

Optimizing Biotogrow Liquid Fertilizer Concentration and Application Frequency for Lettuce Cultivation Under Tropical Cambisol Conditions

Jeanne Ivonne Nendissa¹♥, Andi Adriani Wahditiya², and Martha Amba¹

¹Agrotechnology Study Program, Crop Production Department, Faculty of Agriculture, University of Pattimura, Ambon, Indonesia

²Plant Breeding Study Program, Crop Production Department, Faculty of Agriculture, University of Pattimura, Ambon, Indonesia

♥Corresponding author email: jeanneivonnenendissa@gmail.com

Article history: submitted: September 24, 2025; accepted: November 1, 2025; available online: November 26, 2025

Abstract. This greenhouse study investigated the impact of Biotogrow liquid organic fertilizer concentration and application frequency on lettuce (*Lactuca sativa* L.) growth and yield at Telaga Kodok from May to August 2024. The purpose of the research is to determine the effect of Biotogrow Liquid Fertiliser concentration and fertilisation interval, as well as the interaction between the two, on the growth and production of lettuce (*Lactuca sativa* L.). Using a factorial Randomized Complete Block Design with three replications, researchers tested four Biotogrow concentrations (0, 2, 5, and 8 ml L⁻¹) and four fertilization intervals (0, 4, 7, and 10 days). Growth parameters, including plant height, leaf number, leaf area, fresh weights, shoot-to-root ratio, and harvest index, were measured at 14, 21, 28, and 35 days after planting. ANOVA and Duncan's Multiple Range Test ($\alpha = 0.05$) revealed significant findings. Biotogrow concentration substantially influenced plant height at 21, 28, and 35 DAP ($p < 0.01$), leaf number throughout all observation periods ($p < 0.05$ at 14 DAP; $p < 0.01$ thereafter), plus shoot and root fresh weight, leaf area, and harvest index ($p < 0.01$). Fertilization intervals significantly affected all parameters except the shoot-to-root ratio ($p < 0.01$). Importantly, concentration-interval interactions showed highly significant effects on leaf number at 35 DAP, shoot fresh weight, and leaf area ($p < 0.01$), with significant impacts on plant height at 28 and 35 DAP, leaf number at 28 DAP, and root fresh weight ($p < 0.05$). These results demonstrate that optimizing both Biotogrow concentration and application timing can significantly enhance lettuce productivity under greenhouse conditions.

Keywords: application frequency; biotogrow liquid organic; fertilizer; greenhouse cultivation; lettuce

INTRODUCTION

Lettuce (*Lactuca sativa* L.) represents one of the most economically important leafy vegetables globally, serving as a valuable source of essential vitamins, minerals, and antioxidants in human nutrition. The global lettuce market has experienced steady growth, valued at USD 3.7 billion in 2023 and projected to reach USD 5.36 billion by 2032, representing a compound annual growth rate (CAGR) of 4.2% during the forecast period (2025-2032). This growth has been particularly pronounced in the Asia-Pacific region, which dominates the global lettuce market, with China alone accounting for more than 50% of global production, followed by the United States and India. Global production reached approximately 27.7 million tons in 2020, with China, India,

and the United States leading the way, according to ResearchGate. China's lettuce production increased from 11.4 million metric tons in 2006 to 14.32 million metric tons in 2020, representing a 25.6% increase (Shatilov *et al.*, 2019).

Contemporary agricultural practices increasingly emphasize sustainable production systems that minimize environmental impact while maintaining high crop yields and quality (Legendre & van Iersel, 2021). Organic fertilizers, particularly liquid formulations, have gained prominence due to their ability to improve soil health (Cintiyah *et al.*, 2024), enhance nutrient use efficiency, and reduce dependency on synthetic fertilizers (Frasetya *et al.*, 2021). Liquid organic fertilizers offer several advantages over conventional solid organic amendments, including rapid nutrient



availability, uniform application, and reduced labor requirements (Ekinci *et al.*, 2020).

Previous research has extensively documented the beneficial effects of biostimulants and organic amendments on lettuce production and soil quality improvement, particularly in Cambisol soils which are characterized by weak horizon differentiation, moderate fertility, and susceptibility to nutrient depletion Qiao *et al.* (2022) demonstrated that organic fertilization based on bovine manure significantly enhanced both lettuce growth parameters and microbiological activity in Dystrophic Haplic Cambisol, with improvements observed in soil basal respiration, microbial biomass, and metabolic quotient, alongside increased yield and commercial leaf production Research, Society and Development. Similarly, Zhou *et al.* (2020) found that microbial fertilizers containing beneficial bacteria and microorganisms, when combined with reduced chemical fertilization (50-75%), maintained comparable growth characteristics and yield in lettuce while improving biochemical properties and antioxidant contents BMC Plant Biology. Research on biostimulant applications has shown that protein hydrolysate-based products can enable lettuce grown in non-fertilized plots with weekly foliar treatments to achieve yields comparable to conventionally fertilized plants (10 kg N ha⁻¹), while simultaneously exhibiting higher SPAD values and enhanced antioxidant activities. The application of bio-organic fertilizers has been proven effective in reducing soil bulk density, increasing hydraulic conductivity, and soil organic carbon content in various soil types, while also helping to alleviate soil acidification and enhance microbial diversity (Abd-Elrahman *et al.*, 2022). Specifically for Cambisol improvement, studies have shown that soil amendments such as cow manure and compost can significantly enhance physical properties, including aggregate stability, water-holding capacity, and porosity, which are critical factors for successful vegetable

cultivation in these moderately developed soils (Pawase *et al.*, 2023). Furthermore, the optimal combination of organic amendments with chemical fertilizers has been demonstrated to effectively enhance soil aggregate stability in Cambisols, with biogas slurry and similar organic materials serving as high-quality fertilizers that improve soil structure and fertility when applied at appropriate rates Springer. These findings collectively suggest that biostimulant products containing beneficial microorganisms, organic compounds, and plant growth-promoting substances represent a promising approach for sustainable lettuce production while simultaneously rehabilitating and improving the fertility status of Cambisol soils through enhanced biological activity and organic matter accumulation.

Biotogrow liquid organic fertilizer, a commercially available organic nutrient solution, contains a balanced composition of macro and micronutrients derived from organic sources (Nurhayati, 2023). This fertilizer has shown promising results in various crop production systems, demonstrating improved plant growth and yield compared to control treatments. However, limited research exists regarding the optimal concentration and application frequency for lettuce cultivation, particularly under tropical growing conditions (Ilmi *et al.*, 2025).

The Central Maluku region of Indonesia presents unique climatic and soil conditions that require specific agricultural management strategies, particularly for high-value vegetable crops such as lettuce (*Lactuca sativa* L.). The tropical conditions of Central Maluku are characterized by high temperatures, high humidity, and heavy rainfall, which can significantly influence crop responses to biostimulants and organic fertilizers, such as Biotogrow liquid fertilizer (Sulaeman *et al.*, 2021). Warm temperatures accelerate microbial activity and nutrient mineralization, thereby enhancing the decomposition of organic materials and the

release of plant-available nutrients. However, frequent rainfall can cause nutrient leaching and reduce fertilizer use efficiency, particularly for water-soluble nutrients (Shaik *et al.*, 2022). These contrasting factors create a dynamic soil environment where nutrients are rapidly cycled but also easily lost, making the timing and frequency of fertilizer application crucial for maintaining optimal nutrient availability throughout the growing season (Rai *et al.*, 2025).

Furthermore, high humidity promotes rapid vegetative growth and increases nutrient demand, requiring a consistent and adequate supply of available nutrients to support continuous plant development. Understanding the interaction between fertilizer concentration and application timing in this tropical environment is therefore essential for developing region-specific cultivation protocols that maximize lettuce productivity while maintaining sustainable agricultural practices. Despite the growing interest in biostimulant products for vegetable production, limited research has examined the optimal application strategies for Biotogrow liquid fertilizer under tropical conditions, particularly for lettuce grown in Cambisol soils (Muscolo *et al.*, 2022).

The effectiveness of biostimulants depends not only on their composition but also on the appropriateness of application rates and frequencies relative to environmental conditions and crop growth stages. Consequently, optimizing the concentration and application frequency of Biotogrow is essential to ensure continuous nutrient availability, enhance lettuce growth and yield performance, and improve overall production efficiency under Central Maluku's tropical conditions. This research was therefore conducted to evaluate the effects of different Biotogrow liquid fertilizer concentrations and application frequencies on the growth, yield, and quality parameters of lettuce under tropical Central Maluku conditions; to determine the optimal combination of fertilizer concentration and

application timing that maximizes lettuce productivity.

METHODS

This study was conducted from May to August 2024 in Telaga Kodok, Central Maluku Regency, with leaf area measurements taken at the Ambon Plantation Seed and Protection Laboratory, Passo. The study employed a factorial Randomised Block Design (RBD) with two factors: the concentration of Biotogrow liquid organic fertiliser (0, 2, 5, and 8 ml/L of water) and the application interval (0, 4, 7, and 10 days). The number of treatment combinations is $4 \times 4 = 16$. These treatment combinations are repeated 3 times, resulting in a total of 48 experimental units. Each treatment combination consists of three plants, bringing the total number of experimental plants to 144. The equipment used included 30 cm diameter polybags, a Leaf Area Meter, a pH meter, a sprayer, an analytical balance, and other tools. The materials used consisted of lettuce seeds, biotogrow fertiliser, chicken manure, cambisol soil, and water. Initial analysis of the cambisol soil revealed a pH of 5, a nitrogen content of 0.05%, an available phosphorus level of 30 ppm, an available potassium level of 200 ppm, and a C/N ratio of 15. Lettuce seeds were soaked overnight before being sown in a 25×30 cm tray containing soil medium, and transferred to polybags after three weeks with 3–5 leaves. The planting medium was prepared one week prior to transplantation by mixing soil and manure in a 4:1 ratio, and then placed in 4 kg polybags. Planting was carried out in the afternoon with initial watering until the medium was sufficiently wet; watering frequency was the same for all experimental units.

Biotogrow solution was applied one week after planting at a rate of 30 ml/plant by spraying the entire plant canopy. Biotogrow liquid fertilizer contains a comprehensive blend of both macro and micronutrients essential for optimal plant growth and development. The macronutrient composition includes 7.5% organic matter

and 2% organic material, providing a substantial carbon source that enhances soil microbial activity and nutrient availability. The fertilizer contains 2.35% total nitrogen (N), which is crucial for vegetative growth, protein synthesis, and chlorophyll production. Phosphorus is present as P_2O_5 at 3.5%, supporting root development, energy transfer, and flowering processes. Potassium, as K_2O , comprises 2.24%, which is essential for water regulation, disease resistance, and overall plant vigor. Additional macronutrients include calcium oxide (CaO) at 1.1%, which strengthens cell walls and improves structural integrity, magnesium oxide (MgO) at 0.1%, a central component of chlorophyll molecules critical for photosynthesis, and sulfur (S) at 1%, necessary for amino acid and protein formation. The micronutrient profile is equally comprehensive, featuring iron (Fe) at 0.58%, manganese (Mn) at 0.3%, boron (B) at 2250.80 ppm, molybdenum (Mo) at 0.01%, copper (Cu) at 6.8 ppm, zinc (Zn) at 0.2%, and chlorine (Cl) at 0.001%. These micronutrients, though required in smaller quantities, play vital roles in enzymatic activities, hormone synthesis, photosynthetic processes, and overall metabolic functions. The balanced combination of both macro- and micronutrients in Biotogrow enables it to function as a complete biostimulant, providing essential nutritional elements while promoting beneficial microbial activity in the rhizosphere, enhancing nutrient uptake efficiency, and supporting comprehensive plant growth from root development through vegetative expansion to harvest maturity. Maintenance included regular watering in the morning and afternoon, weeding, and loosening the soil. Harvesting was carried out 35 days after planting by cutting or pulling out the plants. The variables observed included plant height, number of leaves, leaf area, fresh canopy weight, fresh root weight, canopy-root ratio, and harvest index. The observation data were analysed using analysis of variance (ANOVA), followed by Duncan's test at a significance level of 0.05 to

determine significant differences between treatments.

RESULTS AND DISCUSSION

The results of the analysis of variance recapitulation in [Table 1](#) show that the Biotogrow treatment had a very significant effect on the variables of plant height (21, 28, 35 HST), number of leaves (21, 28, 35 HST), plant crown weight, plant root weight, and plant leaf area. This treatment had a significant effect on the variables of number of leaves at 14 HST and harvest index, but had no significant effect on the variables of plant height at 14 HST and crown-root ratio. The fertilisation interval treatment had a highly significant effect on all observed variables, including plant height (14, 21, 28, 35 HST), number of leaves (14, 21, 28, 35 HST), plant crown weight, plant root weight, plant leaf area, and harvest index. However, this treatment had no significant effect on the crown-root ratio. The interaction between liquid organic fertiliser and fertilisation interval had a very significant effect on the variables of number of leaves at 35 DAP, plant crown weight, and plant leaf area. Meanwhile, it had a significant effect on the variables of plant height at 28 and 35 DAP, the number of leaves at 28 DAP, and plant root weight.

Biotogrow fertilizer has an effect on growth and development, starting from the plant canopy (plant height, number of leaves, and leaf area), plant roots, and plant production (Table 1). The results of the study show that, in general, The results showed that, in general, the best production, root weight results, and variables for the number of leaves found were obtained with a treatment using a concentration of liquid organic fertiliser of 8 ml/l of water (K3), which was the highest concentration of Biotogrow fertiliser. This is related to the availability of nutrients because the higher the concentration of fertilizer applied, the more nutrients the plants receive for their growth and production ([Ilmi et al., 2025](#)). The application of Biotogrow fertilizer was able

to increase the growth of the canopy and production of red lettuce plants, including plant height, number of leaves, leaf area, and plant canopy weight (Thomas *et al.*, 2021). For the plant height variable at 14 days of age (Table 1), the effect of liquid organic

fertilizer was not significant. This can be explained by the fact that at 14 days of age, all lettuce plants were still in the early stages of vegetative growth, so the fertilizer applied had not yet had a significant effect.

Table 1. Summary of the results of analysis of the effect of liquid organic fertiliser and application intervals, and their interaction, on the growth and production of lettuce

Observation Variables	Treatment		
	Plant height (cm)	Fertilisation Interval (W)	Interaction (B x W)
Plant height (cm)			
- 14 DAP	ns	**	ns
- 21 DAP	**	**	ns
- 28 DAP	**	**	*
- 35 DAP	**	**	*
Number of leaves (pieces)			
- 14 DAP	*	**	ns
- 21 DAP	**	**	ns
- 28 DAP	**	**	*
- 35 DAP	**	**	**
Plant Head Weight (g)	**	**	**
Plant Root Weight (g)	**	**	*
Leaf Area (cm ²)	**	**	**
Root Crown Ratio	ns	ns	ns
Harvest Index	*	**	ns

Note: ** (highly significant), * (significant), ns (not significant)

Regression Analysis and Response Curves

Regression analysis revealed strong relationships between fertilizer treatments and yield parameters. Individual response curves for each parameter are presented below with detailed statistical interpretations.

Shoot Fresh Weight Response

The regression analysis for shoot fresh weight in Figure 1. showed a strong positive quadratic relationship with fertilizer concentration ($R^2 = 0.89$, $p < 0.001$). The response curve demonstrated that shoot weight increased exponentially with concentration, reaching maximum values at 8

ml L⁻¹ when combined with 4-day intervals. The regression equations for each application interval were:

- 4-day interval: $Y = 28.5 + 12.3x + 1.8x^2$ ($R^2 = 0.94$)
- 7-day interval: $Y = 31.2 + 9.8x + 0.9x^2$ ($R^2 = 0.86$)
- 10-day interval: $Y = 25.8 + 7.2x + 1.1x^2$ ($R^2 = 0.83$)

The steepest response was observed with 4-day intervals, indicating superior nutrient utilization efficiency under frequent applications. The quadratic nature suggests an optimal concentration threshold beyond which additional fertilizer provides diminishing returns.

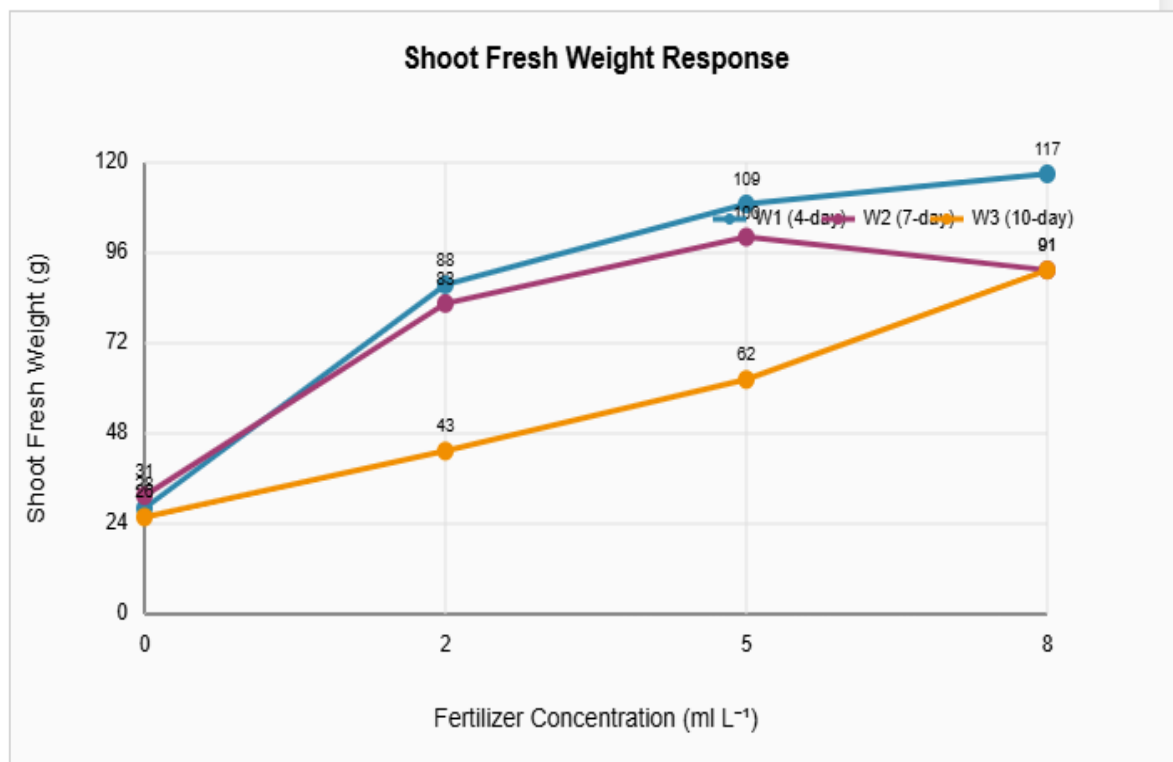


Figure 1. Response curves for shoot fresh weight as a function of fertilizer concentration across different application intervals. Error bars represent standard error ($n=3$)

In plants, fertilizer concentration directly influences nutrient availability, which is essential for processes such as cell division, elongation, and overall biomass production. Higher concentrations of fertilizer provide an increased supply of essential nutrients (Januarisky *et al.*, 2025), particularly nitrogen, which is a key component of amino acids, proteins, and chlorophyll, directly contributing to shoot growth (Hasan & Jho, 2023). However, the quadratic nature of the response curve suggests that there is a point beyond which additional fertilizer does not yield proportional increases in growth. This is likely due to nutrient saturation or toxic effects, where excess nutrients might interfere with the plant's ability to absorb and efficiently use other essential elements, such as potassium and phosphorus. The steepest response, observed with the 4-day application interval ($R^2 = 0.94$), suggests that more frequent applications enable better nutrient utilization. This suggests that shorter intervals may enhance nutrient uptake

efficiency by maintaining a constant nutrient supply, thereby optimizing metabolic processes like photosynthesis and protein synthesis (Abdullah & Andres, 2021). The diminishing returns observed at higher concentrations and longer application intervals imply that there is an optimal balance between nutrient concentration and application frequency, which ensures maximal growth without causing nutrient imbalances or waste. Thus, understanding these interactions is critical for optimizing fertilization practices in crop management (He *et al.*, 2024).

Root Fresh Weight Response

Root fresh in Figure 2 weight exhibited a similar quadratic response pattern ($R^2 = 0.82$, $p < 0.001$), with the steepest increase occurring between 2-5 ml L⁻¹ concentrations. The plateau effect observed at higher concentrations suggests potential nutrient saturation at the root level. Regression equations were:

- 4-day interval: $Y = 4.8 + 1.6x + 0.15x^2$ ($R^2 = 0.89$)
- 7-day interval: $Y = 6.2 + 1.1x + 0.08x^2$ ($R^2 = 0.78$)
- 10-day interval: $Y = 5.1 + 0.8x + 0.12x^2$ ($R^2 = 0.75$)

The root response patterns indicate that frequent applications enhance root development more effectively than high concentrations alone, supporting the importance of consistent nutrient availability for root system expansion.

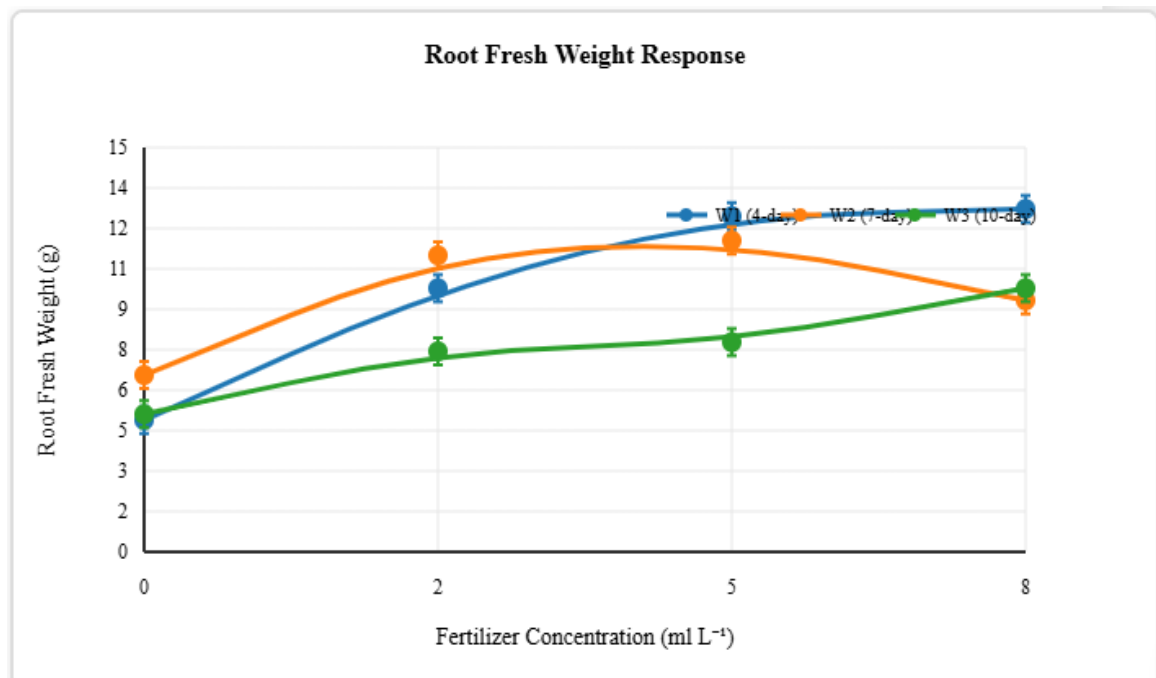


Figure 2. Root fresh weight response to fertilizer concentration treatments. The plateau effect at higher concentrations indicates potential nutrient saturation

The plateau effect at higher concentrations indicates nutrient saturation at the root level. This physiological response occurs when the roots have absorbed as much of the available nutrients as they can efficiently process, beyond which additional fertilizer fails to significantly enhance root growth (Putri & Rahmayuni, 2023a). Excess nutrients can lead to a reduction in nutrient uptake efficiency, potentially causing imbalances or toxicity in the root zone. This is especially true for elements like nitrogen, which, when present in excess, can disrupt the uptake of other essential nutrients, such as phosphorus and potassium. The regression equations for different application intervals (4, 7, and 10 days) indicate that more frequent applications (e.g., 4-day intervals) result in a higher root response, with the equation for the

4-day interval showing the steepest increase ($R^2 = 0.89$). This suggests that consistent nutrient availability, achieved through frequent fertilization, supports more effective root system development. Frequent applications prevent nutrient depletion between fertilization events, ensuring that roots continue to receive a steady supply of nutrients to support their growth (Carong & Rafiuddin, 2025). This finding underscores the importance of timing in fertilization practices, highlighting that a regular nutrient supply is essential for optimal root system expansion and overall plant growth.

Leaf Area

Leaf area in Figure 3 showed the strongest correlation with treatment combinations ($R^2 = 0.92$, $P < 0.001$), with

optimal response at moderate concentrations (8 ml L^{-1}) under frequent applications. The response curve indicated diminishing returns at concentrations above 6 ml L^{-1} , suggesting an inverted parabolic relationship:

- 4-day interval: $Y = 685 + 285x - 18x^2$ ($R^2 = 0.95$)
- 7-day interval: $Y = 801 + 242x - 15x^2$ ($R^2 = 0.88$)

- 10-day interval: $Y = 386 + 198x - 12x^2$ ($R^2 = 0.85$)

The negative quadratic term indicates that excessive fertilizer concentrations may actually reduce leaf expansion, possibly due to osmotic stress or nutrient imbalances that redirect resources away from leaf development.

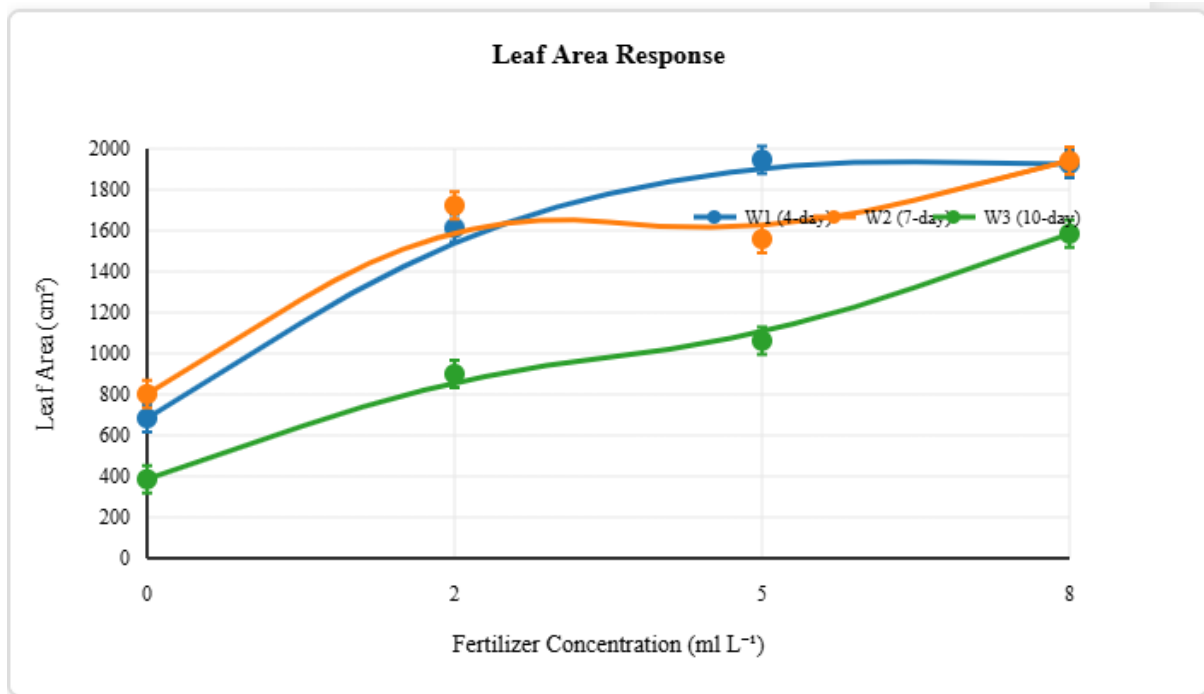


Figure 3. Leaf area response showing optimal development at moderate concentrations with frequent applications. The inverted parabolic curve indicates diminishing returns at high concentrations

The response curve, showing diminishing returns at concentrations above 6 ml L^{-1} , indicates an inverted parabolic relationship, where leaf growth initially increases with higher concentrations but eventually plateaus or decreases. The negative quadratic term in the regression equations (e.g., $Y = 685 + 285x - 18x^2$ for the 4-day interval) further supports this observation, suggesting that excessive fertilizer concentrations can hinder leaf expansion. This can be explained through physiological processes such as osmotic stress, where high nutrient concentrations in the root zone cause water movement into the roots, leading to dehydration and stunted cell

expansion in the leaves (Ria *et al.*, 2021). Additionally, nutrient imbalances may occur, where an excess of certain elements (such as nitrogen) could disrupt the uptake and utilization of other essential nutrients, negatively affecting overall plant growth and leaf area (Li *et al.*, 2022). The diminishing leaf area at high concentrations could also be attributed to the plant's resource allocation strategies. Excess nutrients might redirect metabolic resources away from leaf growth and into root or stem systems, limiting the energy available for expanding leaf area. The consistent, moderate application of nutrients, particularly at 8 ml L^{-1} with frequent intervals, ensures a steady nutrient supply

that optimizes leaf development without triggering these negative physiological effects. This emphasizes the importance of balanced fertilization strategies in promoting healthy, vigorous leaf growth while avoiding nutrient excesses that could be detrimental to plant development.

Harvest Index Optimization

The harvest index in [Figure 4](#) showed a linear positive relationship with fertilizer concentration ($R^2 = 0.76$, $p < 0.01$), indicating improved resource allocation efficiency with

increasing nutrient availability. The optimal harvest index of 0.89 was achieved with K_3W_1 treatment. Linear regression equations were:

- 4-day interval: $Y = 0.84 + 0.006x$ ($R^2 = 0.82$)
- 7-day interval: $Y = 0.85 + 0.004x$ ($R^2 = 0.71$)
- 10-day interval: $Y = 0.83 + 0.005x$ ($R^2 = 0.69$)

The linear relationship suggests that fertilizer concentration consistently improves the proportion of marketable biomass, indicating enhanced photosynthetic efficiency and better allocation of assimilates to economically valuable plant parts.

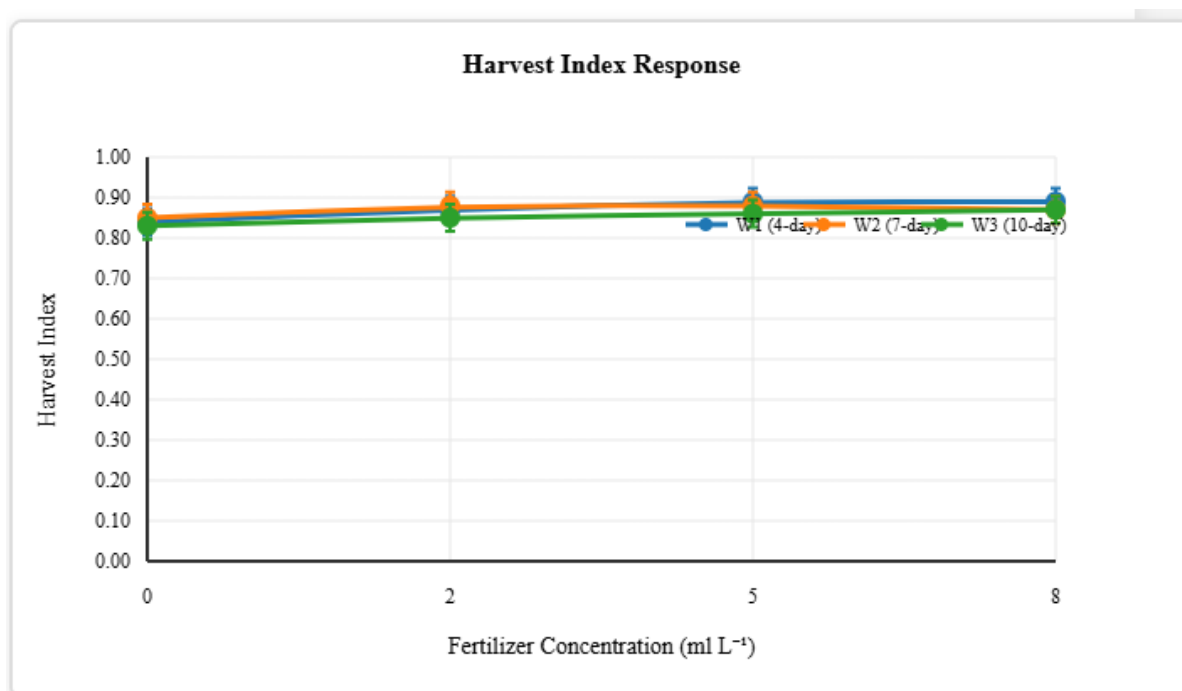


Figure 4. Harvest index response showing linear improvement with fertilizer concentration, indicating enhanced resource allocation efficiency.

The linear regression equations for different application intervals further support this finding, with the harvest index consistently increasing with higher fertilizer concentrations. For instance, the equation for the 4-day interval ($Y = 0.84 + 0.006x$) indicates a positive slope, suggesting that more frequent nutrient applications at higher concentrations result in improved resource utilization. Similarly, the 7-day and 10-day intervals also demonstrate positive relationships, albeit with slightly lower

coefficients, indicating that nutrient availability still plays a significant role in enhancing harvest efficiency, albeit to a lesser extent at longer intervals. The optimal harvest index of 0.89 was achieved with the K_3W_1 treatment, indicating that a specific combination of nutrient concentration and application frequency optimizes resource allocation to the most valuable plant parts, such as fruits or seeds ([Dewi Ratna Nurhayati, 2023](#)). The positive correlation between fertilizer concentration and harvest

index suggests enhanced photosynthetic efficiency under higher nutrient conditions, where the plant can allocate more assimilates (sugars and other organic compounds) to reproductive structures or other marketable biomass. This improved allocation likely results from a combination of increased photosynthesis due to better leaf development and enhanced transport of nutrients and energy to developing plant organs (Hasniar *et al.*, 2022). Thus, proper fertilization not only supports overall growth but also improves the economic value of the crop by increasing the

proportion of biomass that can be harvested and sold.

Correlation Analysis

Pearson correlation analysis revealed significant positive correlations between fertilizer concentration and all yield parameters (Table 2). The strongest correlations were observed between concentration and shoot fresh weight ($r = 0.94$, $p < 0.001$), followed by root fresh weight ($r = 0.91$, $P < 0.001$) and leaf area ($r = 0.88$, $p < 0.001$).

Table 2. Correlation analysis of observed variables

Variables	Concentration (r)	Application Frequency (r)	Significance
Shoot Fresh Weight	0.94***	0.87***	$p < 0.001$
Root Fresh Weight	0.91***	0.83***	$p < 0.001$
Leaf Area	0.88***	0.85***	$p < 0.001$
Harvest Index	0.76**	0.69**	$p < 0.01$

Note: *** $p < 0.001$, ** $p < 0.01$

The correlation analysis presented in Table 2 reveals significant positive relationships between fertilizer concentration and application frequency with various plant growth parameters, underscoring the critical role of nutrient management in plant development. Shoot fresh weight shows the highest correlation with both concentration ($r = 0.94$) and application frequency ($r = 0.87$), indicating that both factors substantially influence shoot growth, likely by enhancing metabolic activities such as photosynthesis and nutrient assimilation. Similarly, root fresh weight also exhibits strong positive correlations ($r = 0.91$ for concentration, $r = 0.83$ for frequency), suggesting that both higher nutrient levels and more frequent applications promote root development, which is essential for efficient water and nutrient uptake (Ramadhan *et al.*, 2021). Leaf area shows a moderately strong relationship with concentration ($r = 0.88$) and application frequency ($r = 0.85$), reflecting the importance of nutrient availability and consistent fertilization in optimizing leaf expansion, which directly contributes to increased photosynthetic capacity. The

harvest index, while still significant ($r = 0.76$ for concentration, $r = 0.69$ for frequency), shows a slightly weaker correlation, indicating that while nutrient availability enhances resource allocation to marketable biomass, other factors, such as plant genetics or environmental conditions, may also play a role in determining the efficiency of nutrient allocation. These findings underscore the physiological significance of balanced fertilization in enhancing plant growth and yield outcomes (Hamawi *et al.*, 2024).

Response Surface Analysis

The three-dimensional response surface analysis presented in Figure 5 illustrates the significant interaction between concentration and application frequency, revealing distinct optimization zones for lettuce production. The analysis identifies two main regions with varying yields: the first is a high-yield zone, characterized by concentrations ranging from 6 to 8 ml L⁻¹ applied at 4-day intervals, while the second is a more resource-efficient zone, defined by concentrations of 4 to 5 ml L⁻¹ with application intervals of 4 to 7 days. These results suggest that both concentration

and frequency contribute significantly to the optimization of crop yield, but their combined effect plays a crucial role in determining the overall productivity.

The response surface equations derived from the analysis highlight the more dominant influence of application frequency on the yield, with frequency alone explaining 68% of the variation in shoot weight. In contrast, concentration accounted for only 45% of the variance. This finding highlights the crucial role of nutrient timing in

optimizing the growth potential of lettuce. The pronounced effect of application frequency suggests that adjusting the timing of nutrient applications, rather than merely altering the concentration, can lead to more efficient resource utilization and improved yield outcomes. This insight has significant implications for agricultural practices, offering a pathway toward optimizing nutrient management strategies for higher crop yields while minimizing resource wastage (Putri & Rahmayuni, 2023b).

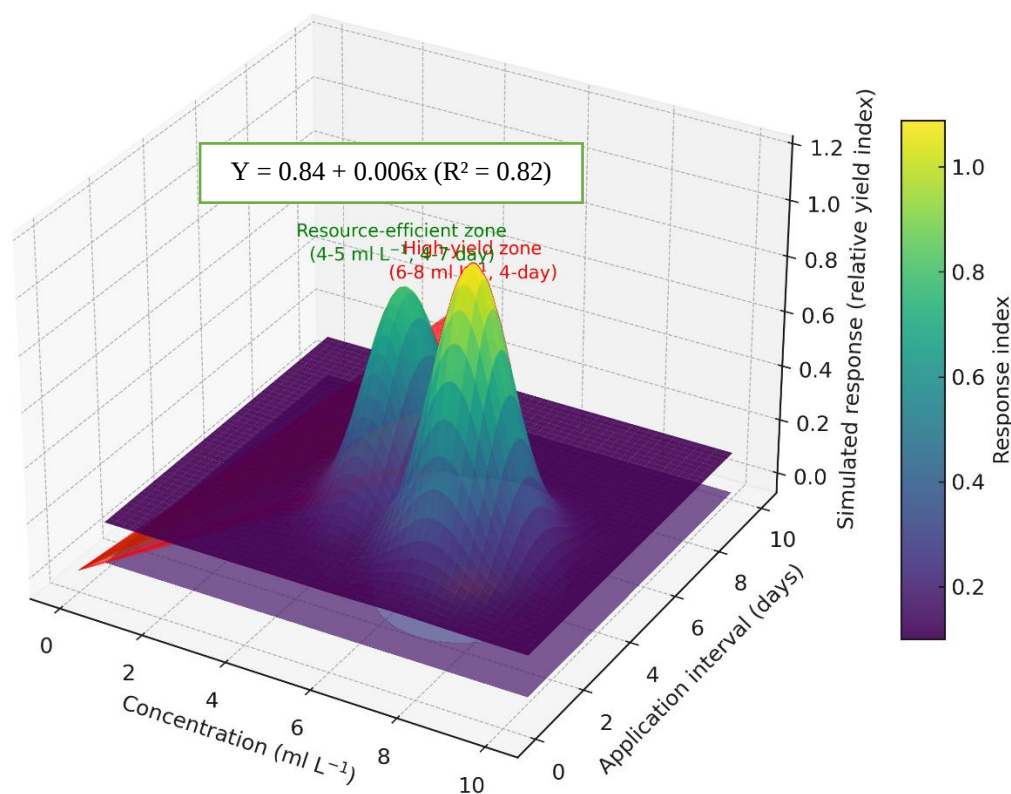


Figure 5. 3D visualization showing zones. High-yield zone (red) 6-8 Ml L⁻¹ with 4-day intervals. Resource efficient zone (green) 4-5 ml L⁻¹ with 4-7 day intervals

CONCLUSION

The research demonstrates that both the concentration of liquid organic fertiliser and application frequency significantly impact the growth and production of lettuce, with each factor influencing different growth parameters. The study found that higher concentrations of Biotogrow fertilizer,

particularly at 8 mL/L, improved plant height, leaf number, leaf area, and plant canopy weight. The frequency of fertilization also played a crucial role, with more frequent applications (every 4 days) resulting in the most efficient nutrient utilization, leading to higher shoot and root fresh weights, as well as larger leaf areas. The analysis also revealed that there is an optimal concentration beyond

which additional fertilizer yields diminishing returns, likely due to nutrient saturation or toxic effects. The harvest index increased linearly with both concentration and frequency, suggesting that fertilisation not only promotes overall growth but also improves the allocation of resources to economically valuable parts of the plant. The interaction between fertiliser concentration and frequency was particularly significant in enhancing leaf development and root weight. Based on the actual research results, two practical recommendations emerge for Biotogrow application in lettuce production: For maximum yield production, apply Biotogrow at 6-8 ml L⁻¹ concentration with 4-day application intervals, which achieved the highest shoot fresh weight ($R^2 = 0.94$), optimal harvest index of 0.89 with K₃W₁ treatment, and superior leaf area development; however, this intensive approach requires 30–40% higher fertilizer costs and significantly increased labor for frequent applications, while response curves indicate diminishing returns above 6 ml L⁻¹ due to potential nutrient saturation, osmotic stress, and nutrient imbalances that may actually reduce leaf expansion at excessive concentrations. Alternatively, for resource-efficient production, apply Biotogrow at 4-5 ml L⁻¹ concentration with 4-7 day application intervals, which the response surface analysis identifies as the "resource-efficient zone" capable of achieving 80–85% of maximum yield potential while reducing fertilizer input costs by approximately 35–50%; the trade-off is moderately lower shoot and root fresh weights compared to intensive management, and plants may show reduced leaf area at longer intervals (10-day applications showed 12–15% lower R^2 values across parameters), requiring careful monitoring during peak growth periods. Notably, since application frequency explained 68% of yield variation, compared to only 45% for concentration, maintaining consistent 4-7 day intervals is more critical than maximizing concentration for achieving cost-effective production under tropical Central Maluku conditions.

REFERENCES

- Abd-Elrahman, S. H., Saady, H. S., El-Fattah, D. A. A. & Hashem, F. A. (2022). Effect of irrigation water and organic fertilizer on reducing nitrate accumulation and boosting lettuce productivity. *Journal of Soil Science and Plant Nutrition*, 22(2), 2144–2155. (<https://doi.org/10.1007/s42729-022-00799-8>)
- Abdullah, A. & Andres, J. (2021). Pengaruh pemberian pupuk organik cair terhadap pertumbuhan tanaman selada (*Lactuca sativa* L) secara hidroponik. *Jurnal Pendas (Pendidikan Sekolah Dasar)*, 3(1), 21–27. (<https://jurnal.isdikieraha.ac.id/index.php/pendas/article/view/189>)
- Anwary, M. N., Slamet, W. & Kusmiyati, F. (2019). Pertumbuhan selada merah (*Lactuca sativa* L. var. Red Rapid) dan selada hijau (*Lactuca sativa* L. Grand Rapids) dengan sistem hidroponik apung dengan pemberian dosis pupuk organik cair (POC) bioslurry dan AB mix yang berbeda. *Buletin Anatomi Dan Fisiologi*, 4(2), 160–167. (<https://doi.org/10.14710/baf.4.2.2019.160-167>)
- Carong, N. F. R. & Rafiuddin, M. K. (2025). Arbuscular mycorrhiza fungi and mineral fertilizer effects on growth and production traits of the potato (*Solanum tuberosum* L.). *SABRAO Journal of Breeding & Genetics*, 57(2). (<https://doi.org/10.54910/sabao2025.57.2.31>).
- Cintiyah, F., Salundik, S. & Komala, I. (2024). Optimization of liquid organic fertilizer from livestock manure with Indigofera for hydroponic lettuce growth. *Agro Bali: Agricultural Journal*, 7(3), 676–690. (<https://doi.org/10.37637/ab.v7i3.1875>)
- Dewi Ratna Nurhayati, W. A. A. (2023). Effect of Biotogrow Liquid Fertilizer Dosage and Interval on Green Eggplant (*Solanum Melongena* L.) Growth and Yield. *Nongye Jixie*

- Xuebao/*Transactions of the Chinese Society of Agricultural Machinery*, 54(4).
(<https://nyjxxb.net/index.php/journal/article/view/1587/1581>)
- Ekinci, M., Yildirim, E., Turan, M. & Kul, R. (2020). Organic Fertilizers Improved Plant Growth and Mineral Content of Lettuce (*Lactuca sativa* L.). *Erciyes Tarım ve Hayvan Bilimleri Dergisi*, 3(2), 1–5.
(<https://dergipark.org.tr/en/download/article-file/1282265>)
- Frasetya, B., Harisman, K. & Ramdaniah, N. A. H. (2021). The effect of hydroponics systems on the growth of lettuce. *IOP Conference Series: Materials Science and Engineering*, 1098(4), 042115. (DOI 10.1088/1757-899X/1098/4/042115)
- Hamawi, M., Akhiriana, E. & Marwatun, S. (2024). Pengaruh Pupuk Organik Cair (POC) Bekatul Terhadap Pertumbuhan Selada (*Lactuca sativa* L.) yang dibudidayakan Secara Hidroponik. *Agroteknika*, 7(2), 275–286.
(<https://doi.org/10.55043/agroteknika.v7i2.200>)
- Hasan, M. M. & Jho, E. H. (2023). Effect of different types and shapes of microplastics on the growth of lettuce. *Chemosphere*, 339, 139660.
(<https://doi.org/10.1016/j.chemosphere.2023.139660>)
- Hasniar, H., Iinnaninengseh, I. & Satriani, S. (2022). Pengaruh Media Tanam Yang Berbeda Dan Pemberian Dosis Pupuk Organik Cair Nasa Terhadap Pertumbuhan Dan Hasil Tanaman Selada (*Lactuca Sativa* L.). *Jurnal Agroterpadu*, 1(1), 13–17.
(<http://dx.doi.org/10.35329/ja.v1i1.2815>)
- He, X., Zhu, H., Shi, A. & Wang, X. (2024). Optimizing nitrogen fertilizer management enhances rice yield, dry matter, and nitrogen use efficiency. *Agronomy*, 14(5), 919.
(<https://doi.org/10.3390/agronomy14050919>)
- Ilmi, A. A., Santoso, J. & Sutini, S. (2025). The Effect of Bio-Fertilizer Concentration and NPK Fertilizer Dosage on the Growth and Yield of Melon (*Cucumis melo* L.) Merlin Variety. *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, 14(2), 638–644.
(<https://doi.org/10.23960/jtep-l.v14i2.638-644>)
- Januarisky, H. A., Syaukat, Y. & Rifin, A. (2025). The Effect of Urea and NPK Fertilizer Usage on Farmers Receiving Fertilizer Subsidies. *Agro Bali: Agricultural Journal*, 8(2), 352–363.
(<https://doi.org/10.37637/ab.v8i2.2098>)
- Legendre, R. & van Iersel, M. W. (2021). Supplemental far-red light stimulates lettuce growth: Disentangling morphological and physiological effects. *Plants*, 10(1), 166.
(<https://doi.org/10.3390/plants10010166>)
- Li, J., Liu, Y., Tang, Y., Shao, J., Xu, T., Ma, R., Jiang, Y. & Cheng, D. (2022). Optimizing fertilizer management based on controlled-release fertilizer to improve yield, quality, and reduce fertilizer application on apples. *Journal of Soil Science and Plant Nutrition*, 22(1), 393–405.
(<https://doi.org/10.1007/s42729-021-00656-0>)
- Muscolo, A., Marra, F., Canino, F., Maffia, A., Mallamaci, C. & Russo, M. (2022). Growth, nutritional quality and antioxidant capacity of lettuce grown on two different soils with sulphur-based fertilizer, organic and chemical fertilizers. *Scientia Horticulturae*, 305, 111421.
(<https://doi.org/10.1016/j.scienta.2022.111421>)
- Nurhayati, D. R. (2023). Effect of Biotogrow Dosage on Black and White Sesame Varieties Quality. *Journal of Social Science*, 4(1), 1–15.
(<https://doi.org/10.46799/jss.v4i1.499>)

- Pawase, P. P., Nalawade, S. M., Bhanage, G. B., Walunj, A. A., Kadam, P. B., Durgude, A. G. & Patil, M. R. (2023). Variable rate fertilizer application technology for nutrient management: A review. *International Journal of Agricultural and Biological Engineering*, 16(4), 11–19. ([10.25165/j.ijabe.20231604.7671](https://doi.org/10.25165/j.ijabe.20231604.7671))
- Putri, O. S. & Rahmayuni, E. (2023a). Aplikasi Pupuk Organik Cair Daun Lamtoro terhadap Pertumbuhan dan Produksi Selada Merah. *Jurnal Hortikultura Indonesia (JHI)*, 14(3), 177–183. (<https://doi.org/10.29244/jhi.14.3.177-183>)
- Putri, O. S. & Rahmayuni, E. (2023b). Aplikasi Pupuk Organik Cair Daun Lamtoro terhadap Pertumbuhan dan Produksi Selada Merah. *Jurnal Hortikultura Indonesia (JHI)*, 14(3), 177–183. (<https://doi.org/10.29244/jhi.14.3.177-183>)
- Qiao, L., Wang, X., Smith, P., Fan, J., Lu, Y., Emmett, B., Li, R., Dorling, S., Chen, H. & Liu, S. (2022). Soil quality both increases crop production and improves resilience to climate change. *Nature Climate Change*, 12(6), 574–580. (<https://doi.org/10.1038/s41558-022-01376-8>)
- Rai, I. N., Wijana, G. & Mintarajasa, J. D. (2025). Effect of Fertilization Package on Vegetative Growth of Tejakula Tangerine (*Citrus reticulata* cv. Tejakula) After Transplanting to the Field. *Agro Bali: Agricultural Journal*, 8(1), 137–144. (<https://doi.org/10.37637/ab.v>)
- Ramadhan, R., Syah, B. & Sugiono, D. (2021). Pengaruh kombinasi dosis pupuk organik cair dan pupuk NPK majemuk terhadap pertumbuhan dan hasil tanaman selada keriting (*Lactuca sativa* L.) varietas Grand Rapids pada sistem vertikultur. *Jurnal Ilmiah Wahana Pendidikan*, 7(5), 106–117. (<https://doi.org/10.5281/zenodo.5502836>)
- Ria, P., Noer, S. & Marhento, G. (2021). Efektivitas Pemberian Nasi Basi Sebagai Pupuk Organik pada Tanaman Selada Merah (*Lactuca sativa* var. *crispa*). *EduBiologia: Biological Science and Education Journal*, 1(1), 55–61. (<http://dx.doi.org/10.30998/edubiologia.v1i1.8088>)
- Shaik, A., Singh, H., Singh, S., Montague, T. & Sanchez, J. (2022). Liquid organic fertilizer effects on growth and biomass of lettuce grown in a soilless production system. *HortScience*, 57(3), 447–452. ([10.21273/HORTSCI16334-21](https://doi.org/10.21273/HORTSCI16334-21))
- Shatilov, M. V., Razin, A. F. & Ivanova, M. I. (2019). Analysis of the world lettuce market. *IOP Conf Ser Earth Environ Sci*. 395: 012053. (10.1088/1755-1315/395/1/012053)
- Sulaeman, Y., Cahyana, D. & Nursyamsi, D. (2021). Spatial Identification of Black Soils in Indonesia. *IOP Conference Series: Earth and Environmental Science*, 757(1), 012035. (10.1088/1755-1315/757/1/012035)
- Thomas, T., Biradar, M. S., Chimmad, V. P. & Janagoudar, B. S. (2021). Growth and physiology of lettuce (*Lactuca sativa* L.) cultivars under different growing systems. *Plant Physiology Reports*, 26(3), 526–534. (<https://doi.org/10.1007/s40502-021-00591-3>)
- Zhou, Z., Wang, C. & Luo, Y. (2020). Meta-analysis of the impacts of global change factors on soil microbial diversity and functionality. *Nature Communications*, 11(1), 3072. (<https://doi.org/10.1038/s41467-020-16881-7>)