Effect of Fertilization Methods on Growth of Grand Rapids Lettuce in Floating Cultivation Systems

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Abstract. Lettuce is an important horticultural crop with high economic value and a short cultivation cycle. In areas with limited land availability, floating cultivation systems offer an innovative and sustainable solution for vegetable production. However, the restricted volume and nutrient-holding capacity of the growing media in such systems require an effective fertilization method to optimize nutrient uptake and plant growth. This study evaluated the effects of four fertilization methods—pouring, spraying, spot, and spreading—on the growth and yield of lettuce cultivated in floating media. Results indicated that fertilization methods had no significant effect on overall growth and yield; however, distinct trends were observed among treatments. Foliar spraying resulted in the highest chlorophyll content (SPAD value), number of leaves, and leaf weight, reflecting enhanced photosynthetic efficiency and vegetative development. In contrast, the spreading method produced slightly higher fresh weight but with lower nutrient-use efficiency. Overall, spraying method was identified as the most effective and efficient fertilization method under floating cultivation conditions, as it enables direct nutrient absorption through the leaves and minimizes nutrient losses. These findings provide valuable insights for improving nutrient management in space-limited systems and contribute to the advancement of sustainable horticultural production practices.

1 Introduction

Lettuce (*Lactuca sativa* L.) is a leafy horticultural commodity with high economic value and a relatively short harvest time, making it widely cultivated by both small and large-scale farmers [1]. The increasing demand for lettuce in domestic and international markets has driven innovation in cultivation technologies, including the development of floating cultivation systems as an alternative solution in areas with limited fertile land [2, 3]. This system enables plants to grow on the water surface using minimal growing media, providing an efficient and space-saving approach for sustainable vegetable production [4].

However, under floating cultivation conditions, the limited volume and nutrient-holding capacity of the growing media often result in suboptimal nutrient absorption by roots [5]. Nutrients can be easily leached or dispersed in water, reducing their availability for root uptake. This inefficiency may restrict biomass accumulation, leaf area development, and ultimately reduce yield. Therefore, selecting an appropriate fertilization method is critical to maintaining nutrient efficiency in such systems. One promising approach is foliar fertilization, which allows nutrients to be directly absorbed through leaf tissues via stomata and cuticles, enabling rapid utilization of macro- and micronutrients [5,6]. Spraying methods using foliar fertilizers such as Gandasil have been shown to enhance nutrient uptake efficiency, particularly during the vegetative growth phase [7]. In contrast, other methods such as pouring, spotting, and spreading rely on nutrient absorption through the roots, which may be less effective under floating conditions due to limited media and potential nutrient losses.

Despite the growing interest in floating cultivation, limited studies have compared the effectiveness of different fertilization methods within this system. Understanding which method optimizes growth and yield under restricted media conditions remains a crucial research gap. Therefore, this study aims to evaluate the effects of four fertilization methods i.e., pouring, spraying, spot, and spreading—on the growth and yield of lettuce in floating cultivation systems. The findings are expected to provide new insights into nutrient management strategies that enhance productivity and support sustainable horticultural practices under space-limited growing conditions.

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2 Material and method

This research was conducted in the experimental pond of the Faculty of Agriculture, Sriwijaya University, Indralaya, South Sumatra. The planting material used was the Grand Rapids lettuce (*Lactuca sativa* L.) cultivar. Seeds were sown in seedling trays filled with a mixture of topsoil and cow manure (2:1, v/v) and transplanted at 14 days after sowing (DAS) when seedlings had two true leaves. The plants were grown in polybags containing the same substrate mixture and arranged on a 2 × 1 m floating raft. The raft was modified with a wick hydroponic system to maintain consistent moisture and nutrient availability in the limited growing media (Figure 1). Four fertilization methods were evaluated, including pouring (P_1), spraying (P_2), spot placement (P_3), and spreading (P_4). These methods were selected to represent different nutrient delivery pathways; root absorption (pouring, spot, spreading) and foliar absorption (spraying), allowing a comparative assessment of their effectiveness under floating conditions. Fertilization was applied regularly throughout the vegetative phase according to each treatment protocol.

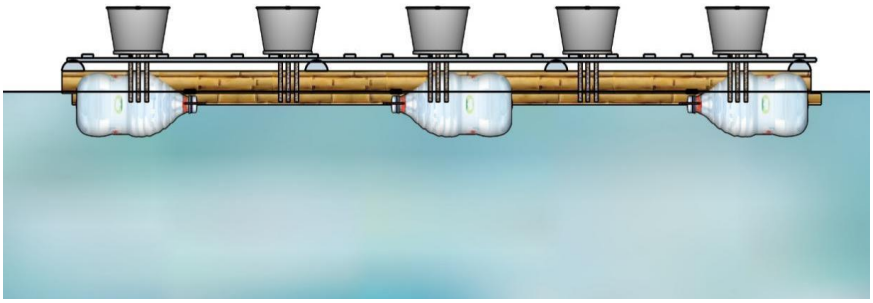


Fig 1. Floating raft design using a wick hydroponic system

2.1 Data collection

Selected leaves were marked for studying the pattern of leaf blade enlargement, starting from the moment the leaf blade unfolded until the leaf blade stopped growing on the 20th day. The length of the leaf midrib (L) and the width of the leaf blade (W) were consecutively measured every day for 12 days. The SPAD value was measured using a chlorophyll meter (SPAD-502 Plus, Konika Minolta). Soil moisture content was observed daily using a Lutron PM-714 soil moisture meter. A digital image analysis system developed by Easlon and Bloom was used to measure the leaf area of the plants precisely. Collected data included the length of the leaf midrib, the width of the leaf blade, the length of the petiole, the leaf thickness, the diameter of the petiole, the leaf fresh and dry weight, and the petiole fresh and dry weight. Stem diameter is measured using a digital caliper. The dry weight of plant materials was measured after oven-drying at 100 °C for 24 to 48 hours, depending on the size or thickness of the samples.

2.2 Experimental design and data analysis

The experiment employed a randomized block design (RBD) with four replications per treatment, each consisting of five plants. Data were analyzed using analysis of variance (ANOVA) in R-Studio software. When significant differences were detected, means were compared using the Least Significant Difference (LSD) test at a significance level of $p \leq 0.05$.

3 Result and discussion

Observations of lettuce leaf length and width growth over 12 days showed a consistent upward trend across all fertilization methods: pouring, spraying, spoting, and broadcasting. The leaf length graph shows that the spraying method produced noticeably higher leaf growth compared to the other treatments, particularly from day 6 to day 12, although the differences are relatively small. On day 12, leaf length in the spraying treatment reached the highest value (±8.8 cm), followed by pouring, spoting, and broadcasting (Figure 2).

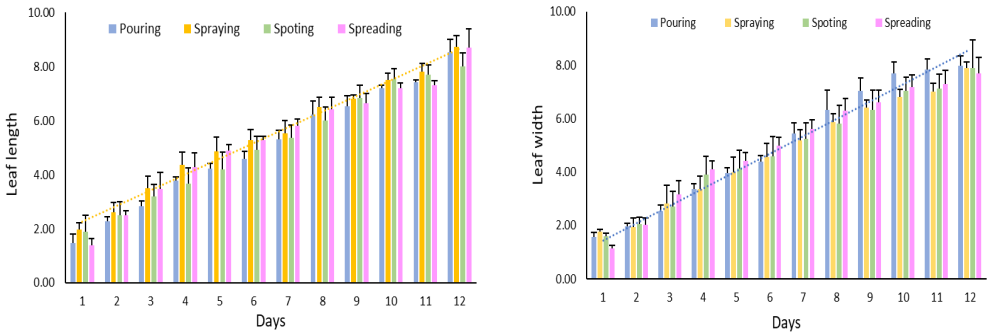


Fig 2. Leaf length and leaf width are affected by various fertilizer methods on Lettuce

These results indicate that all fertilization methods supported lettuce leaf growth in the floating system, with nearly linear growth during the observation period. Compared with other methods, foliar spraying directly supplies nutrients to photosynthetically active tissues, bypassing the limited root absorption capacity in floating systems. Foliar nutrient application can accelerate plant physiological responses, especially during the vegetative growth phase. This rapid absorption allows plants to respond almost immediately through increased chlorophyll formation and leaf expansion. The advantage of the spray method is associated with efficient nutrient absorption through the large and rapid leaf surface, allowing immediate utilization in photosynthesis. The spray fertilizer used was Gandasil D. Gandasil D contains NPK, including 20% nitrogen, 15% phosphorus, 15% potassium, and 1% magnesium [7]. These balanced nutrients contribute to rapid vegetative growth, where nitrogen supports chlorophyll and protein synthesis, phosphorus stimulates cell division and root development, and potassium enhances stomatal regulation and photosynthetic efficiency [8–9].

The drip method also demonstrates high effectiveness, as nutrients are directly delivered to the root zone in a confined floating medium, allowing roots to absorb them immediately and optimally. However, since nutrient uptake through roots in floating systems is constrained by the limited substrate and fluctuating oxygen levels, foliar feeding can compensate for this limitation. Conversely, the sprinkler method is relatively less efficient in this system, as the fertilizer takes time to dissolve and distribute evenly in the nutrient solution, potentially delaying nutrient availability in the early stages of plant growth stages.

Overall, yield differences among the fertilization methods were minor, indicating that the constant water and nutrient environment in floating systems tends to minimize variation in nutrient availability. However, the spray method provided an additional advantage by enhancing early growth rates and maintaining consistent leaf expansion until the end of the observation period. The increase in leaf number in all treatments indicates that each fertilization method can support the vegetative development of lettuce in the floating system (Figure 3).

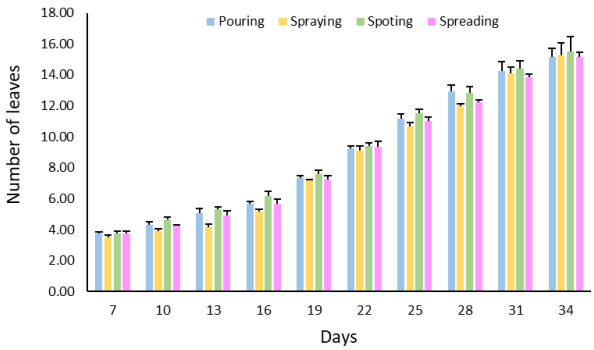


Fig 3. Number of leaves affected by various fertilizer methods on Lettuce

The physiological superiority of the spray method is further confirmed by higher SPAD values, indicating more chlorophyll formation and better nitrogen utilization efficiency. Phosphorus in foliar fertilizers supports cell division in the shoot meristem, and potassium helps distribute photosynthetic products to the growing leaf tissues [10]. This integrated nutrient delivery mechanism helps lettuce maintain active leaf growth even under restricted-root conditions typical of floating systems. Foliar fertilizer application enables direct nutrient absorption through stomata and cuticles,

allowing plants to obtain essential nutrients rapidly without relying on the nutrient retention capacity of the limited medium [11].

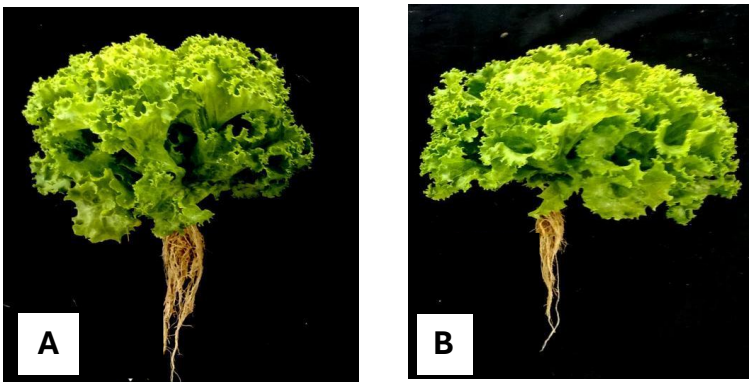
This rapid nutrient assimilation not only enhances chlorophyll synthesis but also supports the biosynthesis of primary metabolites required for leaf expansion and photosynthetic activity [12]. Therefore, the spray method effectively compensates for the nutrient delivery limitations of floating systems with minimal growing media. Although there were no statistically significant differences in morphological traits among treatments, plants treated with the spraying method showed consistently higher SPAD values than others (Table 1). The SPAD value reflects the chlorophyll content in leaves, which is closely related to the plant's nitrogen status, as nitrogen is the main component of chlorophyll molecules [13]. Foliar fertilization through spraying delivers nutrients directly to the leaf surface, allowing rapid absorption through the stomata and cuticle. Once absorbed, nutrients immediately enter the mesophyll tissue and are used for chlorophyll synthesis, thereby enhancing leaf greenness and photosynthetic capacity.

This rapid and direct nutrient uptake is particularly advantageous in floating systems, where nutrient dynamics are unstable due to fluctuations in temperature, pH, and solution concentration [14]. By bypassing root absorption, foliar spraying reduces nutrient losses through leaching and ensures that essential elements such as nitrogen are efficiently utilized. Consequently, plants under the spraying treatment exhibit higher SPAD values, indicating improved nitrogen assimilation and chlorophyll formation efficiency. In contrast, root-based methods such as spotting and spreading depend on the dissolution and diffusion of solid fertilizer in the nutrient solution before becoming available to the roots. This process can delay nutrient uptake and increase the risk of nutrient loss through sedimentation or uneven distribution in the water column. As a result, nutrient absorption efficiency tends to be lower compared to foliar application. Visually, lettuce plants under the spraying and pouring methods displayed more vigorous and uniform growth, whereas spotting and spreading treatments resulted in less pronounced improvements (Figure 4). These findings further support that foliar spraying provides a more efficient pathway for nutrient delivery in floating cultivation systems with limited growing media.

Table 1. Morphology of leaf lettuce affected by various fertilizer methods

Treatment	SPAD Value		Canopy area (cm)		Total leaf area (cm)		Stem diameter (cm)		Root length (cm)		Plant height (cm)	
Pouring (P1)	21.09	a	609.87	a	1515.79	a	10.59	a	31.24	a	0.98	a
Spraying (P2)	23.70	a	562.93	a	1626.91	a	10.50	a	29.00	a	1.02	a
Spotting (P3)	21.82	a	628.31	a	1378.30	a	10.88	a	29.63	a	0.98	a
Spreading (P4)	22.34	a	658.15	a	1602.22	a	10.98	a	27.94	a	1.30	a
LSD 5%	7.12		190.38		397.14		1.27		8.94		0.33	

Mean followed by the same letters within each column were significantly different based on LSD at $P \leq 0.05$ for each treatment



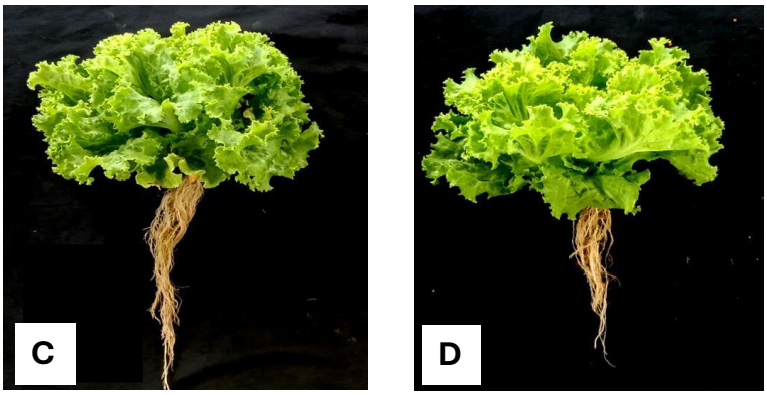


Fig 4. Visualization of lettuce grown using the floating method with various fertilization methods; pouring (A), spraying (B), spotting (C) and spreading (D)

Despite increased SPAD values, plant fresh and dry weights did not differ significantly among fertilization methods (Table 2). This may be attributed to the short growth duration of lettuce, where differences in photosynthetic capacity have not yet translated into significant biomass accumulation. Physiologically, increased chlorophyll content enhances light absorption and CO_2 fixation, potentially increasing assimilate accumulation [15]. However, under floating conditions, other limiting factors such as small root volume, restricted nutrient storage capacity, and fluctuating light intensity may constrain biomass conversion efficiency. In summary, foliar spraying emerged as the most efficient fertilization method in floating lettuce cultivation due to its rapid nutrient absorption, improved chlorophyll synthesis, and enhanced early leaf growth. These findings highlight the importance of selecting an appropriate fertilization strategy to improve nutrient use efficiency under limited substrate conditions, contributing to sustainable horticultural practices in floating cultivation systems.

Table 2. Biomass of leaf lettuce affected by various fertilizer methods

Treatment	LFW	SFW	RFW	LDW	SDW	RDW	Total FW
Pouring (P1)	155.31 a	1.57 a	8.22 b	8.10 a	0.12 a	0.59 a	186.71 a
Spraying (P2)	153.09 a	1.33 a	12.04 a	8.14 a	0.21 a	0.70 a	179.69 a
Spotting (P3)	116.67 a	1.29 a	10.11 ab	7.06 a	0.20 a	0.69 a	142.47 a
Spreading (P4)	127.70 a	1.27 a	9.46 b	7.70 a	0.11 a	0.65 a	153.10 a
LSD 5%	44.58	0.49	2.56	1.38	0.17	0.15	66.38

Mean followed by the same letters within each column were significantly different based on LSD at $P \leq 0.05$ for each treatment

The rapid availability of nutrients absorbed through both roots and leaves plays a crucial role in determining plant biomass accumulation. Among the tested fertilization methods, pouring (P_1) and spraying (P_2) treatments tended to produce higher total fresh weight (FW) compared to others, indicating more efficient nutrient uptake and utilization. The drip method ensures a continuous nutrient supply directly to the root zone, while foliar spraying allows nutrients to be absorbed through the stomata and cuticle, providing a dual advantage under conditions of limited growing media.

This efficient nutrient delivery supports the absorption of key macronutrients (N, P, and K), which are essential for cell division, photosynthesis, and biomass formation [9]. Conversely, the sprinkle method appeared less effective because fertilizer dissolution and distribution in the nutrient solution took longer, leading to uneven nutrient availability and reduced uptake efficiency. In floating systems with limited media volume, maintaining nutrient homogeneity in the solution is critical, as roots depend entirely on the surrounding water for nutrition. Overall, lettuce cultivation in floating systems presents a promising alternative for sustainable vegetable production in areas with limited land availability. Although different fertilization methods did not significantly affect overall growth and yield, the spray method consistently improved leaf-related traits such as SPAD values, leaf number, and leaf weight. Considering the restricted root zone and high risk of nutrient loss in floating systems, foliar spraying proved to be the most effective and efficient fertilization approach. Therefore, foliar spraying is recommended as a practical strategy for optimizing lettuce productivity in floating cultivation systems, while contributing to more efficient nutrient management and supporting sustainable horticultural practices.

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