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Evaluation of different fertilization sources in lettuce (*Lactuca sativa* L.) cultivation

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Abstract: Lettuce (*Lactuca sativa* L.) is one of the most economically important leafy vegetables cultivated in Brazil, and the choice of fertilization source directly influences its growth and productivity. This study aimed to evaluate the effects of four fertilization treatments—control (without fertilization), organic fertilization (30% composted cattle manure by substrate volume), foliar fertilization (NPK 20–20–20 supplemented with micronutrients at 2 g L^{-1}, applied biweekly), and chemical fertilization (NPK 04–14–08 at 100 g m^{-2})—on the growth performance of lettuce cultivated in pots under greenhouse conditions. The experiment was conducted in a completely randomized design with four treatments and six replications, totaling 24 experimental units. At 45 days after transplanting, the following variables were evaluated: plant height (PH), number of leaves (NL), shoot fresh mass (SFM), shoot dry mass (SDM), and root system length (RSL). Data were subjected to analysis of variance (ANOVA), and treatment means were compared using *Tukey's* test at the 5% significance level in the R statistical software. Chemical fertilization resulted in the highest values for PH (22.83 cm), NL (33.17 leaves), SFM (415.33 g), and SDM (24.33 g), differing significantly from the other treatments for most evaluated variables. Organic fertilization showed intermediate performance but exhibited considerable variability among replicates (coefficient of variation up to 67.6% for SFM), likely associated with differences in manure decomposition and nutrient availability. Foliar fertilization alone did not significantly differ from the control treatment for any biomass-related variable. Regarding RSL, the control treatment produced the longest roots (30.83 cm), significantly exceeding those observed under chemical fertilization (19.00 cm), indicating root plasticity in response to nutrient availability. The results demonstrate that chemical fertilization with NPK 04–14–08 promotes superior shoot biomass production during short lettuce production cycles, whereas organic fertilization may represent a viable alternative when high-quality and homogeneous organic inputs are available.

Keywords: *Lactuca genus*; Chemical fertilization; Cattle manure; Foliar fertilization; Vegetable production; Plant biomass.

1. Introduction

Lettuce (*Lactuca sativa* L.) is undoubtedly one of the most widely consumed leafy vegetables in Brazil. With an annual production exceeding 1.5 million tons and a cultivated area greater than 85,000 hectares, Brazil ranks among the world's leading lettuce-producing countries (Filgueira, 2008; IBGE, 2023). A substantial portion of this production is carried out by small- and medium-scale farmers operating intensive production systems with multiple cultivation cycles throughout the year. Within this context, one of the most important management decisions concerns the choice of fertilization strategy.

Adequate nutrient supply is essential for lettuce

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plants to achieve their maximum growth potential, particularly nitrogen, which plays a fundamental role in leaf expansion—the primary commercial product of the crop (Malavolta et al., 1997). The effectiveness of each fertilizer source depends on factors such as nutrient solubility, release rate, and interaction with the growing substrate.

Three major fertilization approaches are commonly employed in vegetable production systems: mineral (chemical) fertilization, which provides nutrients rapidly and predictably; organic fertilization, which not only supplies nutrients but also improves the physical, chemical, and biological properties of the substrate; and foliar fertilization, generally used as a complementary nutritional strategy, especially for micronutrient supplementation (Trani et al., 2013; Sediyama et al., 2014). Each approach presents specific advantages and limitations, making comparative evaluations under local production conditions essential for supporting decision-making by growers.

The municipality of Rio Verde, located in the state of Goiás, Brazil, is an important agricultural production center. However, limited information is available regarding nutrient management practices for leafy vegetables cultivated under protected environments in this region. Therefore, this study is justified both by its practical relevance to local producers and by its potential contribution to the scientific understanding of lettuce nutrition under Cerrado conditions.

The main objective of this research was to evaluate the effects of different fertilization sources—control (without fertilization), organic fertilization (composted cattle manure), foliar fertilization (NPK 20–20–20 supplemented with micronutrients), and chemical fertilization (NPK 04–14–08)—on the growth and development of lettuce cultivated in pots under greenhouse conditions during 45 days after transplanting. Specifically, the study aimed to compare treatments regarding plant height, number of leaves, shoot fresh mass, shoot dry mass, and root length; identify the treatment with the best agronomic performance; and discuss the results in light of current scientific literature on fertilization practices for leafy vegetables.

2. Material and Methods

2.1. Experimental site and growing period

The experiment was conducted in the greenhouse facilities of UniBRAS University Center of Rio Verde, located in Rio Verde, Goiás, Brazil (17°47'53" S and 50°55'41" W; altitude of 748 m above sea level). The cultivation period extended from September to November 2025, comprising 45 days after transplanting (DAT) of lettuce seedlings of the curly lettuce cultivar.

2.2. Experimental design and treatments

A completely randomized design (CRD) was adopted, consisting of four treatments and six replications, totaling 24 experimental units. Each experimental unit consisted of a 5-L plastic pot containing one lettuce plant.

The treatments were as follows:

T1. Control: cultivation without fertilizer application, using only a standard commercial substrate;

T2. Chemical Fertilization: application of NPK 04–14–08 fertilizer at a rate equivalent to 100 g m^{-2}, incorporated into the substrate before transplanting;

T3. Organic Fertilization: incorporation of composted cattle manure at 30% of the total substrate volume;

T4. Foliar Fertilization: biweekly application of a complete foliar fertilizer (NPK 20–20–20 supplemented with micronutrients) at a concentration of 2 g L^{-1}.

2.3. Evaluated variables

The following agronomic variables were assessed at the end of the cultivation cycle (45 DAT):

a) Plant height (PH): measured in centimeters from the stem base to the tip of the highest leaf;

b) Number of leaves (NL): total count of leaves longer than 3 cm;

c) Shoot fresh mass (SFM): determined using a precision balance (0.001 g resolution) and expressed in grams;

d) Shoot dry mass (SDM): obtained after drying plant material in a forced-air oven at 65°C until constant weight and expressed in grams;

e) Root system length (RSL): measured in centimeters from the stem base to the tip of the longest root.

2.5. Statistical Analysis

Data were subjected to analysis of variance (ANOVA). When the *F-test* detected significant differences among treatments, means were compared using *Tukey's* honestly significant difference (HSD) test at the 5% probability level ($p \leq 0.05$). Statistical analyses were performed using R software version 4.3.0. The coefficient of variation (CV) was calculated for each variable to assess experimental precision.

3. Results

3.1. Effects of fertilization treatments on lettuce growth

The analysis of variance (ANOVA) revealed a significant effect of fertilization treatments on all evaluated variables ($p < 0.05$), indicating that at least one treatment differed significantly from the others for each growth parameter assessed. Treatment means, standard deviations, coefficients of variation (CV), *F-test* values, and the results of *Tukey's* multiple comparison test are presented in (Table 1). These findings demonstrate that the type of fertilization significantly influenced the growth and development of lettuce cultivated under greenhouse conditions.

Treatment	PH (cm)	NL (*n*)	SFM (g)	SDM (g)	RSL (cm)
Control	14.83±2.14 b	11.00±1.67 c	59.00±15.32 b	4.67±1.03 c	30.83±5.49 a
Organic	19.17±5.81 ab	19.83±8.50 b	158.67±107.24 b	13.00±7.46 b	26.00±3.16 ab
Foliar	14.17±1.83 b	12.33±1.63 bc	73.67±20.57 b	6.33±1.51 bc	25.83±4.54 ab
Chemical	22.83±0.75 a	33.17±4.40 a	415.33±74.72 a	24.33±5.72 a	19.00±5.55 b
F-value	9.311***	25.551***	36.858***	20.871***	6.208**
p-value	0.0005	<0.0001	<0.0001	0.0001	0.0037
CV (%)	14.4/30.3/13.0/3.3	15.2/42.8/13.2/13.3	26.0/67.6/27.9/18.0	22.1/57.4/23.8/23.5	17.8/12.2/17.6/29.2

Note: [a,b,c] Means followed by the same lowercase letter within a column do not differ significantly according to *Tukey's* test ($p > 0.05$). ***$p < 0.001$; $p < 0.01$. CV (%): values presented in the order Control/Organic/Foliar/Chemical fertilization. PH: Plant height; NL: Number of leaves; SFM: Shoot fresh mass; SDM: Shoot dry mass; RSL: Root system length. Source: Authors, 2026.

3.2. Plant height

Chemical fertilization resulted in the greatest mean plant height among the evaluated treatments, 22.83 cm, differing significantly from foliar fertilization 14.17 cm and the control treatment 14.83 cm according to *Tukey's* test. Organic fertilization showed an intermediate response, with a mean plant height of 19.17 cm, and did not differ statistically from the other treatments, likely due to the high coefficient of variation observed within this group CV = 30.3% (Table 1).

3.3. Number of leaves

The number of leaves was the variable for which treatment differences were most pronounced. Chemical fertilization produced the highest mean value, 33.17 leaves, differing significantly from all other treatments. Organic fertilization 19.83 leaves resulted in a significantly greater number of leaves than the control treatment 11.00 leaves, occupying an intermediate position among the treatments. In contrast, foliar fertilization 12.33 leaves did not differ statistically from the control (Table 1).

3.4. Shoot fresh mass

Shoot fresh mass was the variable of greatest commercial importance, as it is directly associated with marketable yield at the point of sale. Chemical fertilization produced plants with a mean shoot fresh mass of 415.33 g, representing more than seven times the mean mass observed in the control treatment 59.00 g and nearly six times that obtained with foliar fertilization 73.67 g. The differences between chemical fertilization and all other treatments were highly significant ($p < 0.001$) (Table 1).

No significant differences were detected among the control, foliar fertilization, and organic fertilization treatments according to *Tukey's* test, although organic fertilization resulted in a considerably higher mean shoot fresh mass, 158.67 g, compared with the control treatment 59.00 g.

3.5. Shoot dry mass

Shoot dry mass represents the actual amount of organic matter accumulated by the plant and is therefore an important indicator of growth efficiency. Chemical fertilization once again produced the highest mean value, 24.33 g, differing significantly from organic fertilization, 13.00 g, foliar fertilization, 6.33 g, and the control treatment, 4.67 g. Organic fertilization also differed significantly from the control, suggesting a positive effect of the organic amendment on biomass accumulation despite the relatively high variability observed among replicates (Table 1).

The average dry matter content of plants receiving chemical fertilization corresponded to approximately 5.9% of the shoot fresh mass 24.33/415.33, which falls within the expected range for lettuce crops 5–8%. In contrast, the control treatment exhibited a dry matter content of 7.9%, potentially indicating that nutrient-limited plants accumulate proportionally higher concentrations of structural and organic compounds due to reduced water accumulation and overall vegetative growth.

3.6. Root system length

Root system development exhibited a pattern opposite to that observed for shoot growth variables. The control treatment produced the longest roots 30.83 cm, differing significantly from the chemical fertilization treatment 19.00 cm. Organic fertilization 26.00 cm and foliar fertilization 25.83 cm showed intermediate values and did not differ significantly from any of the other treatments according to *Tukey's* test (Table 1).

This response suggests a compensatory root growth mechanism under nutrient-limited conditions, whereby plants allocate greater resources to root elongation in an attempt to explore a larger substrate volume and increase nutrient acquisition. Conversely, under conditions of adequate nutrient availability, such as those provided by chemical fertilization, plants tend to invest more resources in shoot development and biomass accumulation rather than root expansion.

4. Discussion

The results obtained demonstrated that the fertilization source directly influences the growth and productivity of lettuce cultivated under protected conditions (Silva et al., 2017). The superior performance of chemical fertilization in terms of plant height, number of leaves, shoot fresh mass, and shoot dry mass highlights the importance of immediate nutrient availability for short-cycle crops. In leafy vegetables, particularly lettuce, the rapid supply of nitrogen, phosphorus, and potassium promotes cell expansion, protein synthesis, and the formation of photosynthetically active tissues, directly contributing to biomass production (Balkrishna et al., 2025; Rodrigues; Casali, 1999; Taiz et al., 2017).

The greater number of leaves observed under chemical fertilization confirms the high dependence of lettuce on adequate nitrogen supply. According to Oliveira et al. (2019), nitrogen is the nutrient most closely associated with vegetative growth, promoting increases in leaf area and photosynthetic activity. Similar findings were reported by Kano et al. (2012), who observed significant increases in leaf production and fresh biomass of lettuce subjected to balanced mineral fertilization under protected cultivation.

Shoot fresh mass showed marked differences among treatments, with chemical fertilization producing values more than seven times greater than those observed in the control treatment. This response is associated with the rapid uptake of mineral nutrients, a key characteristic for crops with production cycles shorter than 60 days. Cecílio Filho et al. (2015) demonstrated that the immediate availability of nitrogen and potassium promotes greater water accumulation in plant tissues, significantly increasing the commercial fresh weight of lettuce. Likewise, Liu et al. (2025), evaluating different nutritional strategies for leafy vegetables, reported that mineral fertilizers promoted greater vegetative growth than organic sources characterized by slow nutrient mineralization.

Although organic fertilization resulted in lower performance than chemical fertilization, the findings indicate considerable agronomic potential. The high coefficient of variation observed suggests that the quality and degree of stabilization of the cattle manure may have influenced nutrient availability throughout the crop cycle. According to Sampaio et al. (2021), the agronomic efficiency of organic fertilizers depends directly on the composting process, the carbon-to-nitrogen ratio, and environmental conditions regulating organic matter mineralization. Consequently, inadequately composted materials may release nutrients too slowly to meet the demands of short-cycle crops, thereby reducing plant performance.

The results obtained for foliar fertilization corroborate observations widely reported in the literature. Although foliar fertilizers can contribute to the rapid correction of specific nutrient deficiencies, they are generally unable to fully satisfy the macronutrient requirements of crops with high nitrogen demand, such as lettuce. Studies conducted by Ssemugenze et al. (2025) demonstrated that foliar fertilization produces better results when used as a supplement to basal fertilization rather than as the sole nutrient source.

Root system development exhibited an opposite trend compared with shoot growth variables. The longest roots were observed in the unfertilized control treatment, indicating an adaptive mechanism of substrate exploration under nutrient-limited conditions. This phenomenon, known as root plasticity, has been widely documented in cultivated species and represents a physiological strategy to enhance the acquisition of limiting resources (Lynch, 2019). Under conditions of high nutrient availability, such as those provided by chemical fertilization, plants tend to allocate a greater proportion of photoassimilates to shoot growth, thereby reducing investment in root expansion (Marschner et al., 1996).

Overall, the results reinforce that mineral fertilizers remain the most effective option for maximizing lettuce productivity in intensive production systems and short cultivation cycles (Foteinis; Chatzisymeon, 2016). However, considering the growing demand for sustainable agricultural practices, the use of properly stabilized organic fertilizers represents a promising strategy for reducing dependence on synthetic fertilizers. Future studies should investigate integrated fertilization systems combining organic and mineral sources, as well as the nutrient-release dynamics of organic amendments, with the aim of achieving a balance between productivity, sustainability, and crop quality.

5. Conclusion

The results demonstrated that different fertilization sources significantly influence the growth and development of lettuce (*Lactuca sativa* L.) cultivated under greenhouse conditions. Among the evaluated treatments, chemical fertilization with NPK 04–14–08 provided the highest agronomic performance, resulting in superior plant height, number of leaves, shoot fresh mass, and shoot dry mass. These findings indicate that the rapid nutrient availability supplied by mineral fertilizers is particularly advantageous for short-cycle crops such as lettuce, promoting greater biomass accumulation and overall plant growth.

Organic fertilization with composted cattle manure produced intermediate results and showed potential as a sustainable nutrient source. However, the high variability observed among experimental units suggests that the effectiveness of organic fertilization depends strongly on the quality, degree of decomposition, and uniformity of the organic material used. Therefore, proper standardization of manure processing is essential to ensure consistent crop responses.

Foliar fertilization applied as the sole nutrient source was insufficient to meet the nutritional requirements of lettuce and did not significantly improve plant growth compared with the unfertilized control. Consequently, foliar fertilization should be considered a supplementary practice rather than a replacement for soil or substrate fertilization.

Root system development exhibited an inverse response to shoot growth, with the control treatment producing significantly longer roots than the chemically fertilized treatment. This result reinforces the concept of root plasticity, whereby plants allocate greater resources to root exploration under conditions of limited nutrient availability.

Overall, chemical fertilization proved to be the most effective strategy for maximizing lettuce growth during short production cycles. Nevertheless, organic fertilization remains a promising alternative for sustainable production systems, provided that high-quality organic inputs are used. Future studies should investigate integrated fertilization strategies combining organic and foliar fertilization, evaluate nutrient-release dynamics from organic amendments, and increase experimental replication to improve the detection of treatment effects under variable conditions.

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Author’s Contributions

Everton de Araújo Arantes: conceptualization, investigation, methodology, data curation, formal analysis, writing – original draft preparation. *Sabrina Santiago de Moraes*: investigation, data curation, validation, visualization, writing – review & editing. *Elizabete Nunes da Rocha*: supervision, project administration, methodology, validation, resources, writing – review & editing.

Ethics

The authors declare that this study was conducted in accordance with accepted ethical and scientific standards. The authors agree to address and resolve any ethical issues that may arise after the publication of this manuscript.