilizer (LOF) derived from mixed fruit waste on the growth of water spinach (*Ipomoea aquatica* Forsk.) and to identify the most effective concentration. A Completely Randomized Design was employed with four LOF concentration levels (0%, 10%, 20%, 30%), each replicated three times. The parameters observed were plant height, leaf number, and fresh weight, analyzed using Analysis of Variance (ANOVA) followed by a Least Significant Difference (LSD) test at the 5% level. The results showed that LOF significantly affected plant height at 14 and 28 days after planting, with the 30% concentration producing the tallest plants (25.33 cm), significantly different from the other treatments (18.83–20.17 cm). However, LOF had no significant effect on leaf number or fresh weight. The continuously increasing response up to the highest concentration tested suggests that the optimum point lies above 30%, consistent with hormesis theory. This study concludes that mixed fruit-waste LOF has potential as an alternative organic fertilizer to promote plant height growth in water spinach, although further research with a larger number of replications is needed to confirm its effect on other growth parameters.

Keywords: Fresh Weight, Hormesis, Leaf Number, Liquid Organic Fertilizer, Water Spinach

INTRODUCTION

Farmers' continuous reliance on inorganic chemical fertilizers has contributed to a decline in the physical, chemical, and biological quality of the soil, including the accumulation of chemical residues that disrupt the balance of the agricultural ecosystem (Soekamto & al., 2022). Meanwhile, fruit waste from markets and households is still largely underutilized, even though it has the potential to be processed into environmentally friendly liquid organic fertilizer (LOF). LOF produced from fermented organic material contains macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), which plants require to support vegetative growth (Novianto et al., 2024; Kurniawan et al., 2022).

Water spinach (*Ipomoea aquatica Forsk*) was selected as the test plant because it has a short harvest cycle (25–30 days), is easy to cultivate, and is a horticultural commodity widely consumed by the public (Raksun et al., 2022). Several previous studies have examined the effect of LOF from various raw materials on the growth of water spinach, although the optimal results vary depending on the raw material composition and concentration used. (Nindita & al., 2023) reported that a low concentration (10 mL/L) produced the best response in a hydroponic system, whereas (Martha et al., 2025) found the optimal point at a higher concentration (60 mL/L) for LOF made from a mixture of fruit and vegetable waste. This discrepancy in findings indicates that the growth response of water spinach to LOF is specific to the raw material composition, so a study on LOF made purely from mixed fruit waste applied to water spinach remains relevant to explore further. This study aimed to determine the effect of applying LOF from mixed fruit waste on the growth of water spinach plants and to determine the most effective concentration among the four levels tested (0%, 10%, 20%, and 30%).

Beyond its agronomic aspects, the use of fruit waste as a raw material for LOF is also relevant to the principle of the circular economy, in which material once regarded as waste is converted into a valuable agricultural input (Widyabudiningsih, 2021). Fruit waste from markets and households generally has a high water and sugar content, making it easy to decompose through anaerobic fermentation and has the potential to produce LOF with a nutrient content competitive with that of chemical fertilizers, at a much lower production cost for smallholder farmers (Novianto & al., 2024). Accordingly, this study contributes not only to the scientific understanding of agronomy but also to more sustainable organic-waste management efforts.

The growth response of plants to fertilizer concentration can be explained through hormesis theory (*dose-response theory*), which states that the biological response to a stimulus follows a biphasic curve: increasing at low to moderate doses, then decreasing beyond the optimum point due to toxic effects (Godínez-Mendoza et al., 2023). This theory is widely applied in contemporary agronomic and plant-protection research (Dharma et al., 2024).

The availability of nitrogen from LOF plays an important role in supporting plant growth, as nitrogen is a major constituent of proteins, amino acids, and chlorophyll that support the photosynthesis process (Fathi, 2022). Nitrogen also promotes cell division and elongation, which contribute to increased plant height (Oktaviani & Mawardini, 2023), consistent with findings that the application of liquid organic fertilizer generally improves nutrient availability for plant growth (Kurniawan, 2022). In addition to nitrogen, phosphorus plays a role in cell division and energy metabolism, while potassium is involved in osmotic regulation and the translocation of assimilates from source to sink (Rosado-Souza et al., 2023). These three nutrients form the mechanistic basis explaining the effect of LOF on the vegetative growth parameters observed in this study.

In addition to hormesis theory, the growth response of plants to nutrient availability can also be explained through Liebig's Law of the Minimum, which states that plant growth is limited by the nutrient that is least available relative to its requirement, rather than by the total amount of nutrients available (Liebig, 1840). This implies that increasing the LOF concentration will only be effective in enhancing growth as long as the limiting nutrient factor has not been satisfied; once it is satisfied, another nutrient that has not yet reached its optimum may become a new limiting factor for a particular growth parameter.

The concept of the *source-sink relationship* is also relevant for explaining the distribution of photosynthetic products (assimilates) to various plant organs. Leaves, acting as the source, produce photosynthate that is then distributed to sink organs such as the stem, roots, and meristematic tissue according to the *sink strength* of each organ at a given time (Rosado-Souza et al., 2023). This disproportionate distribution among organs explains why different growth parameters (such as plant height and fresh weight) do not always respond uniformly to the same treatment.

The process of producing LOF involves the anaerobic fermentation of organic material with the assistance of decomposer microorganisms contained in the EM4 bioactivator (*Effective Microorganisms-4*), which consists of lactic acid bacteria, yeast, and photosynthetic bacteria. These microorganisms break down the complex organic compounds in the fruit waste into simple

compounds ready for plant uptake, while also producing organic acids that lower the pH of the solution and suppress the growth of pathogenic microorganisms during the fermentation process.

METHOD

The study used a Completely Randomized Design (CRD) with four concentration levels of LOF made from mixed fruit waste (banana, mango, pineapple, papaya, and orange): P0 (0%/control), P1 (10%), P2 (20%), and P3 (30%), each replicated three times, giving 12 experimental units in total. The LOF was produced through anaerobic fermentation for 14–21 days using the EM4 bioactivator. The study was conducted at the experimental garden of Sambong Santren Hamlet, Sambong Dukuh Village, Jombang Subdistrict, Jombang Regency, from May to June 2026.

The parameters observed were plant height and leaf number, measured at 7, 14, 21, and 28 days after planting (DAP), as well as fresh weight at harvest (DAP-28). Data were analyzed using one-way Analysis of Variance (ANOVA) at the 95% confidence level, followed by a 5% Least Significant Difference (LSD) test when the treatment had a significant effect (Steel & Torrie, 1995; Gomez & Gomez, 2010). Prior to ANOVA, the data were first tested for normality (*Shapiro-Wilk*) and homogeneity of variance (*Levene*).

Production of the LOF began with the collection of mixed fruit waste (banana, mango, pineapple, papaya, and orange), which was cleaned and cut into small pieces to accelerate the fermentation process. The material was mixed with EM4 solution and sugar water as an initial energy source for the microorganisms, then placed in an airtight container and fermented anaerobically for 14–21 days, with gas released periodically to prevent excess pressure inside the container. Mature LOF was characterized by the distinctive sour fermentation aroma and a brownish color; it was then filtered before being diluted to the treatment concentration levels and applied to the growing medium.

The mathematical model of the completely randomized design used was $Y_{ij} = \mu + \tau_i + \epsilon_{ij}$, where Y_{ij} is the observed value for the i -th treatment and j -th replication, μ is the overall mean, τ_i

is the effect of the i -th treatment, and ϵ_{ij} is the experimental error. With $t = 4$ treatment levels and $r = 3$ replications, the resulting error degrees of freedom is $t(r-1) = 8$.

RESULT AND DISCUSSION

Water Spinach Plant Height

The results of the analysis of variance showed that the application of LOF had a significant effect on the height of water spinach plants at 14 and 28 days after planting (DAP), but had no significant effect on leaf number or fresh weight at any observation time (Table 1).

Table 1. Mean Water Spinach Plant Height at Various LOF Concentrations

Treatment	DAP-7 (cm)	DAP-14 (cm)	DAP-21 (cm)	DAP-28 (cm)
P0 (0%)	5.00±1.00a	7.00±1.00c	14.17±1.26a	18.83±0.47b
P1 (10%)	6.33±0.58a	9.00±1.00b	15.33±1.53a	19.50±0.50b
P2 (20%)	6.33±2.52a	10.43±0.75b	16.27±1.17a	20.17±0.15b
P3 (30%)	8.00±1.00a	12.77±0.40a	17.17±0.76a	25.33±2.25a
F-value	2.09ns	25.94*	3.38ns	18.93*

Numbers followed by the same letter in the same column are not significantly different (LSD 5%); ns = not significant; * = significant ($p < 0.05$)

At DAP-28, treatment P3 (30%) produced the tallest plants (25.33 ± 2.25 cm), significantly different from P0, P1, and P2, which ranged from 18.83–20.17 cm and did not differ significantly from one another. The consistent increase in plant height up to the highest concentration tested (30%), with no indication of a decline, suggests that the optimum point of the hormesis curve likely lies above the concentration range tested (Godínez-Mendoza et al., 2023). Physiologically, this can be explained by the increased nitrogen availability, which promotes chlorophyll synthesis (Fathi, 2022) as well as auxin and cytokinin hormonal activity in meristematic tissue (Sosnowski et al., 2023). The optimum point identified here differs from that reported by (Nindita & al., 2023) who reported a low concentration (10 mL/L) as the best in a hydroponic system, but is relatively consistent with (Martha et al., 2025) who found effectiveness at a medium-to-high concentration (60 mL/L). This discrepancy is likely influenced by differences in cultivation system and LOF raw material composition (Widyabudiningsih, 2021).

This result is also consistent with Liebig's Law of the Minimum, which explains that as long as the limiting nutrient factor has not been satisfied, an increase in fertilizer concentration will continue to enhance growth (Liebig, 1840). Within the 0–30% concentration range tested, nitrogen from the LOF had likely not yet reached a saturation point relative to the requirements of the water spinach plants, so the increasing concentration continued to produce a positive response in plant height without showing signs of nutrient excess.

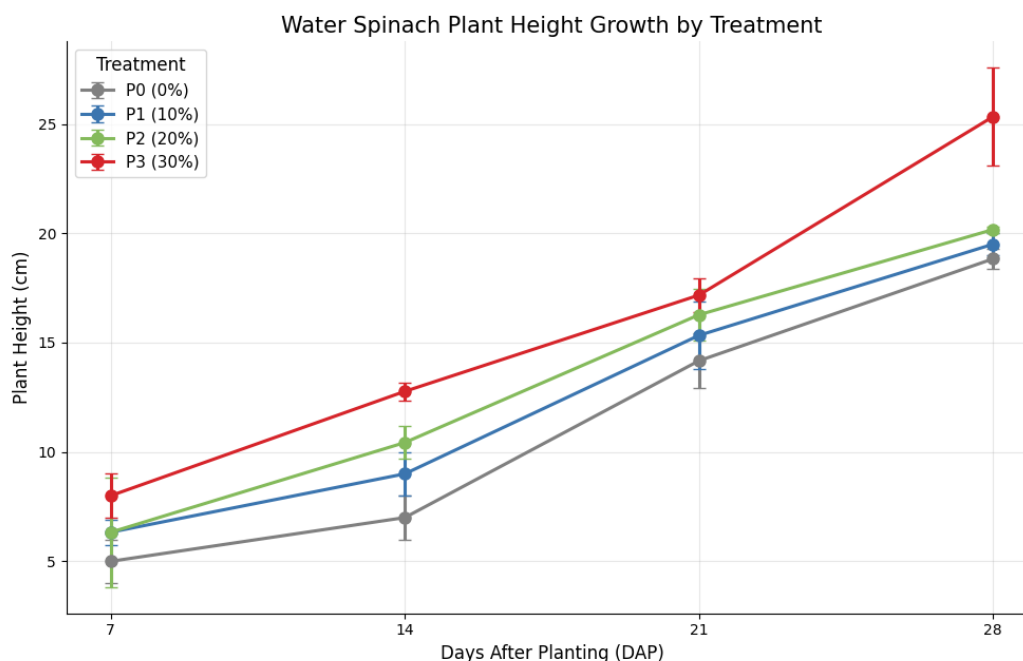


Figure 1. Growth Chart of Water Spinach Plant Height at Various LOF Concentrations

Water Spinach Leaf Number and Fresh Weight

The results of the analysis of variance showed that LOF application had no significant effect on leaf number at any observation time, nor on plant fresh weight at harvest (Tables 2 and 3).

Table 2. Mean Water Spinach Leaf Number at Various LOF Concentrations

Treatment	DAP-7 (leaves)	DAP-14 (leaves)	DAP-21 (leaves)	DAP-28 (leaves)
P0 (0%)	3.33±1.15a	6.33±0.58a	8.33±0.58a	12.67±1.15a
P1 (10%)	3.00±1.00a	6.33±1.15a	9.00±0.00a	14.33±1.15a
P2 (20%)	4.00±1.00a	7.00±1.00a	9.00±1.00a	14.33±0.58a

P3 (30%)	4.00±1.00a	8.00±0.00a	9.33±0.58a	14.67±0.58a
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All treatments followed by the same letter are not significantly different (LSD 5%)

Table 3. Mean Fresh Weight of Water Spinach Plants at Harvest

Treatment	Fresh Weight (g)
P0 (0%)	2.23±0.25a
P1 (10%)	2.33±0.21a
P2 (20%)	2.73±0.38a
P3 (30%)	2.40±0.10a

All treatments followed by the same letter are not significantly different (LSD 5%); $F=2.17$; $p=0.170$

Unlike plant height, leaf number and fresh weight did not differ significantly among treatments, although P3 was numerically consistent as the highest for leaf number and P2 was highest for fresh weight (2.73 g). This lack of significance is presumed to be related to the limited number of replications (error degrees of freedom = 8), which reduced the power of the analysis of variance (Gomez & Gomez, 2010), as well as to the nature of new-organ formation, which is governed by a relatively conservative meristematic cell-division cycle compared with the cell-elongation process in the stem (Sosnowski et al., 2023). The pattern of fresh weight, which did not align with plant height, can also be explained through the concept of the source–sink relationship, namely the distribution of assimilates among organs, which is not always proportional and depends on the sink strength of each organ (Rosado-Souza et al., 2023).

Physiologically, the formation of new leaves is controlled by the activity of the apical and axillary meristems, which produce leaf primordia through organogenesis, regulated by the balance of auxin and cytokinin hormones (Sosnowski et al., 2023). Unlike stem cell elongation, which can respond relatively quickly to an increase in photosynthate, the initiation of new leaf primordia requires a more complex cell-division cycle and depends on a plastochron interval that is relatively fixed genetically, so that the variation in nutrient availability was not yet sufficient to exert significant selective pressure on the rate of new-leaf formation within the 28-day observation period.

The absence of a significant effect in this study contrasts with a number of previous studies reporting a significant effect of LOF on the leaf number and fresh weight of water spinach, such

as (Martha et al., 2025) and (Rantung & al., 2024) which used different raw material compositions and numbers of replications. This discrepancy is most likely methodological, related to the limited number of replications in this study, rather than reflecting an absence of a biological effect of LOF on these two parameters, given that the numerical trend remained consistent in the same direction as the increasing concentration.

These findings carry the scientific implication that vegetative growth parameters do not always respond uniformly to fertilization treatment, so future evaluations of LOF effects should consider a larger number of replications for biologically more conservative parameters such as leaf number. Practically speaking, producers and users of fruit-waste LOF need to adjust the target application concentration to their specific objective: a concentration of 30% is more suitable for promoting plant height growth, whereas for biomass yield (fresh weight), a concentration of 20% shows a slightly better numerical trend, although the difference is not yet statistically significant.

CONCLUSION

Application of liquid organic fertilizer (LOF) from mixed fruit waste had a significant effect on the height of water spinach plants at DAP-14 and DAP-28, with a concentration of 30% being the most effective (25.33 cm), significantly different from the other concentrations (18.83–20.17 cm). However, LOF was not shown to have a significant effect on leaf number or plant fresh weight within the concentration range and number of replications used. The continuously increasing response up to the highest concentration tested suggests that the optimum concentration point likely lies above 30%, consistent with the prediction of hormesis theory.

Based on these findings, several recommendations are proposed for future research: (1) adding LOF concentration levels above 30% to identify the true optimum point; (2) increasing the number of replications to at least 5 so that the error degrees of freedom meets the ideal guideline (≥ 15), thereby increasing the power of the analysis of variance; (3) extending the observation period to evaluate the cumulative effect of LOF on biomass accumulation; and (4) conducting laboratory analysis of the actual N, P, and K content of the LOF used. For farmers, mixed fruit-waste LOF at a 30% concentration can serve as a low-cost, environmentally friendly alternative

organic fertilizer to support plant height growth in water spinach, although further validation at a larger field scale is still needed before it can be widely recommended.

Conflict of Interest

The authors declare that there is no conflict of interest related to this study or its publication.

Generative AI Use

The authors declare that no generative artificial intelligence (AI) tools were used in the preparation, writing, analysis, or development of this manuscript.

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