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Effect of calcium nitrate as a nutrient solution for hydroponic lettuce production

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Abstract
Aim: This study evaluated the effects of varying calcium nitrate concentrations on the growth and yield performance of hydroponically grown lettuce. Specifically, it aimed to determine the optimal calcium nitrate concentration that enhances vegetative growth characteristics and maximizes yield and economic return.
Methodology: The experiment was conducted using a nutrient film technique (NFT) hydroponic system at the Nursery House in San Manuel, Isabela, Philippines. A Completely Randomized Design (CRD) was employed with five treatments and three replications. The treatments consisted of a commercial nutrient solution (100% SNAP) and four calcium nitrate concentrations (1.0, 1.5, 2.0, and 2.5 g/L) combined with nutrient solution. Growth, yield, and economic parameters were measured and analyzed.
Results: Results showed that the application of 2.0 g/L calcium nitrate combined with nutrient solution produced growth and yield performance comparable to the commercial SNAP solution. This treatment resulted in higher plant fresh weight, longer root length, wider leaves, a greater number of leaves, and the highest return on investment among all treatments.
Conclusion: The application of 2.0 g/L calcium nitrate combined with nutrient solution can serve as an effective and economically viable alternative to commercial nutrient solutions for hydroponically grown lettuce.
Keywords: *Calcium nitrate, hydroponics, nutrient film technique, nutrient solution*

INTRODUCTION

The rapid expansion of urban areas, coupled with sustained global population growth, has intensified the demand for accessible, nutritious, and high-quality food. Simultaneously, the continuous reduction of arable land due to urbanization, industrialization, and infrastructure development poses serious challenges to conventional agricultural systems. These constraints are further aggravated by soil degradation, climate variability, water scarcity, and environmental pollution, all of which threaten long-term agricultural productivity and global food security (Ciriello et al., 2021). As a result, the pursuit of innovative, resource-efficient, and sustainable agricultural technologies has become a global priority.

Within this context, hydroponic farming has emerged as a viable alternative to soil-based agriculture. Hydroponics is a soilless cultivation system that supplies plants with nutrient-enriched solutions, allowing precise nutrient control while minimizing land and water use. This technology has demonstrated considerable potential in enhancing yield stability, improving crop quality, and supporting year-round production, particularly for leafy vegetables such as lettuce (*Lactuca sativa* L.) (Jokinen et al., 2022). Globally, hydroponic lettuce production has gained prominence due to its short growth cycle, high market demand, and suitability for urban and peri-urban environments.

In the Philippine setting, hydroponics has been increasingly promoted as a sustainable solution to food production challenges associated with limited land availability, climate-related risks, and rising input costs. Urban and semi-urban communities, including those in Northern Luzon, have gradually adopted small- and medium-scale hydroponic systems to supplement household food supply and support livelihood initiatives. However, despite its growing adoption, hydroponic production in the Philippines remains constrained by the high cost of commercial nutrient solutions and limited locally generated research on nutrient optimization under tropical conditions. These challenges underscore the need for cost-effective, locally adaptable nutrient management strategies to improve the productivity and economic viability of hydroponic systems.

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Nutrient management is a critical determinant of success in hydroponic cultivation. Maintaining an optimal balance of essential macronutrients, including nitrogen, phosphorus, potassium, and calcium, as well as micronutrients such as iron and manganese, is essential for ensuring plant health and maximizing growth and yield. Previous studies have highlighted that inappropriate nutrient concentrations can lead to nutrient imbalances, reduced biomass accumulation, and physiological disorders, particularly in leafy vegetables (Sidhu et al., 2020). Among these nutrients, calcium plays a vital role in cell wall formation, membrane stability, enzyme activation, and overall plant structural integrity.

Calcium deficiency is a common problem in hydroponic lettuce production, often manifesting as tip burn, reduced leaf expansion, and increased susceptibility to physiological stress and pathogens (Moyo et al., 2024). Calcium nitrate [$Ca(NO_3)_2$] is widely utilized in hydroponic systems as a dual source of calcium and nitrogen. While several studies have examined the general role of calcium in hydroponic crops, existing literature largely focuses on standard commercial nutrient formulations or generalized nutrient recommendations. Limited empirical evidence is available on the optimization of calcium nitrate concentrations as a partial or alternative nutrient source, particularly under Philippine climatic conditions and small-scale hydroponic setups.

This gap indicates the need for systematic evaluation of calcium nitrate application rates in hydroponic lettuce production, specifically in comparison with commercially available nutrient solutions. There remains insufficient locally grounded research that identifies optimal calcium nitrate concentrations capable of sustaining plant growth, maximizing yield, and improving economic returns without compromising crop quality. Addressing this gap is essential for developing cost-efficient and context-specific nutrient management practices for Filipino hydroponic growers.

Anchored on the conceptual framework of nutrient concentration influencing plant physiological response, growth performance, yield, and economic viability, the present study investigated the effects of varying calcium nitrate concentrations on hydroponically grown lettuce. The framework assumes that appropriate calcium nitrate levels directly affect nutrient uptake efficiency, vegetative growth characteristics, and biomass accumulation, which in turn influence yield performance and return on investment. This framework guided the selection of treatments, growth parameters, and economic indicators assessed in the study.

Specifically, this study evaluated the effects of different calcium nitrate concentrations combined with a nutrient solution on lettuce growth and yield under a nutrient film technique (NFT) system in Isabela, Philippines. By comparing these treatments with a commercial nutrient solution, the study aimed to identify an optimal calcium nitrate concentration that enhances plant performance while reducing production costs. The findings are expected to contribute to the advancement of hydroponic nutrient management practices by providing empirical evidence on calcium nitrate optimization under local conditions.

Beyond its technical contribution, this study supports the United Nations Sustainable Development Goals (SDGs), particularly Goal 1 (No Poverty), Goal 2 (Zero Hunger), and Goal 3 (Good Health and Well-being), by promoting sustainable food production, improving access to nutritious crops, and enhancing livelihood opportunities through efficient urban agriculture. The results may serve as a scientific basis for developing affordable, region-specific hydroponic nutrient solutions, thereby strengthening the sustainability and profitability of hydroponic lettuce production in the Philippines.

Statement of the Problem

Hydroponic lettuce production has gained increasing attention as a sustainable solution to food security challenges associated with urbanization, land scarcity, and climate variability. While commercial nutrient solutions are widely used to support hydroponic crop growth, their cost and accessibility pose limitations for small-scale and local growers. Calcium nitrate is commonly applied as a source of calcium and nitrogen in hydroponic systems; however, empirical evidence on its optimal concentration for hydroponically grown lettuce, particularly under varying electrical conductivity conditions, remains limited.

Existing studies have largely focused on generalized nutrient formulations or the use of complete commercial solutions, with insufficient emphasis on isolating calcium nitrate concentrations and evaluating their effects on plant growth, yield performance, and economic viability. Moreover, the interaction between calcium nitrate concentration and electrical conductivity, and its influence on both biological and economic outcomes, has not been adequately examined under local production conditions.

This gap in knowledge necessitates a systematic investigation to determine the appropriate calcium nitrate concentration that can support optimal lettuce growth while ensuring cost efficiency. Addressing this problem is essential for developing practical, sustainable, and economically viable nutrient management strategies for hydroponic lettuce production, particularly for small-scale and resource-limited growers.

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Research Objectives

General Objective:

To evaluate the effects of varying concentrations of calcium nitrate and resulting electrical conductivity on the growth and yield performance of hydroponically grown lettuce.

Specific Objectives:

1. To determine the influence of varying concentrations of calcium nitrate on the growth and yield of hydroponically grown lettuce.
2. To assess the effect of electrical conductivity on the growth and yield performance of lettuce.
3. To identify the calcium nitrate concentration that yields the highest return on investment in hydroponic lettuce production.

Research Questions

1. What is the effect of varying concentrations of calcium nitrate on the growth and yield performance of hydroponically grown lettuce?
2. How does electrical conductivity influence the growth and yield of lettuce in a hydroponic system?
3. Which calcium nitrate concentration produces the highest return on investment in hydroponic lettuce production?

METHODS

Research Design

The study employed a quantitative experimental research design using a Completely Randomized Design (CRD). This design was selected because it allowed the comparison of multiple calcium nitrate concentrations under controlled hydroponic conditions while minimizing experimental bias. The CRD was appropriate for the study since the experimental units were considered homogeneous and environmental conditions were uniformly maintained throughout the experimental period.

Population and Sampling

The population of the study consisted of hydroponically grown lettuce plants cultivated under a nutrient film technique (NFT) system. A total of 375 lettuce plants were used in the experiment, with 25 plants per treatment replicated three times across five treatments. All plants were selected using total enumeration, as all viable seedlings produced during the propagation stage were included in the experiment to ensure uniformity and adequate representation.

Instrumentation

Data were gathered using researcher-utilized measuring instruments, including a ruler for plant height and leaf measurements, a digital weighing scale for fresh weight determination, a caliper for precision measurements, and an electrical conductivity/total dissolved solids/pH meter for monitoring nutrient solution properties. All instruments were calibrated prior to data collection to ensure measurement accuracy and consistency. These instruments were deemed appropriate for the quantitative variables measured in the study.

Data Collection Procedure

The experiment was conducted at the Nursery House in Barangay District 1, San Manuel, Isabela, Philippines. Lettuce seeds were sown in sterilized coco peat placed in Styrofoam cups and were transplanted into PVC downspouts ten days after sowing. Nutrient solutions with varying calcium nitrate concentrations were applied according to the designated treatments.

Data collection was conducted at specific growth stages. Plant height was measured at 25 days after transplanting (DAT). Leaf length, leaf width, root length, number of leaves, and fresh weights were measured at harvest, which occurred 32 days after transplanting. Economic data were collected after harvest to compute production costs, gross income, net income, and return on investment.

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Experimental Treatments

The treatments were as follows:
T1 – 100% commercial SNAP solution (control)
T2 – 1.0 g/L calcium nitrate + solution
T3 – 1.5 g/L calcium nitrate + solution
T4 – 2.0 g/L calcium nitrate + solution
T5 – 2.5 g/L calcium nitrate + solution

Data Analysis

Data were subjected to statistical analysis to determine significant differences among treatments. Analysis of variance (ANOVA) was used to evaluate the effects of calcium nitrate concentrations on growth and yield parameters. When significant differences were observed, mean comparisons were conducted using the Least Significant Difference (LSD) test at the 1% level of significance. Return on investment (ROI) was computed using the formula:
ROI (%) = (Net Income / Total Cost of Production) × 100

Ethical Considerations

The study adhered to ethical research practices applicable to plant-based experimental studies. All procedures were conducted in a manner that ensured environmental safety and responsible use of resources. No endangered plant species were involved, and waste materials were disposed of following proper agricultural and environmental guidelines. The study was conducted solely for academic and research purposes.

RESULTS AND DISCUSSION

A. Electrical Conductivity (EC) of the Treatments

Table 1. Electrical Conductivity (EC) at Different Levels of Calcium Nitrate + Solution

TREATMENT	Electrical Conductivity
T_1 – 100% SNAP (Control)	816.00e
T_2 – 1 gram/L Calcium Nitrate + Solution	929.67d
T_3 – 1.5 gram/L Calcium Nitrate + Solution	1188.33c
T_4 – 2.0 gram/L Calcium Nitrate + Solution	1359.00b
T_5 – 2.50 gram/L Calcium Nitrate + Solution	1631.00a
F-RESULT	**
CV (%)	5.10
LSD	121.45

Note: Means within a column represented by common letters are not significant at 1% level using HSD.
** – highly significant

Electrical conductivity (EC) differed significantly among treatments (Table 1). The lowest EC value was recorded in the control treatment using the commercial SNAP nutrient solution (816.00 mS/cm), while the highest EC was observed in Treatment 5 (2.50 g/L calcium nitrate + solution) with a mean of 1631.00 mS/cm. A progressive increase in EC was noted as calcium nitrate concentration increased, indicating a direct relationship between nutrient concentration and solution salinity.

Results further showed that higher EC levels were associated with reduced lettuce fresh weight, particularly in Treatment 5. This finding suggests that excessive EC may have induced osmotic stress, limiting water and nutrient uptake and consequently suppressing plant growth. In contrast, Treatments 1 (SNAP) and 4 (2.0 g/L calcium nitrate + solution), which maintained moderate EC levels, produced superior growth and yield outcomes. These results support earlier findings that lower to moderate EC levels enhance lettuce growth, particularly under high-temperature conditions (Fu et al., 2012; Oyebamiji et al., 2025).

The observed response also aligns with reports that lettuce cultivars vary in salinity tolerance, and excessive salt concentration can negatively affect growth and biomass accumulation (Shannon & Grieve, 2006). Thus, maintaining

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EC within an optimal range is essential for hydroponic lettuce production, especially under tropical environmental conditions.

B. Growth Performance of Lettuce as Affected by Different Levels of Calcium Nitrate

Table 2. Growth Performance of Lettuce as Affected by Different Levels of Calcium Nitrate + Solution

TREATMENT	Leaf Length (cm)	Leaf Width (cm)	Root Length (cm)
T_1 – 100% SNAP (Control)	15.10a	9.48a	21.10a
T_2 – 1 gram/L Calcium Nitrate + Solution	11.67c	7.13c	16.10b
T_3 – 1.5 gram/L Calcium Nitrate + Solution	13.10b	8.23b	17.97b
T_4 – 2.0 gram/L Calcium Nitrate + Solution	15.00a	9.32a	20.87a
T_5 – 2.50 gram/L Calcium Nitrate + Solution	10.13d	6.73c	13.10c
F-RESULT	**	**	**
CV (%)	4.62	3.59	5.80
LSD	1.09	0.53	1.88

Note: Means within a column represented by common letters are not significant at 1% level using HSD.
** – highly significant

Leaf Length (cm)

Highly significant differences in leaf length were observed at 32 days after transplanting (DAT) (Table 2). The longest leaves were recorded in Treatments 1 (SNAP) and 4 (2.0 g/L calcium nitrate + solution), with mean values of 15.10 cm and 15.00 cm, respectively. Conversely, Treatment 5 (2.50 g/L calcium nitrate + solution) produced the shortest leaves.

These results indicate that moderate calcium nitrate concentration supported optimal leaf expansion, whereas excessive levels may have caused nutrient imbalance or osmotic stress. Elevated nitrate and calcium concentrations can interfere with the uptake of other essential nutrients such as potassium and magnesium, which are critical for chlorophyll synthesis and cell expansion (Bhatla & Kathpalia, 2023). This imbalance likely contributed to reduced leaf growth at higher calcium nitrate levels.

Leaf Width (cm)

Leaf width was also significantly affected by calcium nitrate concentration (Table 2). The widest leaves were observed in Treatments 1 and 4, while the narrowest leaves occurred in Treatments 2 (1.0 g/L) and 5 (2.50 g/L). These findings suggest that both insufficient and excessive calcium nitrate levels adversely affect leaf development.

At lower concentrations, nutrient deficiency may have limited cell division and expansion, resulting in narrower leaves. At higher concentrations, nutrient toxicity or ionic imbalance may have suppressed photosynthetic efficiency and cell elongation, leading to reduced leaf width. Similar trends have been reported in hydroponic lettuce, where optimal nitrate levels promoted leaf expansion, while deviations led to growth suppression (Jung et al., 2025).

Root Length (cm)

Root length differed significantly among treatments (Table 2). Treatment 4 produced the longest roots (20.87 cm), which was statistically comparable to the SNAP control. This result indicates that a 2.0 g/L calcium nitrate concentration provided favorable conditions for root elongation, possibly by enhancing calcium availability for cell wall development and root meristem activity. Shorter root lengths observed at higher concentrations may be attributed to salt stress in the root zone, which can restrict root growth and nutrient absorption.

C. Yield Performance of Lettuce as Affected by Different Levels of Calcium Nitrate

Table 3. Yield Performance of Lettuce as Affected by Different Levels of Calcium Nitrate + Solution

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TREATMENT	Number of Leaves at Harvest	Fresh Weight w/ Roots	Fresh Weight w/o Roots	Total Fresh Weight
T_1 – 100% SNAP (Control)	16.33a	141.67a	124.67a	137.17a
T_2 – 1 gram/L Calcium Nitrate + Solution	13.67b	102.67c	90.53c	91.33c
T_3 – 1.5 gram/L Calcium Nitrate + Solution	13.67b	122.00b	109.00b	113.00b
T_4 – 2.0 gram/L Calcium Nitrate + Solution	16.33a	140.00a	122.67a	131.67a
T_5 – 2.50 gram/L Calcium Nitrate + Solution	11.67c	91.67d	81.33d	89.67c
F-RESULT	**	**	**	**
CV (%)	5.10	6.00	2.84	3.50
LSD	1.32	9.21	5.44	7.10

Note: Means within a column represented by common letters are not significant at 1% level using HSD
** – highly significant

Number of Leaves at Harvest

Significant differences were observed in the number of leaves at harvest (Table 3). Treatments 1 and 4 produced the highest leaf counts (16.33 leaves per plant), while Treatment 5 recorded the lowest. These findings indicate that moderate calcium nitrate concentration supported active cell division and leaf initiation.

Nitrogen supplied through calcium nitrate plays a crucial role in vegetative growth, particularly during the final growth stages when nutrient demand is high (Wang et al., 2025). However, excessive nitrogen may lead to nutrient imbalance and reduced productivity, as observed in the highest concentration treatment.

Fresh Weight of Plants With and Without Roots (g)

Fresh weight with roots and without roots differed significantly across treatments (Table 3). Treatments 1 and 4 produced the heaviest plants, while Treatment 5 resulted in the lowest fresh weights. The superior performance of Treatment 4 suggests that the 2.0 g/L calcium nitrate concentration provided an optimal balance of calcium and nitrogen, promoting efficient nutrient uptake and biomass accumulation.

Excessive EC in Treatment 5 likely reduced water absorption and induced salt stress, leading to reduced fresh weight. These findings are consistent with reports that excessive nitrogen and salinity negatively affect lettuce yield in hydroponic systems (Savvas et al., 2006; Tsouvaltzis et al., 2020).

Total Fresh Weight at Harvest

Total fresh weight at harvest followed a similar trend, with Treatment 4 producing yields comparable to the SNAP control. Although calcium plays a critical role in maintaining cell structure and regulating metabolic processes (Zhou et al., 2020), environmental factors such as high ambient temperatures (41.50–44.70°C) during the experimental period may have constrained overall growth. Lettuce is highly sensitive to heat stress, which can reduce water uptake and biomass accumulation regardless of nutrient formulation (Gruda, 2005; Eriksen et al., 2016).

D. Cost and Return Analysis of Hydroponically Grown Lettuce

Table 4. Cost and Return Analysis of Hydroponically Grown Lettuce at Different Levels of Calcium Nitrate + Solution

TREATMENT	Total Cost of Production (Php.)	Gross Income (Php.)	Net Income (Php.)	Return on Investment (%)
T_1 – 100% SNAP (Control)	16.00	18.70	2.70	14.44
T_2 – 1 gram/L Calcium Nitrate + Solution	13.00	13.58	0.58	4.27
T_3 – 1.5 gram/L Calcium Nitrate + Solution	13.50	16.35	2.85	17.43
T_4 – 2.0 gram/L Calcium Nitrate + Solution	14.00	18.40	4.40	23.91
T_5 – 2.50 gram/L Calcium Nitrate + Solution	14.50	12.20	(-2.30)	(-18.85)

Cost of Lettuce @ P150.00/kg
Cost of SNAP A and B P350

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The cost and return analysis revealed clear differences in economic performance among treatments (Table 4). Treatment 4 achieved the highest return on investment (ROI) at 23.91%, indicating superior economic efficiency compared with the SNAP control. In contrast, Treatment 5 resulted in a negative ROI, suggesting that the increased cost and reduced yield outweighed potential benefits at higher calcium nitrate concentrations.

These findings indicate that while calcium nitrate can serve as a cost-effective nutrient source, its economic viability is highly dependent on proper concentration management. Optimal nutrient levels not only enhance yield but also improve profitability in hydroponic lettuce production.

Conclusion

The study demonstrated that varying calcium nitrate concentrations significantly influenced the electrical conductivity, growth performance, yield, and economic returns of hydroponically grown lettuce. Among the treatments evaluated, the application of 2.0 g/L calcium nitrate combined with nutrient solution consistently produced growth and yield parameters comparable to those obtained using the commercial SNAP nutrient solution. This treatment resulted in favorable leaf development, root elongation, fresh weight accumulation, and the highest return on investment.

Excessive calcium nitrate concentration increased electrical conductivity and negatively affected plant growth and yield, while lower concentrations resulted in nutrient insufficiency. Overall, the findings indicate that a balanced calcium nitrate concentration is essential for optimizing hydroponic lettuce production under tropical conditions.

Recommendations

Based on the findings of this study, the application of 2.0 g/L calcium nitrate combined with nutrient solution may be considered a viable alternative to commercial nutrient solutions for hydroponic lettuce production, particularly for small-scale and cost-sensitive growers. This concentration demonstrated favorable growth performance, yield outcomes, and economic returns.

Further studies may be undertaken to evaluate the consistency of these results across different lettuce varieties, multiple cropping cycles, and varying environmental conditions. Additional research on nutrient interactions, temperature management, and long-term system sustainability could further strengthen nutrient optimization strategies for hydroponic lettuce production in tropical regions.

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