

Growth and yield response of lettuce (*Lactuca sativa* L.) planted floatingly to optimization of NPK compound fertilizer

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ABSTRACT

Urban agriculture had expanded rapidly in response to growing population pressures and climate change, especially in densely populated areas of developed countries. South Sumatra holds significant potential for developing floating agricultural systems. This study aimed to evaluate the effects of compound NPK fertilizer and a floating planting system on lettuce growth. A Randomized Block Design (RBD) with four treatment levels was used. Each treatment was repeated 3 times, resulting in 12 treatment units. In the treatment of NPK compound fertilizer doses, P0 = Control, P1 = 1.12 g NPK compound/polybag, P2 = 2.24 g NPK compound/polybag, P3 = 3.36 g NPK compound/polybag. The observation results were analyzed using analysis of variance and the DMRT 5% test. The parameters observed include plant height, number of leaves, fresh weight of the plant, fresh weight of the roots, dry weight of the roots, root length, leaf greenness level, leaf area, and canopy area. Based on the research findings, the application of compound NPK fertilizer at a rate of 2.24 g/polybag (P2) resulted in the most favorable growth and yield performance of floating lettuce, as it consistently produced the highest mean values across all observed parameters. However, the calculated optimum dosage was 2.05 g/polybag. This rate is therefore recommended as the optimal application dose for subsequent studies.

Keywords: floating agriculture, lettuce, NPK fertilizer, urbanitation, sustainable

INTRODUCTION

Lettuce (*Lactuca sativa* L.) was one of the most famous and superior vegetable crops, highly valued by consumers for its nutritional value, taste, and texture. Lettuce has the largest production in the world among other vegetable crops (Tesfa et al., 2018; Martínez-Moreno et al., 2024). Globally, in 2023, the production of lettuce and pakchoi reached 1,261,377 ha, with an average yield of 22,265 kg/ha. Asia became the primary contributor with a harvested area of 899,197 ha, yielding 12,551 kg/ha, while Southeast Asia produced a harvested area of 11,121 ha, with a yield of 12,551 kg/ha (FAOSTAT, 2025). In Europe, lettuce was utilized as the most consumed fresh-cut vegetable product for salads (Serna et al., 2012). In addition, lettuce can be used as a raw material for

nicotine-free cigarettes (Hassan et al., 2021). Due to its short life cycle and small size, lettuce was also suitable for space agriculture, and this has been successfully done previously on the International Space Station (ISS) (Burgess et al., 2024).

Lettuce, which was widely considered one of the most suitable plants for floating system cultivation, was chosen for this study. The concept of greening new urban areas can naturally reduce the problems of rapid urbanization and population growth, which were the causes of food and land scarcity, thereby hindering sustainable community development (Chatterjee et al., 2025). As demographic growth and climate change intensify, urban agriculture especially professional intra-urban farming in densely populated areas has expanded rapidly in northern countries. However, there were still no

specific criteria to assess its environmental, social, and economic sustainability (Clerino & Fargue-Lelièvre, 2020). Soil fertility decline due to excessive agrochemical use adds to the challenge (Sharma et al., 2018). To reduce the environmental impact of food production, various resource-efficient methods have been developed (Bañón & Raspall, 2022), including freshwater-based innovations such as floating farming an idea introduced by Dutch engineer Peter Van Wingerden in 2012 (Simon, 2018). This method shows synergy potential with conventional farming (Gumisiriza et al., 2023) and was gaining global attention for its efficiency, high-quality yields, and improved nutrient uptake in crops like lettuce (Sharma et al., 2018; Alvarado-Camarillo et al., 2020; Liu et al., 2025).

Floating agriculture has emerged as a promising alternative cultivation method in response to various challenges, particularly the decline in soil fertility, which remains a major constraint in vegetable production systems such as lettuce cultivation in sub-Saharan Africa (Temegne et al., 2024). The use of organic fertilizers can enhance the physical and biological activity of the soil, but their nutrient content was relatively low, requiring larger quantities to meet plant growth needs (Roba, 2018). Innovation in fertilization strategies is needed to support sustainable agriculture (Dehghani et al., 2025).

Efficiency plays a critical role in optimizing crop production systems (Kiba & Krapp, 2016). The application of NPK fertilizer to lettuce can effectively address nutrient deficiency issues, as NPK comprises essential macronutrients that have been demonstrated to enhance plant growth and significantly improve yield performance (Salama et al., 2024, Gil-Ortiz et al., 2020). This research specifically sought to determine how varying NPK concentrations affect key growth parameters such as leaf number, biomass accumulation, and leaf area, with the ultimate goal of identifying an optimal fertilization strategy for sustainable lettuce production in soilless conditions. The objective of this research was to evaluate the efficiency of different doses of NPK fertilizer on the growth performance of lettuce (*L. sativa* L.) cultivated in a floating system.

MATERIALS AND METHODS

This research was conducted at Sriwijaya Universitas in Indralaya District, Ogan Ilir Regency, South Sumatra, Indonesia and the Plant Physiology Laboratory of the Agricultural Cultivation Department, Faculty of Agriculture, Universitas Sriwijaya, Indralaya District, Ogan Ilir Regency, South Sumatra, Indonesia from July to September 2022.

Research Prosedures

Floating Cultivation System Preparation

The construction of a floating bamboo raft measuring 2×1 meters involves several systematic stages. The initial stage comprises the selection and preparation of materials, specifically bamboo with a diameter ranging from 8 to 12 cm, which was pre-dried to enhance its resistance to water. The bamboo was then cut to the required dimensions: 2.2 meters for the primary frame and 1 meter for the transverse supports. Subsequently, six to eight bamboo poles were arranged in parallel to form the base platform, while an additional three to four poles were positioned perpendicularly beneath the base to provide structural reinforcement. All intersections between bamboo poles were securely bound using durable nylon rope to ensure the overall stability and structural integrity of the raft.

Plant Material Preparation

The utilisation of polybags with a diameter of around 25–30 cm, which have been perforated at the base for drainage purposes. The planting media comprises a mixture of soil and compost in a 2:1 ratio, which was thoroughly blended before being filled into the polybag to approximately 80% of its capacity.

Planting and Maintenance

Lettuce seeds were considered ready for planting when they have developed 4–5 true leaves or have reached 21 HSS. Each planting hole should be filled with a single seedling, and transplantation was conducted in the afternoon to minimize the risk of wilting. Maintenance of lettuce cultivated using the floating system involves regular weeding, replanting as

necessary, and the implementation of pest and disease management measures.

Measure Plant Height

Lettuce height was measured with a ruler, from the surface of the growth medium to the apex of the leaves or main stem. Measurements were conducted at regular time periods to assess plant growth. Plant height measurements were documented in centimetres (cm) and analysed to assess the impact of the therapy administered on lettuce growth. The height of the lettuce plants measured from the root base to the growth point.

Experimental design

This research was conducted using a Randomized Block Design (RBD) with 1 treatment factor. The treatment factor was the dose of compound NPK fertilizer, which consists of 4 treatment levels and 3 replications, where each treatment will have 4 plants, resulting in a total of 48 plant sample units. The treatments that will be used in this research were:

- P0 = Control (Without treatment)
 P1 = 300 kg/ha
 (1.2 g fertilizer NPK/polybag)
 P2 = 600 kg/ha
 (2.4 g fertilizer NPK /polybag)
 P3 = 900 kg/ha
 (3.6 g fertilizer NPK /polybag)

Analisis Data

The observed data were then statistically tested using analysis of variance (ANOVA). Then, if the results of the analysis of variance

show a significant difference, further tests such as DMRT and polynomial orthogonal will be conducted to determine the response curve pattern of the plants to NPK application. Data analysis was performed using RStudio and Excel 2022. The optimal concentration for regression analysis was determined from the response curve.

RESULTS

The analytical results (Table 1) indicated that different doses of NPK fertiliser significantly influenced the parameters of leaf count, fresh plant weight, and leaf area. The application of different doses of NPK fertiliser did not significantly influence the parameters of plant height, leaf greenness, plant dry weight, root fresh weight, root dry weight, root length, and canopy area.

The application of various doses of compound NPK fertilizer had a significant effect on the fresh weight of the plant (Table 2). The highest fresh weight was observed at the 2.4 g/polybag treatment, which was significantly different from the control and statistically comparable to the 1.2 g/polybag and 3.6 g/polybag treatments. This suggests that 2.4 g/polybag represented the optimal dose for enhancing vegetative biomass accumulation. In contrast, the dry weight of the plant did not show significant differences among treatments, although the highest value was also recorded at 2.4 g/polybag. Similarly, the fresh and dry weights of roots followed a positive trend with increasing fertilizer doses.

Table 1. Results of the analysis of variance (ANOVA) on the growth and yield variables of lettuce

Variables	F	Pr>F	CV%
Plant Height (cm)			
2 Week After Planting	4.103	0.066 ^{tn}	6.33
3 Week After Planting	4.608	0.053 ^{tn}	4.07
4 Week After Planting	3.972	0.071 ^{tn}	4.00
Number of Leaves (sheets)			
2 Week After Planting	8.328	0.014*	11.58
3 Week After Planting	3.794	0.077 ^{tn}	6.88
4 Week After Planting	9.254	0.011*	7.12
Leaves Greenes Level	2.411	0.165 ^{tn}	12.68
Fresh Weight of Plant (g)	8.455	0.014*	18.49
Dry Weight of Plant (g)	1.337	0.348 ^{tn}	17.28
Fresh Weight of Root (g)	4.192	0.064 ^{tn}	17.64
Dry Weight of Root (g)	4.235	0.062 ^{tn}	18.97
Lenght of Root (cm)	2.713	0.137 ^{tn}	10.55
Canopy Area	1.430	0.324 ^{tn}	14.82
Leaf Area (cm ²)	6.897	0.022*	18.95

Table 2. Average fresh weight of the plant, dry weight of the plant, fresh weight of the roots, and dry weight of the lettuce roots

Various Doses of Compound NPK Fertilizer	Fresh Weight of Plant (g)	Dry Weight of Plant (g)	Fresh Weight of Root (g)	Dry Weight of Root (g)
Control	54.06 c	5.80 a	6.42 b	1.44 b
1.2 g/polybag	100.40 ab	6.36 a	8.49 ab	1.73 ab
2.4 g/ polybag	117.33 a	8.46 a	10.77 a	2.46 a
3.6 g/ polybag	79.76 bc	8.36 a	9.41 ab	2.07 ab

The root fresh weight peaked at 2.4 g/polybag, and the dry root weight reached it was highest at the same dose, both significantly higher than the control. These results indicate that moderate application of compound NPK fertilizer, particularly at 2.4 g/polybag, promotes better growth performance in terms of shoot and root biomass accumulation.

Plant Growth

The application of compound NPK fertilizer on lettuce plants yields results in the plant height variable. Each treatment experienced an increase every week (Figure 1). From week 1 to week 2, the height of the plants tended to increase rapidly with relatively similar values across each treatment. Treatment P2 showed the highest growth in the second week compared to the other treatments. Next, from the 3rd to the 4th week, the growth rate of the plants gradually increased, especially in the P2 treatment, which showed a higher increase compared to the other treatments. The number of leaves in various treatments increased weekly (Figure 2). From week 1 to week 2, the number of plant leaves tended to increase gradually with a relatively similar pattern in each treatment. based on the results of

the analysis of variance (ANOVA) in the 2nd and 4th weeks, significant results were observed. The level of leaf greenness in various treatments shows an increase over time (Figure 3).

Yield Based on the results of the analysis of variance (ANOVA), it shows a significantly affected response. Treatment P2 had the highest fresh weight of plants among all observation treatments (Figure 4). Followed by the dry weight of the plants (Figure 5). (Figure 6) shows the analysis results of the fresh root weight, which did not differ significantly across treatments, with the biomass results following the dry root weight results (Figure 7). On the canopy area variable, the results showed no significant differences for each treatment (Figure 9), which was in contrast to the analysis results of the leaf area variable that showed significant differences with the highest treatment in P2 with an average of 935 (Figure 10). Meanwhile, in the observation of root length, no significant differences were found (Figure 8). Based on the analysis results of all the lettuce biomass variables, treatment P2 was obtained as the treatment with the highest average, although only fresh weight and leaf area showed significantly different results.

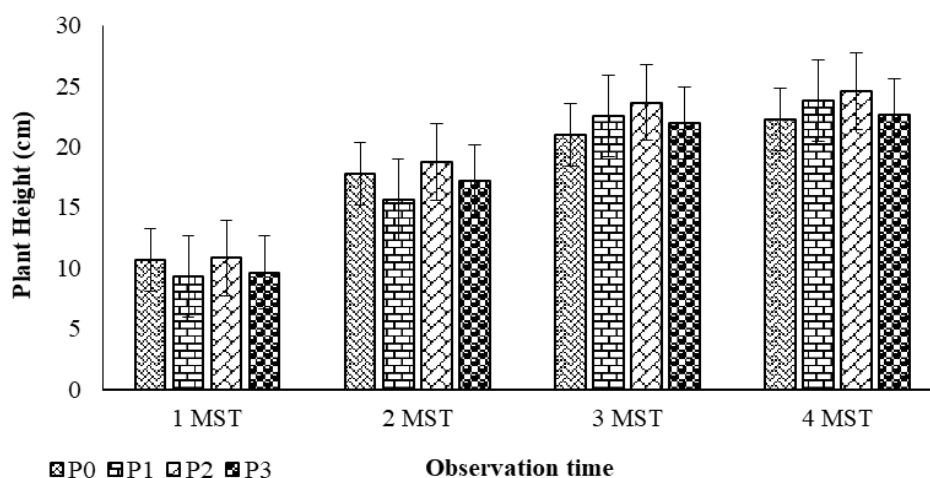


Figure 1. The average height of lettuce plants with the application of various doses of compound NPK fertilizer

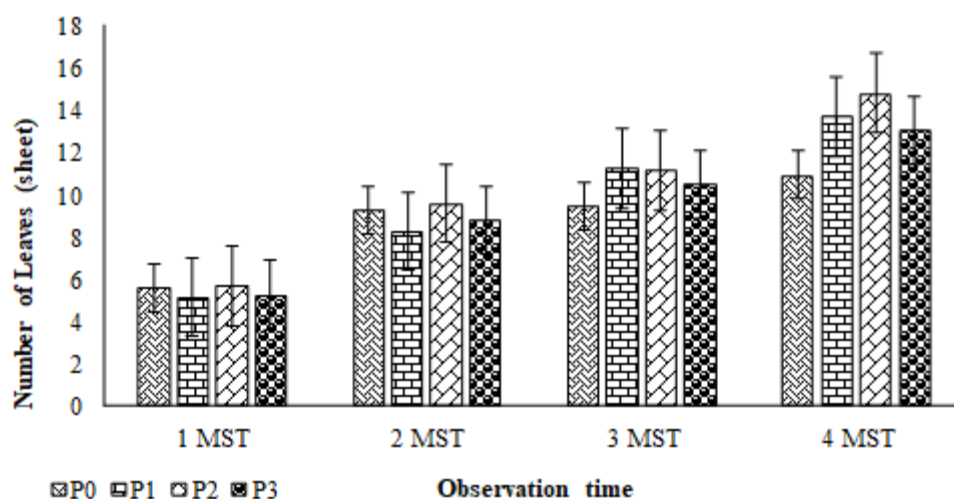


Figure 2. The average number of leaves (sheets) with the application of various doses of compound NPK fertilizer

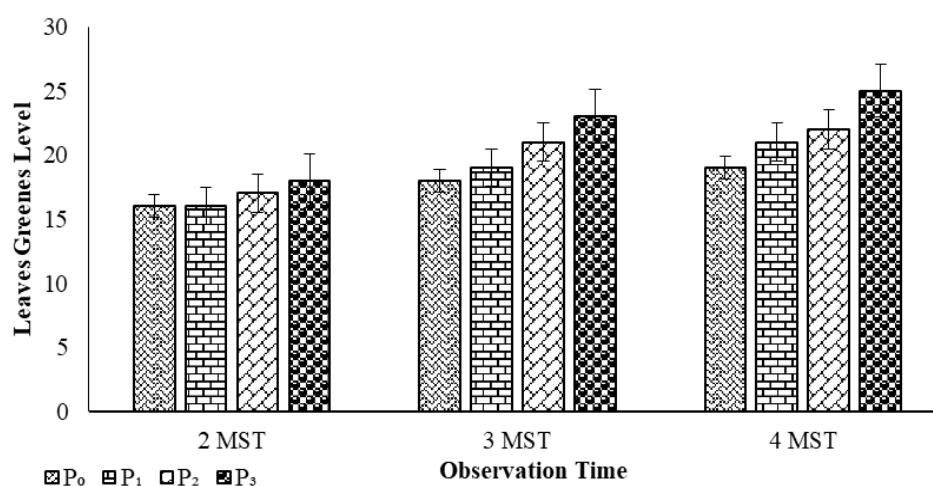


Figure 3. The average leaves greenness level with the application of various doses of compound NPK fertilizer

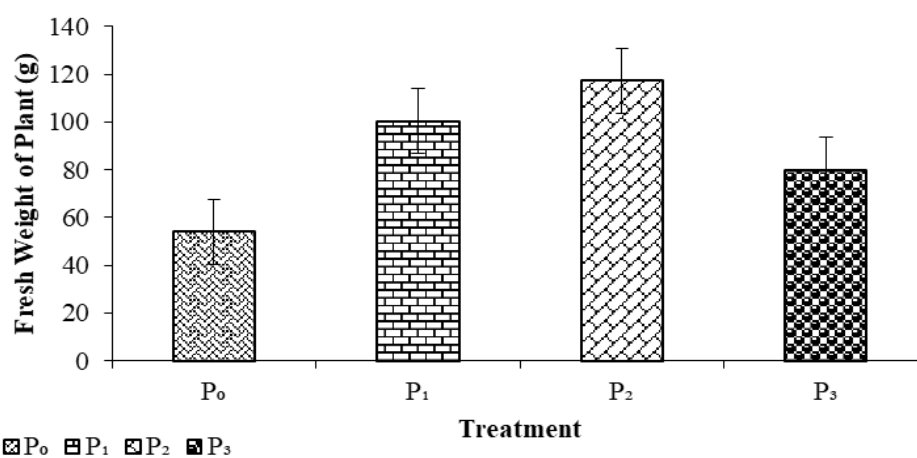


Figure 4. The average fresh weight of plant (g) with the application of various doses of compound NPK fertilizer

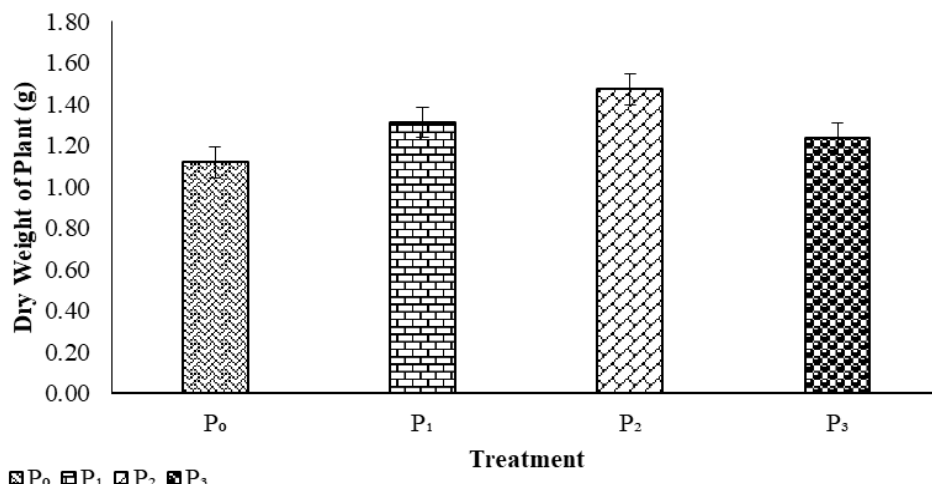


Figure 5. The average dry weight of root (g) with the application of various doses of compound NPK fertilizer

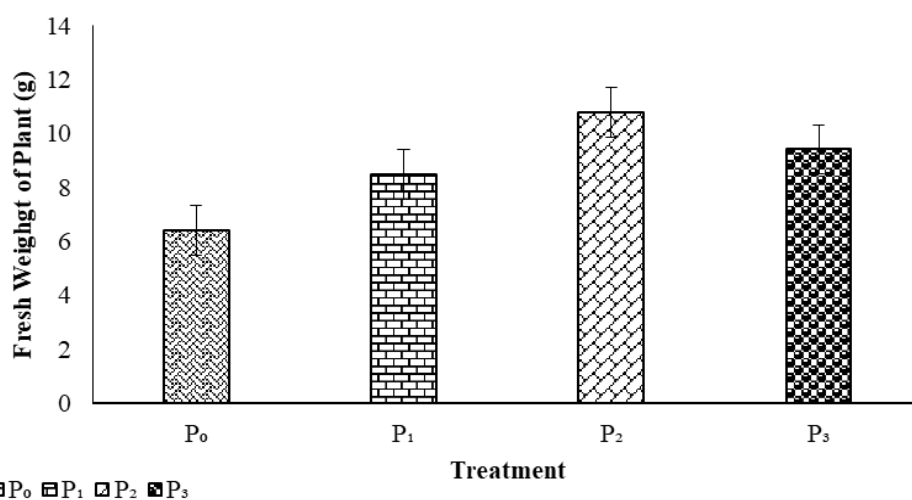


Figure 6. The average fresh weight of root (g) with the application of various doses of compound NPK fertilizer

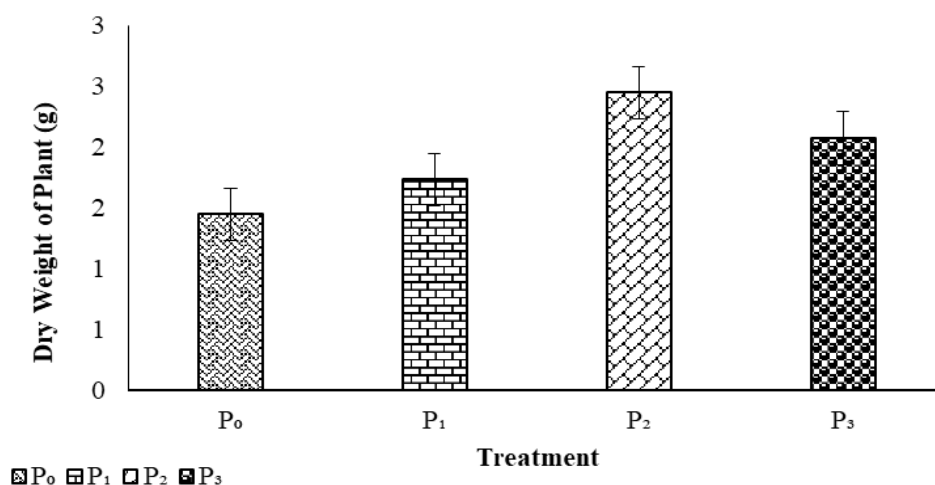


Figure 7. The average dry weight of root (g) with the application of various doses of compound NPK fertilizer

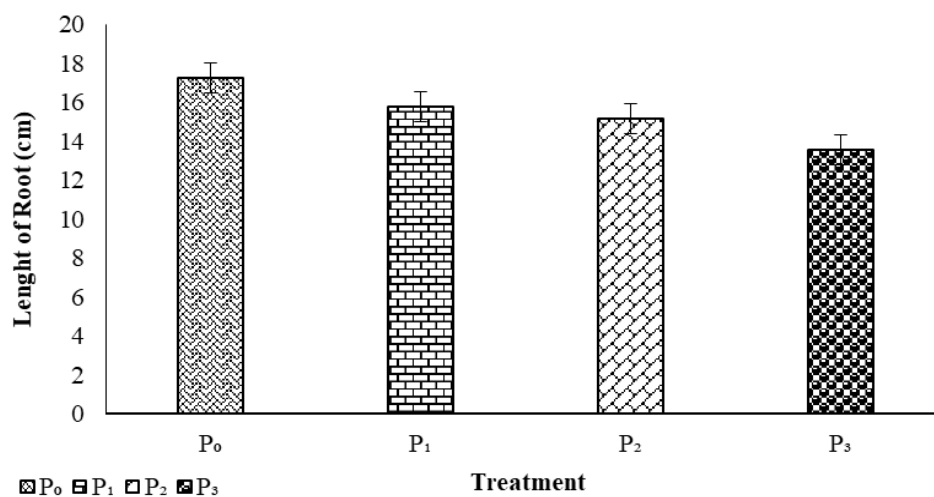


Figure 8. The average length of root (cm) with the application of various doses of compound NPK fertilizer

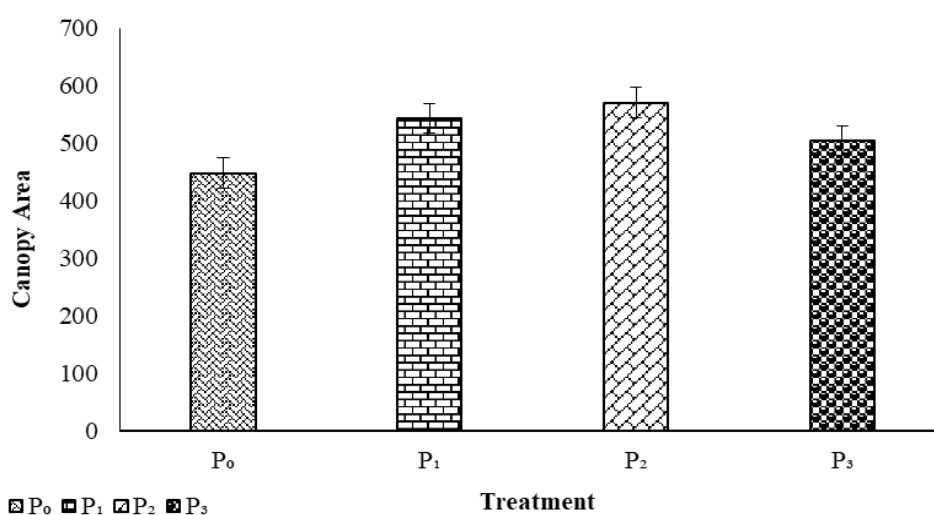


Figure 9. The average canopy area with the application of various doses of compound NPK fertilizer

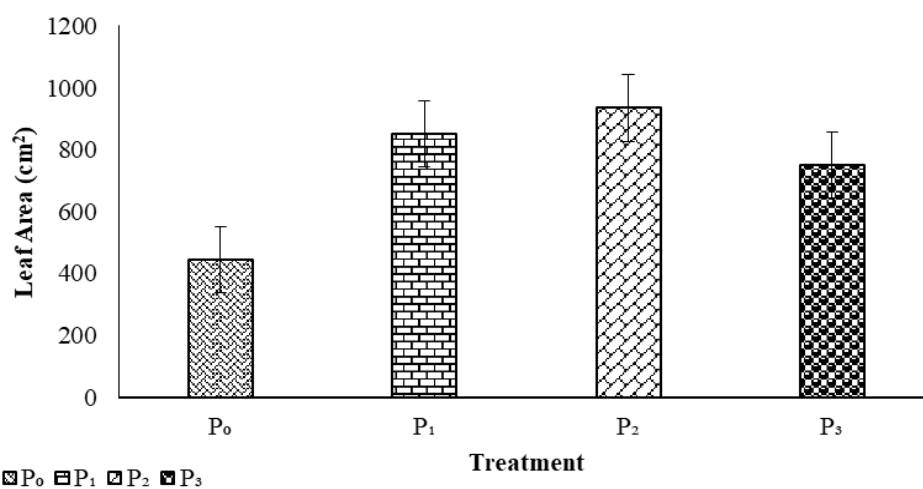


Figure 10. The average leaf area (cm²) with the application of various doses of compound NPK fertilizer

Regression Analysis

The results of the orthogonal polynomial post hoc test showed a quadratic response in the fresh weight variable of the plants. The data were then analyzed with a response curve (Figure 11). Based on the regression curve analysis, the regression equation for the application of compound NPK fertilizer on the fresh weight of the plants was $Y = -16.721x^2 + 64.579x + 52.812$, so the optimum dosage was at 1.93 g/polybag.

The results of the orthogonal polynomial post hoc test showed a linear response in the variable number of leaves at 2 MST, therefore a DMRT post hoc test was conducted on the variable number of leaves at 2 MST and the best result was obtained with the treatment of 2.4 g/polybag with an average of 9.55. The quadratic response obtained from the polynomial orthogonal

continuation test at 4 Weeks After Planting (WAP). The data was then analyzed with a response curve (Figure 12). Based on the regression curve analysis, the regression equation for the application of compound NPK fertilizer on the number of 4 MST was $Y = 0.8435x^2 + 3.432x + 10.794$, so the optimum dose was 2.04 g/polybag.

The results of the orthogonal polynomial post hoc test showed a quadratic response in leaf area. The data were then analyzed with a response curve (Figure 13). Based on the regression curve analysis, the regression equation for the application of compound NPK fertilizer on the fresh weight of the plants was $Y = -16.721x^2 + 64.579x + 52.812$, so the optimal dose was 2.05 g/polybag.

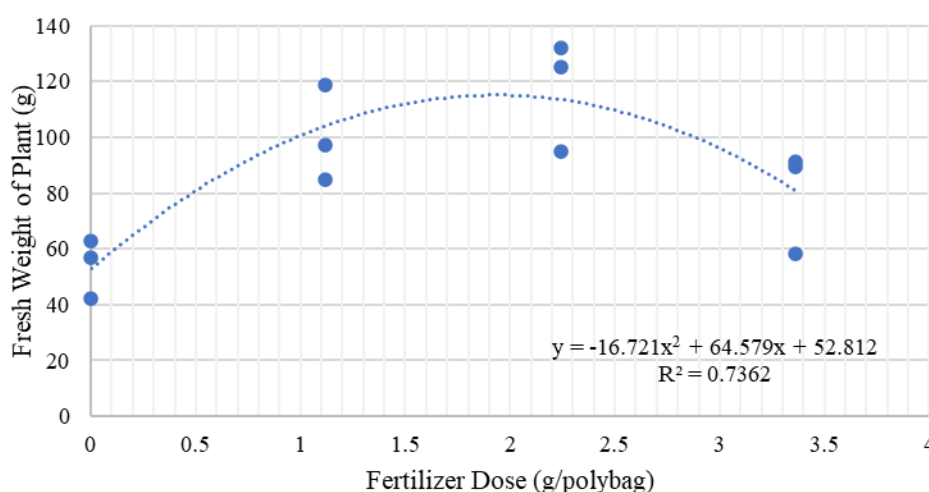


Figure 11. Response curve of the effect of various doses of compound NPK fertilizer on the fresh weight of lettuce

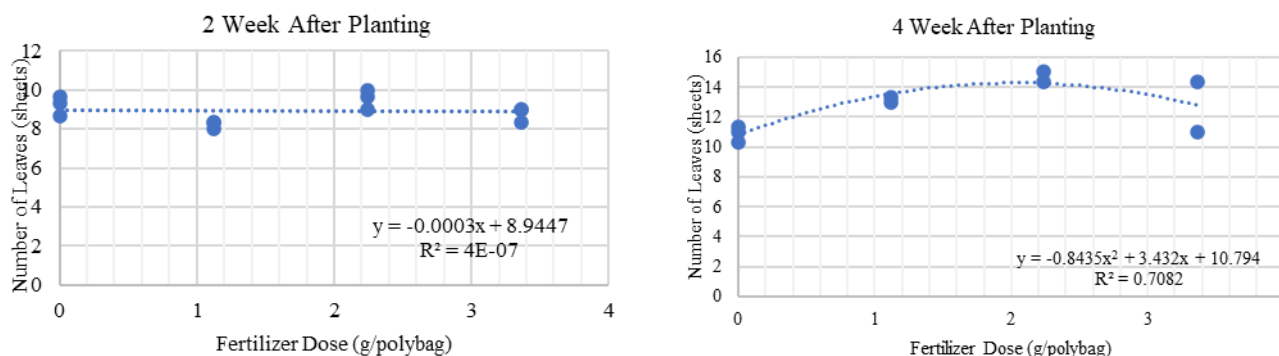


Figure 12. Response curve of the effect of various doses of compound NPK fertilizer on 2 and 4 week after planting

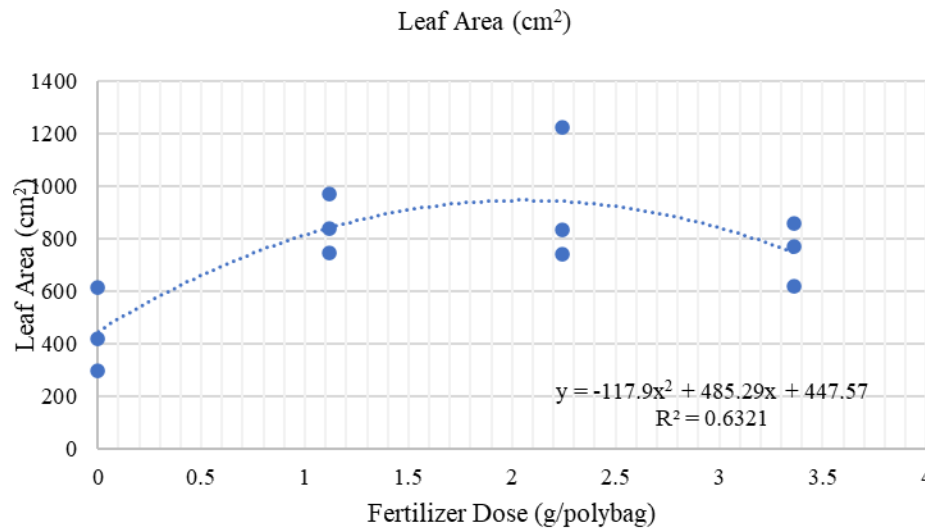


Figure 13. Response curve of the effect of various doses of compound NPK fertilizer on the leaf area

DISCUSSION

The research findings indicate that different quantities of NPK fertilizer applied to lettuce cultivated in a floating system significantly influence the number of leaves, fresh weight, and leaf area of the lettuce (Table 1). The suboptimal growth of lettuce is attributed to various environmental and internal factors. These considerations rendered some criteria unimportant in our investigation. The characteristics include plant height, leaf greenness level, dry weight of the plant, fresh weight of the roots, dry weight of the roots, root length, and canopy area (Table 1). The absence of additional nutrients in the soil results in no substantial variation in the height of the lettuce plants. The absence of other nutrients, both macro and microelements, can significantly impact the growth of lettuce seedlings and affect the greenness of the leaves (Filip et al., 2023).

The use of 2.4 g of fertilizer for lettuce demonstrated statistically significant outcomes, attaining the highest weight compared to other treatments (Figure 4). The leaf area significantly influences the photosynthesis process and the assimilation yield in plants. With adequate leaf area, plants can perform photosynthesis and generate assimilates that subsequently influence their fresh weight, consistent with the findings of (Nabayi et al., 2023), which indicate that NPK fertilizer application can enhance plant growth and nutrient uptake. The floating plant growing method enhances efficiency by eliminating the need for regular watering, allowing lettuce roots

to grow and collect minerals and nutrients from the soil through the use of NPK. (Lazaratou et al., 2021) asserted that the utilization of NPK fertilizer markedly enhances root development and shoot elevation. As stated by (Ekawati & Saputri, 2020), shaded leaves exhibit morphological alterations as a response to low light circumstances, becoming broader and thinner to optimize light absorption for photosynthesis. In this investigation, shade was not implemented, resulting in the lettuce receiving direct sunshine. The average values for the canopy area variable ranged from 448 to 570, and the analysis of variance indicated no significant findings (Figure 9).

The analysis of plant growth rates in conjunction with root growth in this study produced consistent findings (Table 1), indicating that the non-significant variables of root length and plant height may be attributed to elevated solar radiation exposure, leading to increased evaporation rates that diminish water availability for the plants (Maulidiya & Edy, 2022). This issue can be resolved by including phosphorus nutrients, which have demonstrated efficacy in augmenting overall root development and enhancing soil conditions in the placement zone, owing to the increased availability of phosphorus that fosters early-stage plant growth (Sica & Magid, 2024). The incorporation of phosphorus as a vital nutrient can diminish membrane lipid peroxidation by augmenting the activity of both enzymatic antioxidants (catalase and ascorbate peroxidase) and non-enzymatic antioxidants (carotenoids, flavonoids, anthocyanins)

(Dolatmand-Shahri, 2025). The absorption of NPK elements in this study positively influenced several parameters, including fresh weight and leaf area (Table 1), while not significantly affecting root length. This aligns with the findings of (Hefner et al., 2024), which indicated that N elements did not lead to a significant increase in root length in lettuce plants. Kindly provide the text you wish for me to translate. The application of inorganic NPK fertilizers and rice husk biochar can enhance soil quality. N can serve as an energy source and facilitate nutrient recycling for soil microbes (Addai et al., 2023).

CONCLUSION

This study demonstrated that the application of different doses of NPK compound fertilizer significantly affected several key growth and yield parameters of lettuce (*Lactuca sativa* L.) cultivated in a floating system. Significant effects were observed in the number of leaves at 2 and 4 weeks after planting, fresh plant weight, and leaf area ($P < 0.05$). Among these, the number of leaves and leaf area are critical indicators of plant productivity and nutrient uptake efficiency, while fresh weight reflects the plant's overall biomass accumulation. In contrast, variables such as plant height, root traits, and dry weights showed no statistically significant differences, although some presented positive trends with increasing fertilizer doses. These findings suggest that optimizing the NPK fertilizer dose is essential to enhance specific physiological traits contributing to lettuce growth performance in soilless conditions.

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