Fadil Rohman

Improvement of Lettuce Growth and Yield by Foliar Fertilizer in Nutrient Film Technique Hydroponics

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Improvement of Lettuce Growth and Yield by Foliar Fertilizer in Nutrient Film Technique Hydroponics

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ABSTRACT

Lettuce is an important leafy vegetable widely cultivated in hydroponic systems such as the Nutrient Film Technique (NFT) due to their high efficiency in water and nutrient use. However, under intensive cultivation conditions, temporary nutrient imbalance, restricted root activity, or suboptimal nutrient absorption may still reduce plant growth and productivity. Foliar fertilization can therefore serve as a complementary nutrient supply strategy to support plant performance in NFT systems. This study aimed to evaluate the effect of foliar fertilizer concentration on the growth and yield of curly lettuce grown in an NFT hydroponic system. The experiment was arranged in a Completely Randomized Design (CRD) with eight concentrations of commercial foliar fertilizer (Gandasil D®: 0, 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 g L^{-1}), three replications, and three plants per experimental unit. Foliar fertilizer was sprayed weekly from transplanting until harvest in a greenhouse NFT system. Parameters observed included plant height, number of leaves, leaf area, chlorophyll content, root volume, and plant fresh weight. Results showed that foliar fertilizer significantly affected plant height, number of leaves, leaf area, root volume, and plant fresh weight ($p < 0.05$), while chlorophyll content was not significantly affected. The highest plant performance was obtained at 3.5 g L^{-1}, which increased plant fresh weight by 105% compared to the control. Plant fresh weight was strongly associated with leaf area, number of leaves, and root volume. Foliar fertilizer application at 3.5 g L^{-1} is recommended to improve lettuce growth and yield in NFT hydroponic systems.

Keywords: biomass, curly lettuce, nutrient management, plant yield, soilless cultivation

INTRODUCTION

Lettuce (*Lactuca sativa* L.) is an important leafy vegetable widely cultivated worldwide due to its short production cycle, nutritional value, and high market demand. In recent years, hydroponic cultivation systems, particularly the Nutrient Film Technique (NFT), have gained popularity because of their efficiency in water and nutrient use as well as suitability for intensive production (Chowdhury *et al*., 2024). Despite these advantages,

nutrient imbalances or suboptimal nutrient uptake through the root system may still occur, potentially limiting growth and yield.

Foliar fertilization has been proposed as a complementary practice to overcome such limitations by supplying nutrients directly to the leaves, thus bypassing potential restrictions of root uptake. This technique has been shown to enhance growth, photosynthesis, and yield in lettuce and other leafy vegetables (Salama *et al*., 2024; Samarakoon *et al*., 2020). However, the effectiveness of foliar fertilization largely depends on the nutrient source, concentration, and application frequency. Inappropriate concentrations may not provide benefits or may even result in osmotic stress and reduced growth.

Foliar fertilization using water-soluble Calcium Chloride and amino acids-based fertilizers has been proposed as a complementary practice to overcome such limitations by supplying nutrients directly to the leaves, thus bypassing potential restrictions of root uptake (Samarakoon *et al*., 2020; Souza *et al*., 2024). Although these findings confirmed the potential of foliar sprays, many experiments used a limited concentration range or single application levels, making it difficult to establish clear guidelines on effective dosage levels for lettuce under hydroponic NFT conditions. In the present study, a commercial foliar fertilizer (Gandasil D®; N = 20%, P = 15%, K = 15%, Mg = 1%) was evaluated as a supplemental nutrient source for lettuce cultivated under NFT hydroponic conditions.

This created a research gap because the response of lettuce to a systematic range of foliar fertilizer concentrations, particularly at low to moderate levels (0.5 to 3.5 g L^{-1}), had not been thoroughly investigated. Determining this response was essential, as very

low doses may be insufficient to stimulate plant growth, whereas high concentrations could surpass plant physiological tolerance. Therefore, this study aimed to evaluate the effect of a wide range of foliar fertilizer concentrations on the growth and yield of curly lettuce grown under the NFT system. This study provides practical information on optimal foliar fertilizer use for efficient and sustainable hydroponic lettuce cultivation.

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METHODS

Experimental Site and Design

The experiment was conducted in a greenhouse located in Gunungsari Village, Jember District, East Java, Indonesia, from July to September 2024. The study was arranged in a Completely Randomized Design (CRD) with eight concentrations of foliar fertilizer: 0, 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 g L^{-1}. Each treatment was replicated three times, resulting in 24 experimental units. Each experimental unit consisted of three plants, and the mean value of the three plants within each unit was used for statistical analysis.

Experimental Procedures

Prior to transplanting, the greenhouse and hydroponic facilities were sterilized by removing weeds and plant residues, and cleaning the NFT installation, including 2-inch PVC pipes and the nutrient reservoir tank using water and detergent. Seeds of curly lettuce (*Lactuca sativa* L. cv. Batavia Brava) were germinated on rockwool cubes (2.5 × 2.5 cm). Each cube was perforated, seeded with one seed, placed in trays, moistened with water, and maintained for 21 days until seedlings had three true leaves.

Transplanting was carried out in the afternoon to reduce transplanting shock, placing seedlings into planting holes in the NFT installation at a spacing of 25 × 25 cm. During cultivation, AB Mix nutrient solution was applied at a concentration of 1000 ppm from transplanting until harvest. The nutrient solution was maintained at pH 5.8–6.5 and electrical conductivity (EC) of approximately 1.2–1.8 mS cm^{-1} throughout the cultivation period. Nutrient solution concentration was monitored regularly using a TDS meter, and nutrient solution was replenished weekly to maintain stable nutrient availability. The AB Mix nutrient solution served as the primary root nutrient source, while foliar fertilizer was applied as a supplementary nutrient input intended to enhance nutrient use efficiency and support vegetative growth under intensive hydroponic cultivation.

A commercial foliar fertilizer (Gandasil D®; N = 20%, P = 15%, K = 15%, Mg = 1%) was applied at the designated concentrations. Fertilizer solutions were sprayed onto the leaves using a hand sprayer at 7-day intervals, beginning at transplanting. Spraying was conducted in the morning to improve absorption and minimize evaporation. Plastic sheet partitions were placed between treatment units during foliar spraying to minimize spray drift and prevent cross-contamination among treatments. Lettuce was harvested at 30 DAT, corresponding to the commercial harvest stage for curly lettuce cultivated under hydroponic conditions, characterized by fully expanded leaves and marketable fresh biomass.

Observed Parameters and Data Analysis

Parameters measured included plant height (cm), number of leaves (blades), leaf area (cm^2), chlorophyll content (units mm^{-2}), root volume (mL), and plant fresh weight (g).

Plant height and number of leaves were measured weekly from 1 to 4 weeks after transplanting (WAT), whereas leaf area, chlorophyll content, root volume, and plant fresh weight were measured at harvest. Plant height was measured from the stem base to the highest leaf, while leaf number was recorded manually. Leaf area was determined at harvest using the gravimetric method. Chlorophyll content was measured on fully expanded mature leaves located in the middle canopy using a SPAD-502 chlorophyll meter. Root volume was measured by water displacement in a graduated cylinder, and plant fresh weight was determined by weighing the entire plant at harvest. Data were analyzed using analysis of variance (ANOVA) at the 5% significance level and Duncan's Multiple Range Test (DMRT) at the 5% level.

RESULTS AND DISCUSSION

Effect on Plant Height and Number of Leaves

The application of foliar fertilizer significantly affected the vegetative growth of lettuce, as shown by changes in plant height and the number of leaves (Figure 1 and Figure 2). Plant height and leaf number increased with increasing concentrations of foliar fertilizer up to 3.5 g L^{-1}. At 1 to 4 weeks after transplanting (WAT), lettuce plants treated with 3.5 g L^{-1} were significantly taller and had more leaves compared to the control (0 g L^{-1}) and the lowest concentration (0.5 g L^{-1}). Although the highest mean values were obtained at 3.5 g L^{-1}, plant responses in the range of 2.5–3.5 g L^{-1} were not significantly different. This suggested that foliar fertilizer application at moderate-to-high concentrations (2.5–3.5 g L^{-1}) was sufficient to support optimal vegetative growth, while concentrations below this range were less effective in promoting lettuce growth.

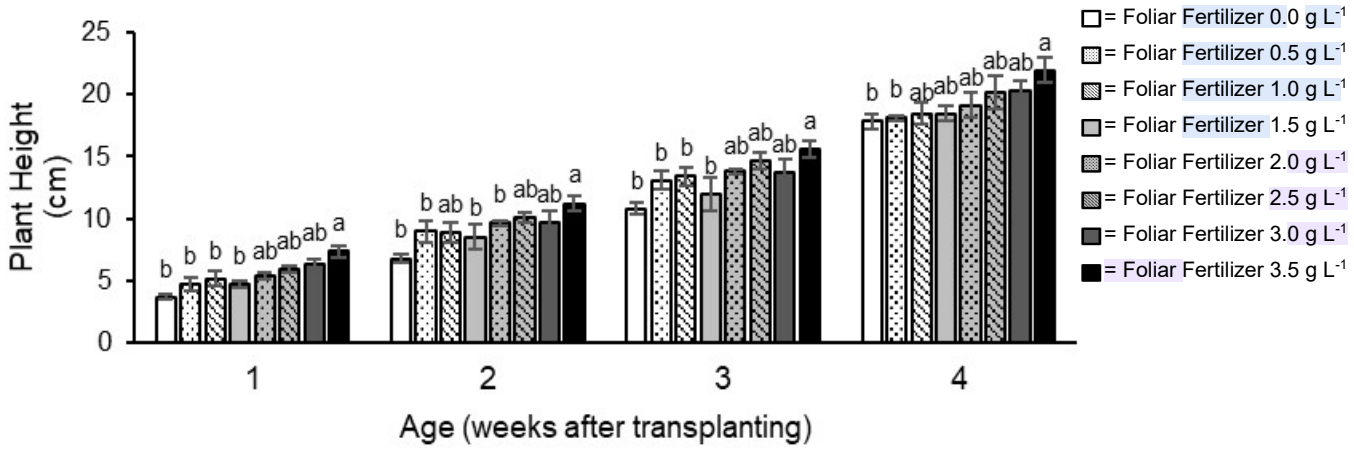


Figure 1. Plant height at various concentrations of foliar fertilizer.
Note: Charts with the same letter at certain age showed no significant difference according to 5% DMRT test.

Physiologically, improved vegetative growth under foliar fertilization was consistent with the roles of macronutrients delivered to leaves: nitrogen (chlorophyll synthesis, cell division/expansion), phosphorus (energy transfer), and potassium (enzyme activation and osmotic balance). Recent reviews also emphasize that foliar routes can increase nutrient use efficiency and support growth responses while avoiding limitations of root uptake, particularly in intensive or soilless systems (Niu *et al*., 2021).

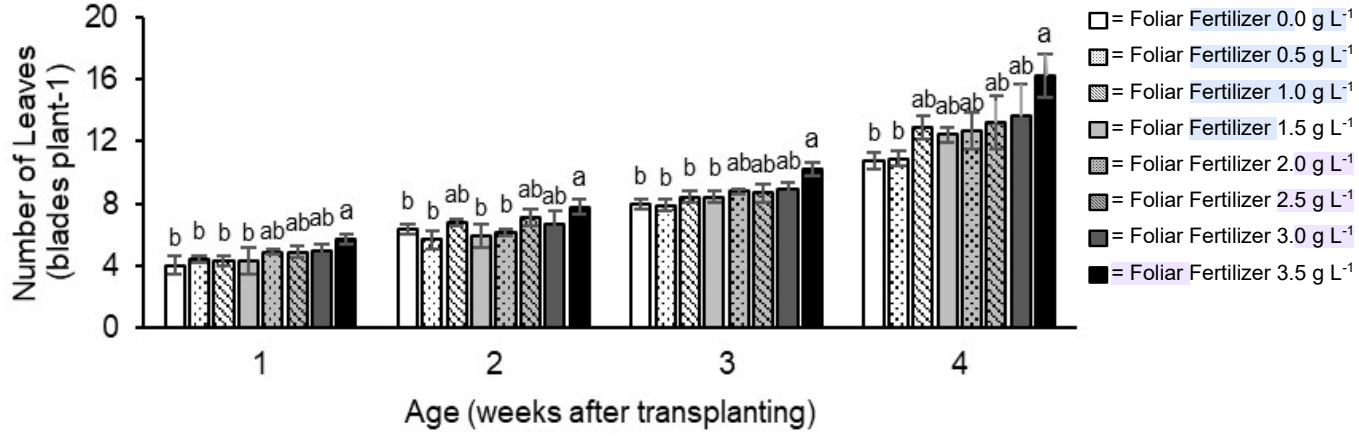


Figure 2. The number of leaves at various concentrations of foliar fertilizer.
Note: Charts with the same letter at certain age showed no significant difference according to 5% DMRT test.

Evidence of recent lettuce-focused studies aligned with our results. Hidayat & Suhardjono (2025) observed improved growth traits, including plant height and leaf number, when lettuce was treated with foliar fertilizer under hydroponic conditions. Likewise, in floating hydroponics, foliar application of vegetal protein hydrolysates enhanced yield and qualitative attributes across cultivars, confirming that foliar inputs could effectively drive vegetative performance in lettuce (Cristofano *et al*., 2021).

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Effect on Leaf Area and Leaf Chlorophyll Content

The application of foliar fertilizer significantly affected the leaf area of lettuce (Figure 3A). Plants treated with 3.5 g L^{-1} exhibited the highest mean leaf area, which was significantly greater than control and lower concentrations. This result indicated that increasing foliar fertilizer concentration enhanced leaf expansion, with the strongest response observed at 3.5 g L^{-1}. The positive effect of foliar application on leaf area reflected the improved supply of nutrients that support cell division and enlargement, thereby increasing the photosynthetic surface of the plant.

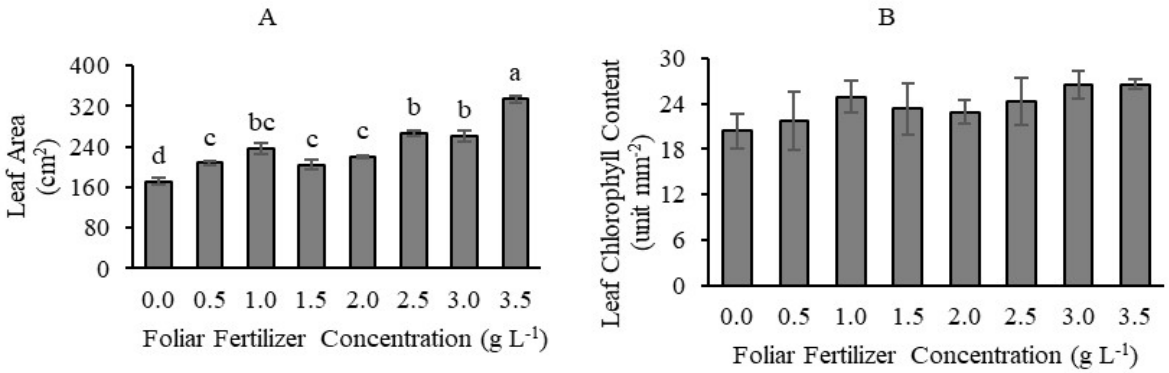


Figure 3. Effect of foliar fertilizer concentration on leaf area (A) and leaf chlorophyll content (B).

Note: Charts with the same letter at certain age showed no significant difference according to 5% DMRT test.

In contrast, leaf chlorophyll content was not significantly affected by foliar fertilizer concentration (Figure 3B). Although slight increases were observed in some treatments, statistical analysis revealed no significant differences among treatments. This suggested that, under the conditions of this study, foliar application enhanced leaf expansion but did not markedly alter chlorophyll biosynthesis. It was possible that baseline nutrient availability in the system was already sufficient to maintain chlorophyll levels.

These findings were in line with previous reports that foliar fertilization can strongly influence morphological parameters such as leaf expansion, while effects on physiological traits like chlorophyll content may vary depending on environmental conditions and baseline nutrient supply. For example, Cristofano *et al*. (2021) found that foliar protein hydrolysates increased leaf area and biomass in lettuce, while chlorophyll responses were less consistent. Similarly, a study on biopolymer-based foliar sprays reported significant improvements in leaf morphology but only minor or non-significant effects on chlorophyll concentration (Fragalà *et al*., 2024).

1

Effect on Root Volume and Plant Fresh Weight

The application of foliar fertilizer significantly affected root volume and plant fresh weight of lettuce (Figure 4A and 4B). Plants treated with 3.5 g L^{-1} exhibited the highest mean root volume, which was significantly greater than the control and lower concentrations. This indicates that foliar fertilization enhanced root growth, likely through improved nutrient assimilation and translocation to the root system.

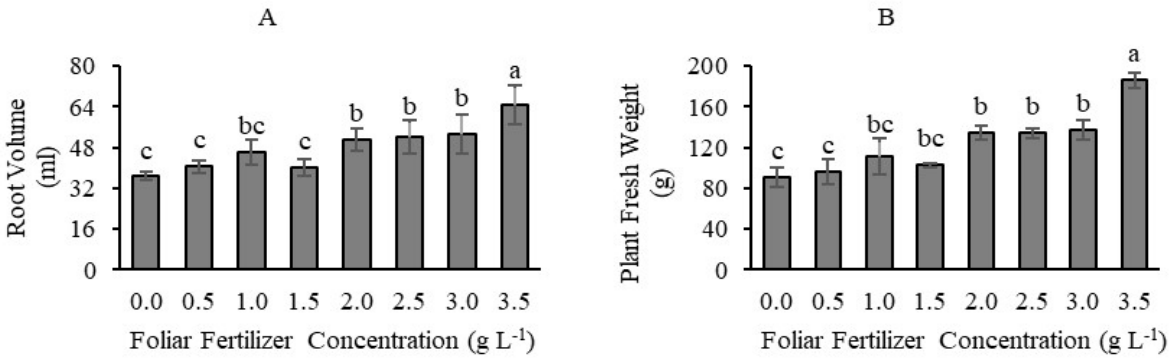


Figure 4. Effect of foliar fertilizer concentration on root volume (A) and plant fresh weight (B).

Note: Charts with the same letter at certain age showed no significant difference according to 5% DMRT test.

Plant fresh weight followed a similar trend, where the highest mean fresh biomass was obtained at 3.5 g L^{-1}, significantly higher than the control and low concentrations. These results demonstrate that foliar application effectively improved the yield of lettuce by promoting both root development and shoot biomass accumulation. The increase in fresh weight is consistent with enhanced leaf expansion (Figure 3A) and improved nutrient assimilation, which together increase the photosynthetic capacity of the plant.

Previous studies supported these findings. Carillo *et al*. (2022) reported that foliar sprays of plant-based biostimulants significantly improved lettuce root system traits, which in turn supported higher shoot biomass. Similarly, Cristofano *et al*. (2021) found that foliar protein hydrolysates enhanced lettuce biomass production in floating hydroponic systems, highlighting the role of foliar feeding in maximizing yield. A recent review by Niu *et al*. (2021) also emphasized that foliar fertilization improves overall nutrient use efficiency, resulting in higher crop productivity.

Relationship between Growth Parameters and Yield

In this discussion, yield was represented by plant fresh weight, as it directly reflects the marketable portion of lettuce. Regression analysis (Figure 5) showed positive relationships between plant fresh weight and several growth parameters, including plant height (Figure 5A), number of leaves (Figure 5B), leaf area (Figure 5C), and root volume (Figure 5D).

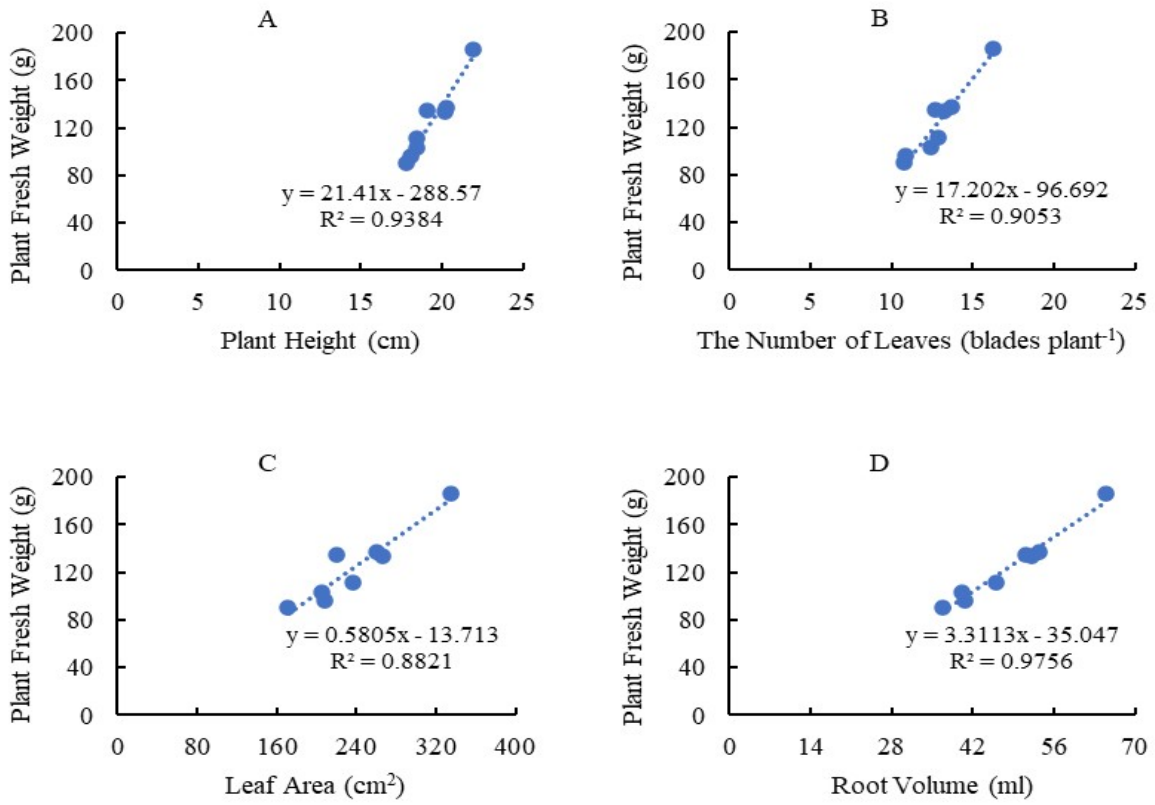


Figure 5. The relationship between lettuce production and plant height (A), number of leaves (B), leaf area (C) and root volume (D)

Note: Regression lines indicate significant positive correlations ($p < 0.05$)

Among these parameters, leaf area and number of leaves exhibited the strong associations with fresh weight, suggesting that aerial morphological traits play a dominant role in determining yield. Larger leaf surface area allows greater light

interception and photosynthetic activity, while a higher number of leaves contributes to increased assimilate production. These findings are consistent with Li *et al*. (2024), who demonstrated that improved root architecture enhanced nutrient uptake, which in turn promoted shoot development and leaf expansion.

Root volume also showed a positive correlation with fresh weight, highlighting its role in nutrient and water uptake. Studies on vertical hydroponic systems similarly found that nutrient solutions promoting greater root mass also resulted in higher fresh biomass of lettuce (Alkaabi *et al*., 2025). Furthermore, in semi-hydroponic cultivation, foliar biofertilizers improved lettuce root development and overall biomass accumulation, indicating that both root and shoot growth must be optimized to maximize yield (Guimarães *et al*., 2020).

Interestingly, leaf chlorophyll content was not significantly influenced by foliar fertilizer concentration in this study (Figure 3B). The absence of significant differences in chlorophyll content may indicate that the baseline nutrient supply from the AB Mix solution was already sufficient to maintain chlorophyll biosynthesis across treatments. Therefore, foliar fertilization primarily enhanced morphological growth traits such as leaf expansion and biomass accumulation rather than increasing chlorophyll concentration. While leaf chlorophyll content is often considered indicators of photosynthetic efficiency, our results suggested that lettuce yield was more strongly driven by morphological traits such as leaf area than by physiological traits like chlorophyll concentration. Similar observations have been reported in experiments using liquid organic fertilizers, where shoot biomass was more closely aligned with leaf expansion than with leaf chlorophyll content (Shaik *et al*., 2022).

Implications for Hydroponic Lettuce Cultivation Practices

25 The results of this study highlight several important implications for hydroponic lettuce production. Since vegetative growth and yield responses peaked at concentrations of 2.5–3.5 g L^{-1}, growers should apply foliar fertilizer within this range to achieve optimal results. Concentrations lower than this range may not fully exploit the potential of foliar application. These findings suggest that proper management of foliar fertilization can improve nutrient use efficiency and reduce the risk of over-application in hydroponic systems.

Although the highest response was obtained at 3.5 g L^{-1}, excessively high foliar fertilizer concentrations may potentially induce phytotoxic effects such as leaf burn, osmotic stress, or nutrient imbalance. Previous studies have reported that excessive foliar nutrient concentrations can reduce growth efficiency and impair physiological performance in leafy vegetables (Chaski & Petropoulos, 2022a, 2022b). Therefore, increasing concentration beyond the optimal range may not necessarily improve lettuce productivity.

Integrating foliar fertilization with other inputs, such as liquid organic fertilizers and plant-derived biostimulants, can also enhance sustainability. For example, Chowdhury *et al*. (2024) demonstrated that liquid organic fertilizers improved lettuce biomass in certain hydroponic systems, while İkiz *et al*. (2024) reported that biostimulants mitigated saline stress in hydroponic lettuce and supported yield stability. Similarly, a study on floating systems indicated that biofertilizers enhanced both yield and quality traits of lettuce, suggesting that foliar application can complement organic and biological approaches to nutrient management (Dasgan *et al*., 2023). These studies confirm that foliar fertilization

should be viewed not in isolation but as part of an integrated strategy for hydroponic nutrient supply.

System compatibility is another important consideration. Not all hydroponic systems respond equally to foliar supplementation. Chowdhury *et al*. (2024) noted that substrate-based hydroponics benefited more from organic liquid fertilizers compared to NFT or DWC systems, highlighting the need to adjust foliar strategies according to the cultivation method. Novel approaches, such as the foliar application of Fe-Alg-$CaCO_3$ microparticles, have also been shown to enhance lettuce yield in aquaponic system (Frassine *et al*., 2024). These findings underscore the role of technology in improving foliar absorption efficiency while reducing nutrient losses.

Taken together, these implications demonstrate that foliar fertilization is a promising strategy for hydroponic lettuce cultivation, particularly when applied at optimal concentrations and integrated with other nutrient management practices. Based on the present results, application of Gandasil D® at 3.5 g L^{-1} every 7 days starting from transplanting is recommended to improve growth and fresh yield of lettuce cultivated in NFT hydroponic systems. Future studies should explore interactions between foliar applications and environmental factors such as light intensity, salinity, and cultivation system type, as well as assess their long-term impacts on lettuce quality and marketability.

CONCLUSION

The application of foliar fertilizer significantly improved the growth and yield of lettuce in a hydroponic system. Plant height, number of leaves, leaf area, root volume, and plant

fresh weight all increased with increasing concentrations of foliar fertilizer. Yield, represented by plant fresh weight, was most strongly associated with leaf area, number of leaves and root development supporting nutrient and water uptake. The optimal response was obtained at concentrations of 3.5 g L^{-1}, where lettuce plants exhibited significantly higher growth and yield compared to other treatments.

These results indicated that foliar fertilization can serve as an effective strategy to enhance vegetative development and fresh yield of lettuce in hydroponic systems. Integrating foliar fertilization within broader nutrient management practices may help optimize crop productivity, resource efficiency, and sustainability in controlled environment agriculture.

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