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

**Fadil Rohman*, Tri Rini Kusparwanti, Edi Siswadi, Rindha Rentina Darah Pertami, Danang Wahyu Setiyawan**

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## ABSTRACT

**Lettuce (*Lactuca sativa* L.) is a popular leafy vegetable grown in hydroponic systems such as the fertilizer Film Technique (NFT) because of its excellent water and fertilizer efficiency. However, even under intense cultivation circumstances, transitory nutritional imbalance, reduced root activity, or poor nutrient absorption can impair plant growth and output. Foliar fertilization can thus be used as an additional fertilizer supply approach to improve plant performance in NFT systems. The purpose of this study was to evaluate how different foliar fertilizer concentrations affected the growth and yield of curly lettuce produced in an NFT hydroponic system. The experiment used a Completely Randomized Design (CRD) with eight different dosages of commercial foliar fertilizer (Gandasil D®: 0, 0.5, 1, 1.5, 2, 2.5, 3, and 3.5 g L$^{-1}$). Each experimental unit consisted of three replications and three plants. The fertilizer was applied weekly from transplanting to harvest in a greenhouse NFT system. Plant height, leaf number, leaf area, chlorophyll content, root volume, and fresh weight were among the parameters measured. Foliar fertilizer significantly increased plant height, number of leaves, leaf area, root volume, and plant fresh weight ($p < 0.05$), but had no significant effect on chlorophyll content. Plants performed best at 3.5 g L$^{-1}$, with a 105% increase in fresh weight compared to the control group. Plant fresh weight was substantially related to leaf area, number of leaves, and root volume. To boost lettuce growth and productivity in NFT hydroponic systems, apply 3.5 g of foliar fertilizer per L.**

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

## INTRODUCTION

Lettuce (*Lactuca sativa* L.) is a popular leafy vegetable globally due to its short production cycle, nutritional value, and strong market demand. Hydroponic growing systems, particularly the Nutrient Film Technique (NFT), have grown in favor in recent years due to their water and fertilizer efficiency, as well as their appropriateness for intense production (Chowdhury *et al*. 2024). Despite these benefits, nitrogen imbalances or poor nutrient uptake through the root system may persist, thereby restricting growth and yield.

Foliar fertilization has been recommended as a supplementary approach to overcome such limits by feeding nutrients directly to the leaves, so avoiding any root uptake constraints. This method has been demonstrated to improve growth, photosynthesis, and yield in lettuce and other leafy plants vegetables (Salama *et al*. 2024; Samarakoon *et al*. 2020). However, the efficacy of foliar fertilization is heavily dependent on the nutrient source, concentration, and application frequency. Inappropriate concentration may not provide any benefits and may potentially cause osmotic stress and impaired growth. Foliar fertilization using water-soluble calcium chloride and amino acid fertilizers has been recommended as a supplemental approach to address such limits by providing nutrients directly to the leaves, thereby bypassing potential root uptake restrictions (Samarakoon *et al*. 2020; Souza *et al*. 2024).

Although these data verified the efficacy of foliar sprays, several tests used a narrow concentration range or single application levels, making it impossible to develop precise parameters for optimum lettuce dose levels under hydroponic NFT conditions. In the current study, a commercial foliar fertilizer (Gandasil D®; N = 20%, P = 15%, K = 15%, Mg = 1%) was tested as a supplemental nitrogen source for lettuce grown under NFT hydroponic conditions. This generated a study gap because the response of lettuce to a systematic range of foliar fertilizer doses, especially at low to moderate levels (0.5 to 3.5 g L$^{-1}$), was not adequately examined. Determining this response was critical, as extremely low doses may be insufficient to drive plant growth, while excessive quantities may exceed plant physiological tolerance.

As a result, the purpose of this study was to assess the influence of various foliar fertilizer concentrations on the growth and production of curly lettuce cultivated in an NFT system. This study provides practical

Department of Agricultural Production, Politeknik Negeri Jember, East Java 68121, Indonesia
* Corresponding Author:
E-mail: fadil.rohman@polije.ac.id

information on how to use foliar fertilizer to grow hydroponic lettuce efficiently and sustainably.

## METHODS

### Experimental Site and Design

The experiment took place in a greenhouse at Gunungsari Village, Jember District, East Java, Indonesia, from July to September 2024. The study used a Completely Randomized Design (CRD) with eight foliar fertilizer concentrations: 0, 0.5, 1, 1.5, 2, 2.5, 3, and 3.5 g/L. Each treatment was repeated three times, totaling 24 experimental units. Each experimental unit was made up of three plants, and the statistical analysis was based on the mean value of the three plants.

### Procedures

Before transplanting, the greenhouse and hydroponic facilities were disinfected by removing weeds and plant residues and washing the NFT system, which included 2-inch PVC pipes and the nutrient reservoir tank, with water and detergent. Curly lettuce seeds (*Lactuca sativa* L. cv. Batavia Brava) germinated on 2.5 cm × 2.5 cm rockwool cubes. Each cube was perforated, sown with one seed, placed in trays, watered, and left for 21 days until the seedlings developed three true leaves.

To minimize transplant shock, seedlings were planted in 25 cm × 25 cm spacing holes in the NFT installation in the afternoon. AB Mix fertilizer solution was applied at a concentration of 1000 ppm from transplanting to harvest. During cultivation, the nutrient solution maintained a pH of 5.8−6.5 and an electrical conductivity of 1.2−1.8 mS $cm^{-1}$. A TDS meter was used to measure the nutrient solution concentration on a regular basis, and the nutrient solution was replaced weekly to ensure consistent nutrient availability. The AB Mix nutrient solution was used as the major root nutrient supply, with foliar fertilizer added as a supplementary nutrient input to improve nutrient usage efficiency and stimulate vegetative development during intense hydroponic production.

A commercial foliar fertilizer (Gandasil D®; N = 20%, P = 15%, K = 15%, Mg = 1%) was used at specified concentrations. Fertilizer solutions were sprinkled into the leaves using a hand sprayer at 7-day intervals beginning with transplantation. Spraying was done in the morning to maximize absorption and reduce evaporation. Plastic sheet walls were installed between treatment units during foliar spraying to reduce spray drift and cross-contamination. Lettuce was picked 30 days after transplanting (DAT), which is the commercial harvest stage for curly lettuce grown under hydroponic circumstances, with fully expanded leaves and marketable fresh biomass.

### Observed Parameters and Data Analysis

The parameters measured were plant height (cm), number of leaves (blades), leaf area ($cm^2$), chlorophyll concentration (units $mm^{-2}$), root volume (mL), and plant fresh weight (g). Plant height and number of leaves were measured weekly between 1 and 4 weeks after transplanting (WAT), whereas leaf area, chlorophyll content, root volume, and plant fresh weight were assessed at harvest. Plant height was measured from the stem base to the topmost leaf, and leaf count was recorded manually. The gravimetric approach was used to determine leaf area during harvest. The chlorophyll content of fully grown adult leaves in the intermediate canopy was measured using a SPAD-502 chlorophyll meter. Water displacement in a graduated cylinder was used to quantify root volume, and the fresh weight of the plant was calculated by weighing the entire plant upon harvest. The data were evaluated by 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 had a substantial impact on lettuce vegetative development, as evidenced by changes in plant height and leaf count (Figures 1 and 2). Increasing foliar fertilizer concentration to 3.5 g $L^{-1}$ resulted in enhanced plant height and leaf number. At 1 to 4 WAT, lettuce plants treated with 3.5 g $L^{-1}$ grew substantially taller and had more leaves than the control (0 g $L^{-1}$) and the lowest dose (0.5 g $L^{-1}$). The greatest mean values were observed at 3.5 g $L^{-1}$, while plant responses in the 2.5−3.5 g $L^{-1}$ range were not substantially different. Foliar fertilizer treatment at moderate-to-high concentrations (2.5−3.5 g $L^{-1}$) supports good vegetative growth. Concentrations below this range are less helpful in encouraging lettuce growth.

Physiologically, increased vegetative development following foliar fertilization was consistent with the roles of macronutrients given to leaves: nitrogen (chlorophyll synthesis, cell division/expansion), phosphorus (energy transfer), and potassium (enzyme activation and osmotic equilibrium). Recent reviews have also emphasized that foliar pathways can improve nutrient utilization and growth responses while avoiding root absorption restrictions, especially in intensive or soilless settings (Niu *et al.* 2021). Recent lettuce-focused investigations provided evidence that supported our findings. Hidayat and Suhardjono (2025) found that applying foliar fertilizer to lettuce under hydroponic conditions boosted growth parameters such as plant height and leaf number. Similarly, in floating hydroponics, foliar application of vegetal protein hydrolysates increased productivity and qualitative features across cultivars, demonstrating that foliar inputs can successfully drive vegetative performance in lettuce (Cristofano *et al*. 2021).

**Effect on Leaf Area and Leaf Chlorophyll Content**

The foliar fertilizer spray had a considerable impact on lettuce leaf area (Figure 3A). Plants treated with 3.5 g $L^{-1}$ showed considerably higher mean leaf area compared to control and lower doses. Increasing foliar fertilizer concentration resulted with increased leaf expansion, with the highest response at 3.5 g $L^{-1}$. Foliar application had a good effect on leaf area because it boosted the delivery of nutrients that support cell proliferation and expansion, increasing the plant's photosynthetic surface.

In contrast, foliar fertilizer concentration had no significant effect on leaf chlorophyll content (Figure 3B). Despite minor gains in some treatments, statistical analysis found no significant differences across treatments. This suggested that, under the conditions of this investigation, foliar treatment increased leaf expansion but did not significantly affect chlorophyll biosynthesis. It is possible that the system's baseline nutrition supply was sufficient to maintain chlorophyll levels. These findings were consistent with prior research indicating that foliar fertilization can have a significant impact on morphological characteristics such as leaf expansion, but effects on physiological traits such as chlorophyll concentration may vary depending on environmental conditions and baseline nutrient availability. For example, Cristofano *et al*. (2021) discovered that foliar protein hydrolysates enhanced leaf area and biomass in lettuce, but chlorophyll responses were inconsistent. Similarly, a study on biopolymer-based foliar sprays found considerable changes in leaf morphology but no significant impacts on chlorophyll content (Fragalà *et al*. 2024).

**Effect on Root Volume and Plant Fresh Weight**

Foliar fertilizer application had a substantial effect on lettuce root volume and plant fresh weight (Figures 4A and 4B). Plants treated with 3.5 g $L^{-1}$ had considerably higher mean root volume compared to controls and lower doses. This suggests that foliar fertilization increased root growth, most likely through improved nutrient digestion and transfer to the root

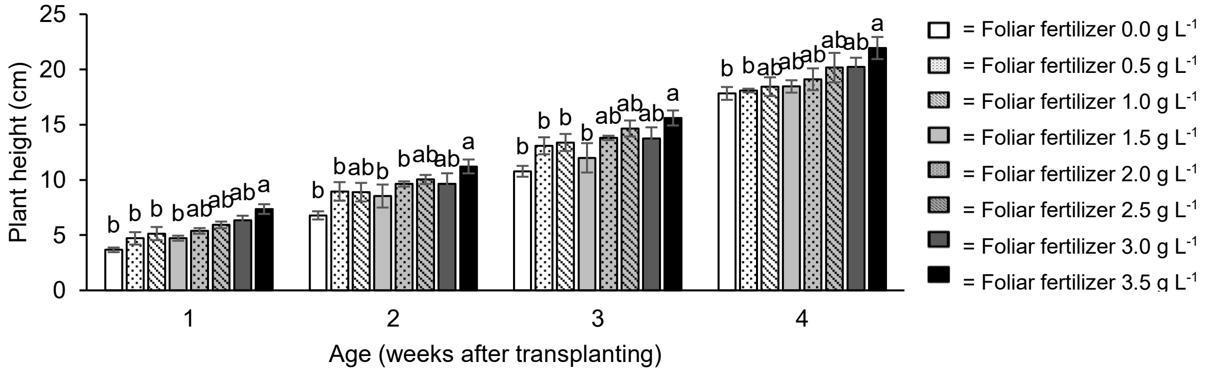


Figure 1 Plant height at various concentrations of foliar fertilizer. Note: Charts with the same letter at certain age showed no significant difference according to 5% DMRT test.

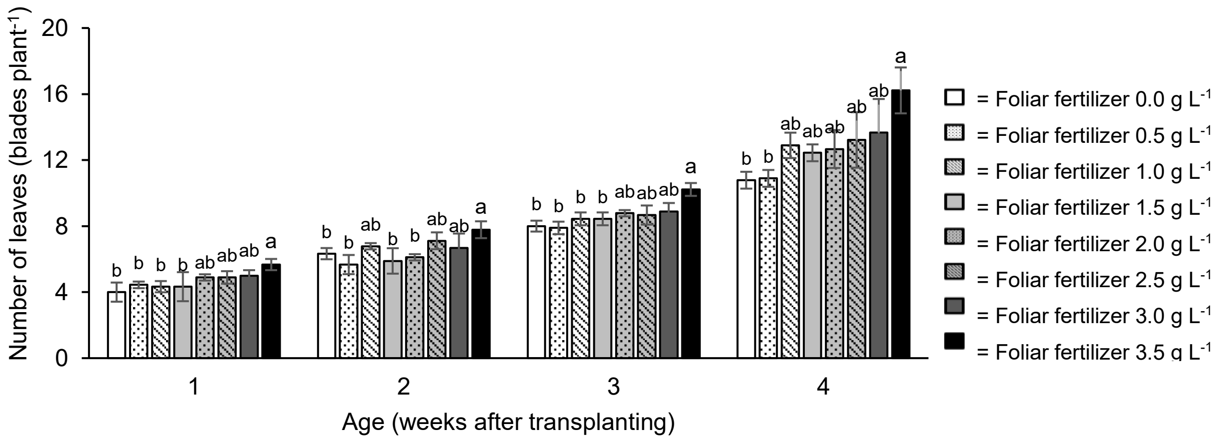


Figure 2 The number of leaves at various concentrations of foliar fertilizer. Note: charts with the same letter at certain age showed no significant difference according to 5% DMRT test.

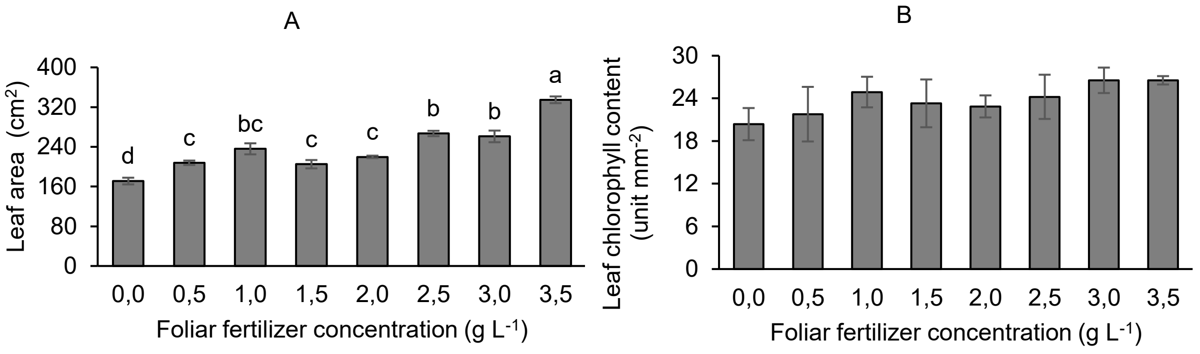


Figure 3 Effect of foliar fertilizer concentration on leaf area (A) and leaf chlorophyll content (B). Note: charts with the same letter showed no significant differences according to the 5% DMRT test.

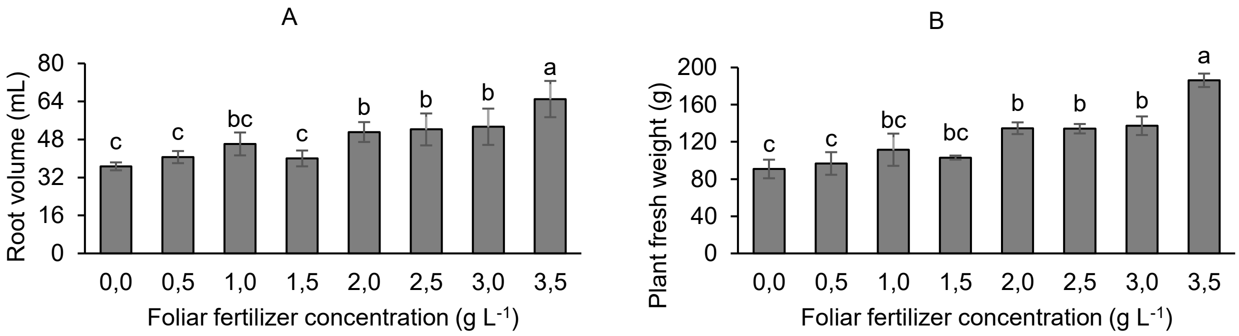


Figure 4 Effect of foliar fertilizer concentration on root volume (A) and plant fresh weight (B). Note: charts with the same letter showed no significant differences according to the 5% DMRT test.

system. The plant fresh weight showed a similar pattern, with the maximum mean fresh biomass achieved at 3.5 g $L^{-1}$, substantially greater than the control and low concentrations. These findings show that foliar treatment significantly increased lettuce output by increasing root development and shoot biomass buildup. The increase in fresh weight is compatible with higher leaf expansion and improved nutrient assimilation, both of which boost the plant's photosynthetic capacity.

Previous research validated these conclusions. Carillo *et al*. (2022) found that foliar sprays of plant-based biostimulant dramatically improved lettuce root system features, resulting in greater shoot biomass. Similarly, Cristofano *et al.* (2021) discovered that foliar protein hydrolysates increased lettuce biomass production in floating hydroponic systems, emphasizing the importance of foliar feeding in optimizing productivity. A recent review by Niu *et al.* (2021) stressed that foliar fertilization increases overall nitrogen usage efficiency, resulting in higher crop output.

**Relationship between Growth Parameters and Yield**

In this discussion, yield was defined as plant fresh weight, which directly reflects the marketable fraction of lettuce. Regression analysis (Figure 5) revealed positive associations between plant fresh weight and numerous growth characteristics, including plant height (Figure 5A), number of leaves (Figure 5B), leaf area (Figure 5C), and root volume (Figure 5D). Among these factors, leaf area and leaf number had high relationships with fresh weight, implying that aerial morphological attributes are important in influencing yield. A larger leaf surface area provides for better light interception and photosynthetic activity, while a greater number of leaves adds to more assimilate production. These findings are comparable with those of Li *et al.* (2024), that better root design increased nutrient uptake, promoting shoot development and leaf expansion.

Root volume also correlated positively with fresh weight, emphasizing its importance in nutrition and water intake. In studies on vertical hydroponic systems, nutrient solutions that promote increased root mass resulted in higher fresh biomass of lettuce (Alkaabi *et al*. 2025). Guimarães *et al*. (2020) also found that foliar biofertilizers boosted lettuce root development and biomass accumulation in semi-hydroponic farming, highlighting the importance of optimizing both root and shoot growth for yield.

Interestingly, foliar fertilizer concentration had no significant effect on leaf chlorophyll content in this investigation. The lack of substantial variations in chlorophyll content suggests that the AB Mix solution's baseline nutrition supply was sufficient to maintain chlorophyll production throughout treatments. As a result, foliar fertilization predominantly improved morphological development parameters including leaf expansion and biomass accumulation rather than boosting chlorophyll content. While leaf chlorophyll content is commonly used as a measure of photosynthetic efficiency, our findings indicated that lettuce output was more significantly influenced by morphological factors such as leaf area than physiological traits such as chlorophyll concentration. Similar findings were observed in trials utilizing liquid organic fertilizers, where shoot biomass was more closely related to leaf expansion than leaf chlorophyll concentration (Shaik *et al*. 2022).

**Implications for Hydroponic Lettuce Cultivation Practices**

The findings of this study have significant significance for hydroponic lettuce cultivation. To attain the best results, gardeners should apply foliar fertilizer 2.5−3.5 g $L^{-1}$ concentration range, as this is where vegetative growth and yield responses peak. Concentrations below this range may not fully realize the benefits of foliar treatment. These data indicate that good foliar fertilization management can increase nutrient utilization efficiency and reduce the risk of over-application in hydroponic systems. Although the maximum response was found at 3.5 g $L^{-1}$, overly high foliar fertilizer concentrations may potentially generate phytotoxic consequences such as leaf burn, osmotic stress, or nutritional imbalance. Previous research has shown that high foliar nutrient concentrations can affect growth efficiency and physiological performance in leafy vegetables (Chaski & Petropoulos 2022a; 2022b). As a result, increasing concentration over the ideal range may not always boost lettuce productivity.

Combining foliar fertilization with other inputs, such as liquid organic fertilizers and plant-derived biostimulant can improve sustainability. Chowdhury *et al*. (2024) found that liquid organic fertilizers increased lettuce biomass in hydroponic systems, while İkiz *et al*. (2024) reported that biostimulant reduced salinity stress in hydroponic lettuce and improved yield stability. Similarly, a study on floating systems found that biofertilizers improved lettuce yield and quality features, implying that foliar application can supplement organic and biological nutrient management strategies (Dasgan *et al*. 2023). These results demonstrate that foliar fertilization should be considered as part of a comprehensive hydroponic nutrient supply strategy.

System compatibility is another crucial factor to consider. Not all hydroponic systems respond to foliar supplements in the same way. Chowdhury *et al*. (2024) discovered that substrate-based hydroponics profited more from organic liquid fertilizers than NFT or DWC systems, emphasizing the importance of adjusting foliar tactics based on culture mode. (Frassine *et al*. 2024).found that applying Fe-Alg-$CaCO_3$ microparticles to lettuce leaves can increase yield in aquaponic systems. These findings highlight the

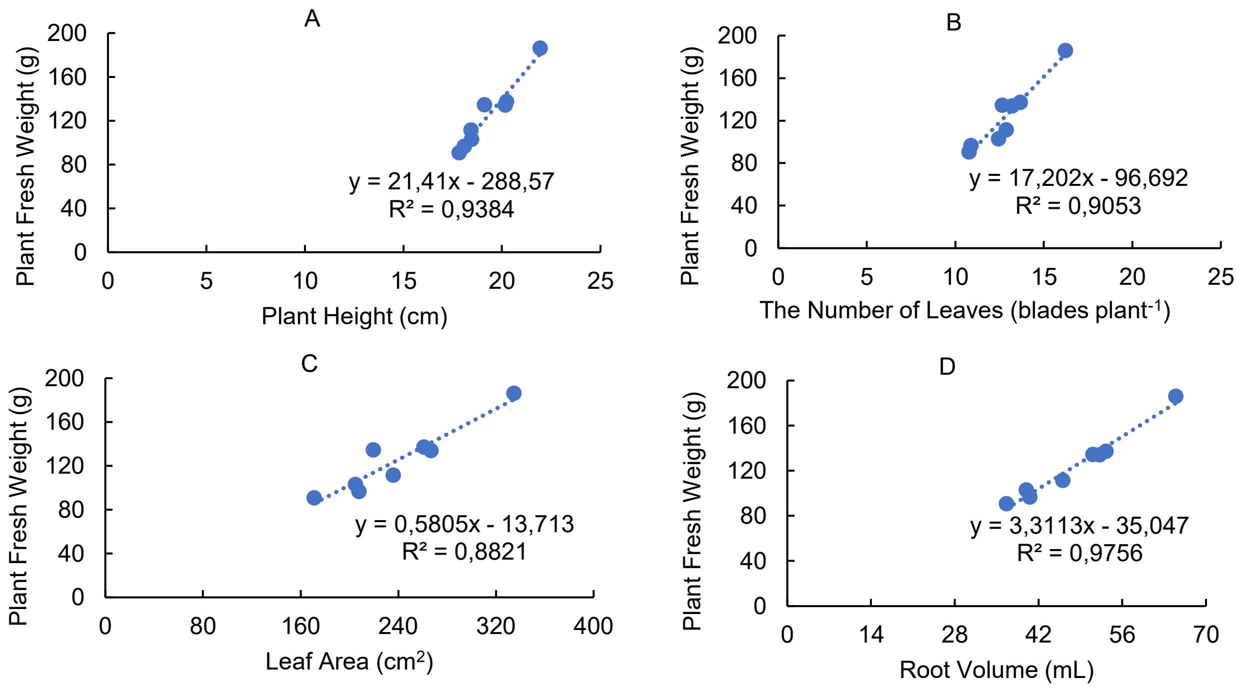


Figure 5 The relationship between lettuce production and plant height (A), number of leaves (B), leaf area (C) and root volume (D). Note: regression lines indicate significant positive correlations ($p < 0.05$).

significance of technology in increasing foliar absorption efficiency while lowering nutrient losses.

Taken together, these findings show that foliar fertilization is a promising technique for hydroponic lettuce cultivation, especially when administered at optimal quantities and combined with other nutrient management practices. To boost lettuce growth and yield in NFT hydroponic systems, apply Gandasil D® at 3.5 g $L^{-1}$ every 7 days beginning with transplanting. Future research should investigate the connections between foliar sprays and environmental parameters such as light intensity, salinity, and growing system type, as well as examine the long-term effects on lettuce quality and marketability.

## CONCLUSION

The use of foliar fertilizer greatly boosted lettuce growth and productivity in a hydroponic system. As foliar fertilizer concentrations increased, so did plant height, leaf number, leaf area, root volume, and plant fresh weight. Yield, as measured by plant fresh weight, was most closely associated with leaf area, leaf number, and root growth, all of which promote nutrition and water intake. The ideal concentration of 3.5 g $L^{-1}$ resulted in significantly greater growth and yield in lettuce plants than other treatments. These findings suggested that foliar fertilization can be an effective technique for increasing vegetative development and fresh output of lettuce in hydroponic systems. Integrating foliar fertilization into broader nutrient management strategies may improve crop yield, resource efficiency, and sustainability in controlled environment agriculture.

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