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Relative Growth and Performance of Hydroponic Lettuce in Inorganic and Organic Fertiliser-Based Hydroponic Systems

[1]Adamu Alhassan Amaan; [2]Mangse George and [3]Taofik Olatunde Uthman
[1,2,3]Department of Biochemistry and Biotechnology, Faculty of Science (FOS), Nile University of Nigeria.
amaanalhassan2004@gmail.com / +2349057905681.

Abstract

This paper evaluated the relative growth performance and oxidative stress responses of lettuce (*Lactuca sativa* L.) cultivated in organic and inorganic fertiliser-based hydroponic systems. Four treatments were assessed: Treatment A (Masterblend nutrient solution), Treatment B (Bicgro nutrient solution), Treatment C (composted cow manure tea), and Treatment D (distilled water control). Each treatment consisted of four replicates grown under controlled growth chamber conditions using cocopeat as the growing medium. Growth parameters, including leaf area, leaf number, and leaf height were measured weekly for five weeks, while fresh weight was recorded at harvest. Oxidative stress indicators, which include malondialdehyde (MDA), superoxide dismutase (SOD), and catalase (CAT) activities, were also analysed. The results showed that inorganic nutrient solutions significantly enhanced lettuce growth and yield compared to the organic and control treatments. Treatment B recorded the highest growth performance with superior leaf area 37.30 ± 24.14 cm^2, plant height 3.13 ± 3.54 cm, fresh weight 4.83 ± 5.03 g, and SOD activity 4.939 ± 0.011 U/mL, while treatment A showed the highest catalase activity 27.17 ± 0.29 U/mL. The organic treatment supported moderate growth but performed below the inorganic treatments. Moreover, the control treatment exhibited the lowest growth performance and the highest MDA concentration 0.00626 ± 0.00001 mM, indicating severe oxidative stress and cellular damage caused by nutrient deficiency. However, the findings demonstrate that inorganic hydroponic nutrient solutions provide more efficient nutrient availability for lettuce production, resulting in improved growth, biomass accumulation, and oxidative stress management. Although the organic nutrient solution showed potential as a sustainable alternative, its performance remained comparatively lower than the inorganic systems.

Keyword: Hydroponics, Lettuce (*Lactuca sativa*), Organic fertiliser, Inorganic fertiliser, Oxidative stress.

1.0 Introduction

Hydroponics is a modern method of growing plants without soil, using water enriched with essential nutrients. It helps address challenges such as limited farmland, soil degradation, and inefficient water use (Balogun et al., 2021; Jan et al., 2020). The technique allows precise control of growing conditions, resulting in faster growth and higher yields. Lettuce (*Lactuca sativa L.*) is a preferred hydroponic crop because of its short growth cycle and high market demand (Velazquez-Gonzalez et al., 2022). However, most hydroponic systems rely on inorganic fertilisers, which, although effective, raise environmental concerns and can lead to nitrate accumulation in edible leaves (Martínez-Moreno et al., 2024). Lettuce (*Lactuca sativa L.*) is a member of the Asteraceae family and it is widely recognised as one of the most important leafy vegetable crops in terms of crop value. It is a delicious vegetable that is consumed all over the world due to its crispness, palatability, and high levels of phytonutrients. Lettuce is one of the most widely grown hydroponic vegetables. Additionally, several reports have shown that lettuce has a high yield and good quality when grown in a soilless system (Ahmed et al., 2021).

Recently, organic hydroponics using composted manure tea and other compost-based liquid extracts has gained attention as a sustainable alternative. Hence, the viability of using organic solutions as an alternative in hydroponic systems has been researched on several plants, such as tomatoes, cucumbers, and lettuce, which are popular commercial crops in Nigeria (Adekiya et al., 2022; Phibunwatthanawong & Riddech, 2019).

Inorganic hydroponic systems are designed for maximum yield, but their sustainability and effects on consumer health are still debated. On the other hand, organic hydroponic systems follow ecological principles, yet they often struggle with problems like inconsistent nutrient release and lower yields, which raises questions about their commercial viability. Using composted manure as an organic nutrient source is a more sustainable and safer option than fresh manure, as it lowers the risks of phytotoxicity and pathogen contamination (Folorunso et al., 2023; Szekely & Jijakli, 2022). However, there are still uncertainties about its nutrient availability, solution stability, and overall productivity in hydroponic systems. Consequently, a direct, systematic comparison under controlled conditions is needed to assess the growth and yield trade-offs between a standard inorganic method and a composted organic input. This paper evaluates and compare the growth performance (plant height, leaf number, and area) of lettuce in all treatments (organic and inorganic hydroponic systems), monitor oxidative stress indicators (MDA, SOD, and Catalase) in relation to growth and yield performance, and determine the fresh weight of lettuce from organic and inorganic systems.

2.0 Literature Review

This section presents the review of the related literature of the paper.

2.1 Hydroponic Systems

There are different types of hydroponic systems, the different methods for growing food using hydroponics, and their application depends on the specific plant, local climate, and budget, among other factors (Velazquez-Gonzalez et al., 2022). The different types of hydroponic systems are as follows:

i. Deep water culture: In deep water culture, the roots of the plants are suspended in nutrient-rich water and the roots are aerated using an air stone. The roots of the plants are submerged in the nutrient-rich water, while the top part of the plants is supported above water level using polystyrene, cork bark or wood, among other materials (Jan et al., 2020; Velazquez-Gonzalez et al., 2022).

ii. Drip system: This is the most widely used type of hydroponic system in the world. It uses timers to control submerged pumps. The timer turns the pump on and the nutrient solution is dripped onto the base of each plant by a small drip line. In this system, the nutrient solution is stored in a tank reservoir, and the plants are grown separately in a soilless medium such as cocopeat or composted rice husks (Jan et al., 2020; Shrestha & Dunn, 2025).

iii. Aeroponics System: It is a high-tech system that uses the least amount of water. The plant roots are suspended in an empty tank with pumps and nozzles that mist the roots with the nutrient solution at intervals determined using a timer. The advantage of this system is that it does not require air pumps or stones to aerate the nutrient solution (Velazquez-Gonzalez et al., 2022; Shrestha & Dunn, 2025).

iv. Nutrient Film Technique: In this system, the plant roots aren't fully submerged in water; instead, a steady flow of nutrient solution is pumped to provide a cost-effective way to supply nutrients and ensure access to air for the roots (Velazquez-Gonzalez et al., 2022).

v. Ebb and Flow System: This system works by temporarily flooding the plants' roots with the nutrient solution and relies on gravity to return the solution to the reservoir (Velazquez-Gonzalez et al., 2022; Shrestha & Dunn, 2025).

2.2 Lettuce (*Lactuca sativa*)

Lettuce *(Lactuca sativa)* is a crop that belongs to the Asteraceae family, with its origin in the Mediterranean. It is globally consumed and holds high nutritional and economic value, with a production of 27 million metric tons annually (Shi et al., 2022; Veronica et al., 2025; *World Food and Agriculture – Statistical Pocketbook 2023*, 2023). Valued highly for its high water content and low calorie count, lettuce is widely consumed in many cultures globally. Not only is it an affordable crop, but it is also packed with vitamins, minerals, and bioactive compounds such as polyphenols, carotenoids, and chlorophyll (Shi et al., 2022). Lettuce under optimal growing conditions is usually ready to harvest in 30-45 days, making it a suitable crop for hydroponic systems (Veronica et al., 2025).

Lettuce is globally significant, with ~27 million metric tons annual production. Optimal conditions include pH 5.5–6.5, EC 1.2–2.0 dS m^{-1}, and 18–22°C root zone temperature (Gong et al., 2024; Vought et al., 2024). Furthermore, Table 1, 2 and 3 present the macronutrient, micronutrient, and physical requirements of lettuce.

Table 1. Macronutrient Requirements of Lettuce

Nutrient	Optimised Concentration (mmol·L^{-1})	Converted Value (ppm)	Physiological Role in Lettuce
Nitrogen (N)	~12.0–14.0	168–196 ppm	Leaf expansion, chlorophyll synthesis, biomass accumulation
Phosphorus (P)	2.71	84 ppm	Energy transfer (ATP), root development
Potassium (K)	6.42	251 ppm	Stomatal regulation, enzyme activation
Calcium (Ca)	5.58	224 ppm	Cell wall stability, prevention of tip burn
Magnesium (Mg)	7.11	173 ppm	Chlorophyll structure, enzyme activation

Source: Gong et al., (2024); Vought et al., (2024).

Table 2. Micronutrient Requirements of Lettuce

Micronutrient	Recommended Range (ppm)	Notes on Uptake
Iron (Fe)	2.0–3.0	Low uptake efficiency; chelated forms recommended

Manganese (Mn)	0.5–1.0	Moderate uptake; excess may cause toxicity
Zinc (Zn)	0.05–0.10	Required in trace amounts
Copper (Cu)	0.02–0.05	Essential but toxic at high levels
Boron (B)	0.3–0.6	Cell wall formation and sugar transport

Source: Gong et al., (2024); Vought et al., (2024).

Table 3. Physical Requirements of Lettuce

Parameter	Recommended Range	Scientific Basis
Ph	5.5 – 6.5	Maximises nutrient solubility and uptake
Electrical Conductivity (EC)	1.2 – 2.0 dS m^{-1}	Balances growth rate and stress avoidance
Solution Temperature	18–22 °C	Prevents root stress and nutrient precipitation

Source: Gong et al., (2024); Vought et al., (2024).

2.3 Inorganic Nutrient Solutions in Hydroponics

Inorganic nutrient solutions are obtained from mineral compounds that contain the elemental requirements of plants. These solutions are usually in water-soluble forms and are absorbed by the plants in their ionic forms. The nutrients listed in the previous section are the elements usually found in commercial inorganic nutrient solutions in their ionic forms (Almeselmani, 2022). Some of the commercially available brands of inorganic hydroponic nutrients include: General hydroponics**,** advanced nutrients, Masterblend 4-18-38 Hydroponic Fertiliser, VIVOSUN base A & B Hydroponic Nutrients, Humboldt's secret A & B, and Gro A & B (Bicgro), produced by BIC Farms Concepts, founded in 2006 in Abeokuta, Nigeria. A two-part solution containing calcium nitrate, phosphorus, potassium, and magnesium.

2.4 Organic Nutrient Sources in Hydroponic Systems

Organic nutrient solutions are derived from organic waste, which can be either domestic or agricultural. Unlike inorganic nutrient solutions, organic sources aren’t usually available in ionic forms but have to be broken down by the action of microorganisms or enzymatic activity to make the nutrients available to the plants (Renganathan et al., 2025; Szekely & Jijakli, 2022; Upendri & Karunarathna, 2021).

2.5 Plant Stress Physiology and Reactive Oxygen Species

Plant stress can be triggered by several abiotic factors such as salinity, drought, extreme temperatures, metal toxicity, flooding, UV radiation, and herbicide exposure. Reactive oxygen species (ROS) are generated as a response to these environmental stresses. Usually, ROS are generated in low amounts to regulate plant homeostasis and signalling, but abiotic stresses can trigger an excessive accumulation of ROS. This is referred to as oxidative stress and can cause damage to lipids, proteins, and DNA, which can lead to cell death. A plant's ability to regulate and manage oxidative stress through the use of antioxidants is crucial to its survival (Bano et al., 2022; Chaki et al., 2020).

Abiotic stresses induce reactive oxygen species (ROS), causing lipid peroxidation (measured by MDA), protein/DNA damage. Antioxidant enzymes SOD (dismutates O_2^- to H_2O_2) and CAT (decomposes H_2O_2) mitigate damage (Bano et al., 2022; Chaki et al., 2020). Nutrient imbalances exacerbate this in hydroponics.

2.5.1 Relationship between oxidative stress and lettuce growth

Oxidative stress serves as a physiological constraint on the growth of lettuce (*Lactuca sativa*) due to ROS impairing the growth of the plants. While ROS serves as an important signalling component in plants, its overproduction leads to cellular damage, which results in reduced biomass, shoot and root size, and the overall yield. This can be seen in systems that cultivate stress, such as the NFT system, where root zone hypoxia is induced, which triggers a significant accumulation of hydrogen peroxide (H_2O_2) and markers of lipid peroxidation like malondialdehyde (MDA), which correlates with stunted shoot and root growth. Thus, the growth and productivity of lettuce are linked to the plant's oxidative state (Bano et al., 2022; Sakamoto & Suzuki, 2024).

2.6 Growth Performance of Lettuce under Organic and Inorganic Nutrients

The type of nutrient solution used greatly impacts the growth of lettuce in hydroponic systems. A study comparing fish waste-based organic nutrient solution and a standard inorganic nutrient solution showed that plants grown in organic nutrients had reduced growth over time.

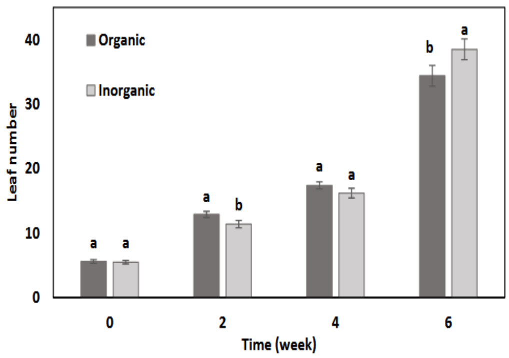


Figure 1: *Lettuce leaf number*

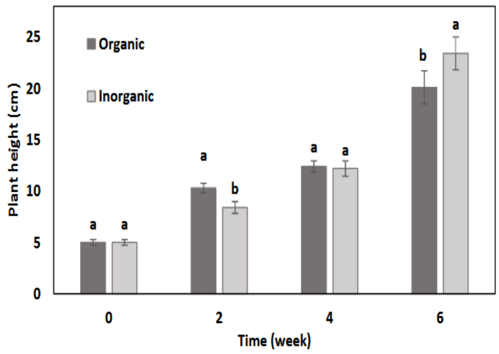


Figure 2: *Lettuce plant height*

Source: *Authors Construct, (2026)*

Figures 1 and 2 show the effect of nutrient solution in a hydroponic system on figure 1 (lettuce leaf number) and on figure 2 (lettuce plant height) (Ahmed et al., 2021).

Although the organic nutrient solution initially promoted a higher leaf count at week two, by harvest (week six), organically grown lettuce had significantly fewer leaves (~34) compared to inorganically grown plants (~38). Similarly, plant height and leaf area were consistently lower in the organic treatment throughout the growth cycle (Ahmed et al., 2021; Frasetya et al., 2021). These differences are due to the composition and nutrient availability of the solutions. Organic nutrient solutions, such as those derived from fish waste, contain nutrients in complex organic forms that require microbial or enzymatic action to break down the complex molecules before becoming plant-available (Frasetya et al., 2021; Szekely & Jijakli, 2022). This process can be irregular and sometimes doesn't match up with plant demand, leading to periods of nutrient deficiency. In contrast, inorganic solutions provide nutrients in readily available mineral forms, which support faster and more uniform growth (Ahmed et al., 2021).

2.7 Yield and Biomass Accumulation

The differences in growth performance are also observed in the overall yield of the lettuce grown in different systems. Lettuce plants grown using the inorganic nutrient solution achieved a significantly higher average fresh shoot weight (182.3 g/plant) compared to those grown with the organic nutrient solution (163.9 g/plant); the difference in root fresh weight was also similar. However, there was little difference between the dry weights from the two solutions, indicating that the weight difference was primarily due to the water content of the fresh weight and biomass, rather than the weight of the structural mass (Ahmed et al., 2021; Frasetya et al., 2021).

This difference in yield is a common challenge in organic hydroponics due to balancing nutrient availability from organic sources being complex. Optimising the mineralisation process and nutrient balance is essential to achieve yields comparable to conventional inorganic hydroponics (Ahmed et al., 2021; Szekely & Jijakli, 2022).

3.0 Methodology

The experiment was conducted under controlled growth chamber conditions using a completely randomized design. Four treatments were established: Treatment A (Masterblend hydroponic nutrient solution), Treatment B (Bicgro hydroponic nutrient solution), Treatment C (composted cow manure tea), and Treatment D (distilled water control). Each treatment consisted of four replicates, giving a total of sixteen experimental units. Rapido 344 lettuce seeds were germinated in pre-wetted cocopeat and transplanted after two weeks into perforated plastic cups containing buffered cocopeat. Nutrient solutions were prepared according to manufacturer recommendations and adjusted to electrical conductivity values close to 1.2 dS m−1. The organic nutrient solution was produced from composted cow manure tea prepared through aqueous extraction and dilution.

Plants were maintained under a 12-hour photoperiod using a 36 W LED light source. Fertigation was performed manually to maintain approximately 70–80% moisture retention within the substrate. Leaf area, leaf number, and plant height were recorded weekly over a five-week growth period. Fresh weight was measured at harvest. Oxidative stress biomarkers were analyzed using standard biochemical procedures. MDA concentration was quantified using the thiobarbituric acid reactive substances assay. SOD activity was determined through inhibition of nitroblue tetrazolium reduction, while CAT activity was measured through hydrogen peroxide decomposition. Data were expressed as mean ± standard deviation and presented graphically using Microsoft Excel.

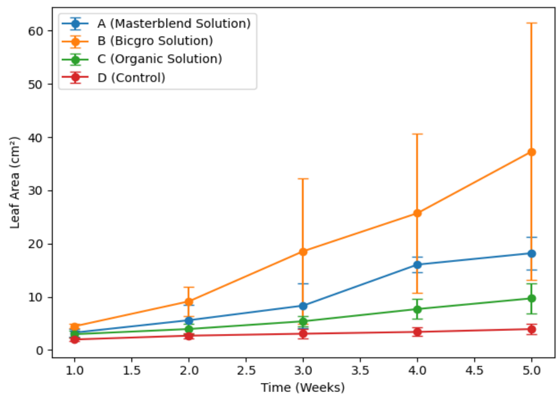
4.0 Results and Discussion

4.1 Results

This section presents the results of the research and the discussion of the findings.

4.1.1 Leaf area and leaf number

Figure 3 shows the Leaf area across 5 weeks. Treatment B showed superior growth (peak ~37 cm²). Order: B > A > C > D. While figure 4 shows the Leaf number with inorganic treatments highest point (~7 leaves).



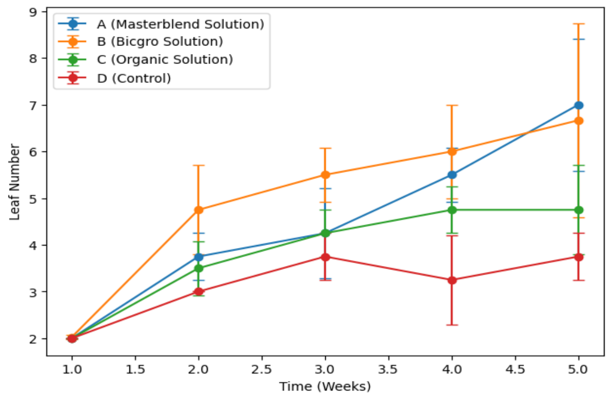


***Figure 3**: Leaf Area* ***Figure 4:** Leaf Number*

***Source:** Authors Construct, (2026)*

The leaf area (y-axis) shows a general trend of an upward increase in size with hydroponic treatments. From the data shown in the multi line graph, it is clear to point out that group B shows the best and optimum response among the other groups in the study. Group D however, shows the worst performance with little to no change as the hydroponic treatment increases. Based on the leaf area group B>A> C>D. Group B boasts the biggest size, while group D is consistently low. Group A (approx. 5-20 cm^2) showed a positive upward trend in leaf area with minimal error bars. This indicates that the treatment provided to leaves in group A provided steady growth and stability. The large increase in the leaf area shown when hydroponic treatment is between 3.0 and 3.5 may be indicative of a threshold region where the leaves respond optimally to the treatment. Group B (approx. 5-40 cm^2) displays the best response to the hydroponic treatment; however shows large error gaps after the 2.5 mark on the x-axis. This may be as a result of wildly varying data for the areas of the leaves or a small sample size. Group C (approx. 3-10 cm^2) shows a slow but consistent increase with minimal error bars. This indicates the treatment was effective and had a positive impact on the growth of the plants.

For Figure 4, the Leaf number shows a generally upward trend as the hydroponic treatment increases. Group A and B both show the highest number of leaves as the treatment increases while group D shows the least. At the peak of the hydroponic treatment the highest to the lowest number of leaves is as follows: A>B>C >D. Group A indicated by the blue line shows a steady increase in the number of leaves from 2 to 7, the presence of a large error bar indicates the discrepancy between the leaf number within the group, some plants may have had higher numbers of leaves and some plants may have had a lower number of leaves. Group B indicated by the orange line is a close second, which shows the number of leaves rising from 2- approx. 7, the error bar shown in the data above is for the same reason stated earlier. Group C indicated by the green line shows a steady increase in the number of leaves, the leaves increase from 2- approx. 5 in number. The error bars for group C are smaller than the ones observed in groups A and B, this indicates that the number of leaves across the plants in that group were closer to the mean value. Group D indicated by the red line shows the least amount of leaf numbers across the hydroponic treatment, with a steady increase from 1.0-3.0, then a sharp decline in the number of leaves at 4.0, this may be as a result of the treatment being ineffective around that range, at 5.0 the number of leaves went back up finishing at approximately 4, barely just doubling its total.

4.1.2 Leaf height

Figure 5 shows the Leaf height where B (Bicgro Solution) is the highest (~13 cm).

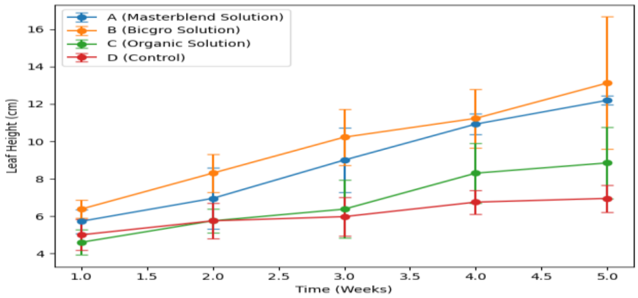
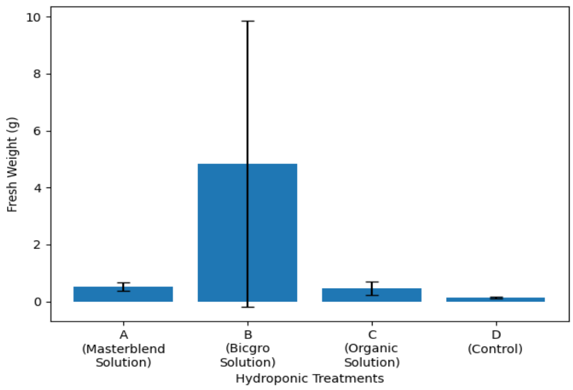


Figure 5: *Leaf height of lettuce in hydroponic treatments across 5 weeks.*
Source: *Authors Construct, (2026).*

Leaf height shows an upward trend for all the groups in the study. Group B has the longest leaf height while group D has the shortest leaf height. The leaf height from highest to lowest is as followed: B>A>C>D. Group A indicated by the blue line shows a steady increase in leaf height of approximately 6cm to approximately 12 cm across the given hydroponic treatment, the error bars are marginal in this group except for 3.0 on the x-axis which indicates a huge discrepancy in the height of the leaves within that group, the treatment given to group A shows increasing leaf height which means the treatment steadily improves leaf growth. Group B indicated by the orange line shows a steady increase in leaf height with small error bars on all the hydroponic treatment except for 5.0 which shows a large error bar. Group B shows an increase in leaf height from approximately 6 cm to approximately 13cm which shows the treatment favored rapid increase in leaf height across the group. Group C indicated by the green line shows a fairly steady increase in leaf height, the leaves are in the range of approximately 5 cm to approximately 8 cm in height, this indicates the treatment for group C works but it is not as effective as group B and A. Group D shows the worst leaf height among the groups, the leaf height ranges from approximately 5 cm to 7 cm, this barely shows an increase in leaf height across the hydroponic treatment.

4.1.3 Fresh weight and MDA concentration

Figure 6 show the fresh weight of lettuce in hydroponic treatment with the B (Bicgro Solution): 4.83 ± 5.03g being the highest and D (Control), the lowest. While for MDA connection, D is the highest (0.00626 mM) indicating severe stress.



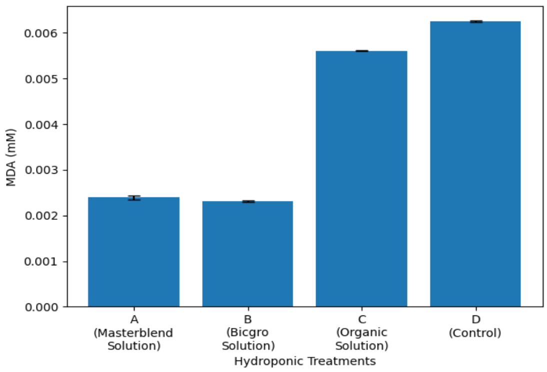


Figure 6: Fresh weight of lettuce in hydroponic treatments

Figure 7: MDA concentration of lettuce in hydroponic treatments

Source: *Authors Construct, (2026).*

Figure 6 shows a bar chart with error bars showcasing the relationship between the fresh weight in grams and the hydroponic treatment. According to the data, group B has a fresh weight of approximately 5 g grams this shows that the hydroponic treatment for group B promotes healthy growth of plants and provides abundant nutrients, however the error bar for group B is large this can be explained by having a small sample size or large differences between the fresh weight in the group . The remaining groups have relatively low mass fresh weight compared to group B, it can be interpreted as the treatments not providing as much nutrients compared to group B treatments.

Furthermore, in Figure 7, MDA refers to malondialdehyde, measured in millimoles per litre. The MDA value of group D is the highest with approximately 0.006 mM, this relatively high value of MDA indicates destructive degradation or cellular damage that happens in cells due to the effects of free radicals or oxidative stress, it shows that the plants in that group did not handle oxidative stress as well as group A and B.

4.1.4 Catalase and SOD concentrations

Figure 8 shows CAT with A (masterblend solution) being the highest (27.17 U/mL). While Figure 9 presents SOD with B (Bicgro solution) as the highest (4.939 U/mL).

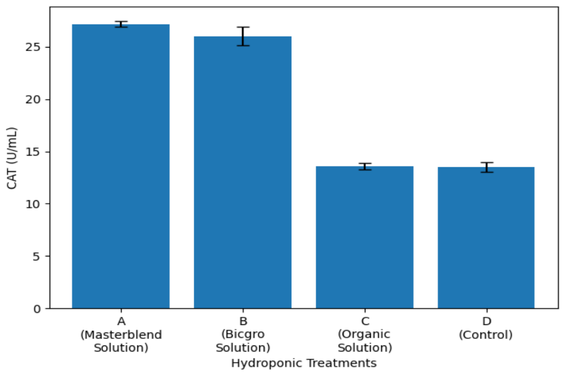


Figure 8: Catalase concentration of lettuce in hydroponic treatments

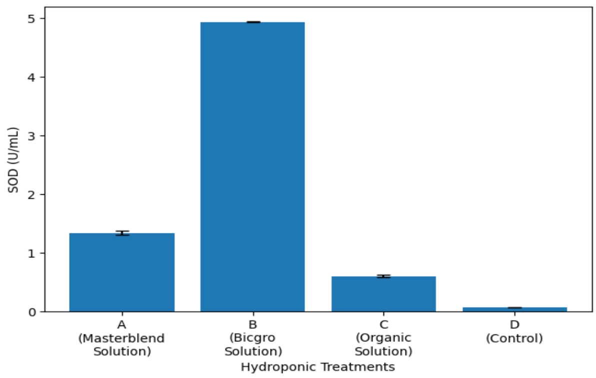


Figure 9: SOD concentration of lettuce in hydroponic treatments

Source: Authors Construct, (2026).

Figure 8 shows the catalase activity (CAT) measured in units per milliliter, group A displays the highest value with approximately 27 U/mL, this indicates group A having antioxidant property within this parameter compared to the other groups. Group C and D are approximately equal and possess lower oxidative property compared to group A. While figure 9 shows the superoxide dismutase (SOD) of the different hydroponic treatments, group B displays the highest value of approximately 5 U/mL which indicates a higher antioxidant capacity to combat oxidative stress. Group A follows as second, having a SOD value of approximately 1 U/mL, group C and D are below 1 U/mL

4.2 Discussion

The results of this paper is discussed in the subsequent sections.

4.2.1 Growth Performance

The results from the growth performance indicated that the inorganic treatments A (Masterblend solution) and B (Bicgro solution) outperformed treatment C (Cow manure tea) and treatment D (control), with treatment B being the best performing group with a final leaf area of 37.30 ± 24.14cm^2, and a final leaf height of 13.13 ± 3.54cm. Treatment A was the second-best result with a final leaf area of 18.20 ± 3.12cm^2 and a final leaf height of 12.20 ± 0.24 m. Treatment C performed considerably less than the aforementioned treatments with a leaf area of 9.71 ± 2.85cm^2, and a leaf height of 8.85 ± 1.91cm. Treatment D (control) showed minimal growth throughout the course of the study which could be attributed to the absence of mineral nutrients in distilled water. These findings are consistent with those of Ahmed et al. (2021), who reported significantly greater leaf counts, leaf area, and shoot biomass in inorganically fertilised hydroponic lettuce compared to organically fertilised lettuce.

The superior growth performance of the inorganic groups could be attributed to the bioavailability of mineral nutrients in the solutions which allowed easier uptake of nutrients in those groups (Almeselmani, 2022). Nitrogen which is vital to the vegetative growth of lettuce is readily available in nutrient formulations such as Masterblend and Bicgro, these solutions supply nitrogen at 168–196 ppm, which is the optimal range for lettuce growth and is consistent with most inorganic formulations (Gong et al., 2024; Vought et al., 2024).

Interestingly, treatment B slightly outperformed treatment A despite having the same EC (~1.2 dS/m). The differences in the micro and macro nutrient ratios could be the cause of the disparity between the groups, variability between inorganic solutions has been shown to influence lettuce growth and yield (Martínez-Moreno et al., 2024; Velazquez-Gonzalez et al., 2022). Unlike treatments A and B, treatment C exhibited poor growth performance, with the difference in nutrient bioavailability being the root cause; organic nutrients require enzymatic mineralisation of organic compounds by microorganisms to make them bioavailable to plants. Thus inhibiting the growth of lettuce due to varying availability of nutrients in the solution (Renganathan et al., 2025; Szekely & Jijakli, 2022).

Treatment D showed a small drop in leaf number at week 4. This happens when a plant runs out of nutrients entirely with treatment D having no nutrients in the solution to begin with. Chlorosis sets in, and the older leaves begin to die off (Phibunwatthanawong & Riddech, 2019).

4.2.2 Yield Performance

The highest fresh weight was recorded from treatment B (4.83 ± 5.03g) and the lowest was treatment D (0.13 ± 0.03g) which is supported by studies that show a proportional relationship between plant mass and bioavailable nutrients. Ahmed et al. (2021) reported 182.3g per plant for inorganic and 163.9g for organic lettuce at a far larger scale. The proportional gap between organic and inorganic treatments is comparable to the observed results in the study. Large error bars were present in treatment B despite being exposed to the same conditions; this is likely due to high biological variability within a small sample size (n=4) and not an issue with the solution itself (Folorunso et al., 2023).

4.2.3 MDA as an Indicator of Oxidative Stress

The highest MDA levels were observed in treatment D (0.00626 ± 0.00001 mM) indicating high lipid peroxidation and oxidative membrane damage. Lack of bioavailable nutrients causes progressive stress and brings about the accumulation of reactive oxygen species (ROS), which overwhelms the antioxidant system of the lettuce plants and causes lipid peroxidation (Bano et al., 2022; Chaki et al., 2020; Olaitan et al., 2022). Observed lower MDA levels in Treatments A and B confirm that adequate availability of nutrition maintains cellular homeostasis and reduces antioxidant enzyme burden (Yavuz et al., 2021).

Furthermore, studies have shown that MDA concentrations correlate inversely with lettuce growth performance which matches the high MDA levels compared to the poor growth and yield performance of treatment C and D (Tomov et al., 2021). Although treatment C's performance was better than treatment D, which suggests the organic nutrient supply in treatment C slightly buffered oxidative stress (Renganathan et al., 2025; Szekely & Jijakli, 2022).

4.2.4 Catalase Activity

Treatment A showed the highest catalase activity (27.17 ± 0.29 U/mL), even higher than treatment B, which displayed better growth compared to treatment A. ROS signaling theory explains the observation: when plants face moderate oxidative stress, they boost catalase activity to break H_2O_2, which is a byproduct of photorespiration and nitrogen assimilation (Bano et al., 2022). Therefore, Treatment A's high catalase activity likely arises from a higher oxidative load. Nitrate-nitrogen assimilation naturally produces H_2O_2 as a side effect (Sakamoto & Suzuki, 2024).

As for Treatment D, its low catalase levels suggest the antioxidant system was overwhelmed rather than upregulated, given the high MDA values. Treatment C showed moderate catalase levels, pointing to partial antioxidant activation under the slower release of organic nitrogen (Tomov et al., 2021).

4.2.5 SOD Activity

The highest SOD activity was observed in treatment B (4.939 ± 0.011 U/mL), with treatment A following behind (1.343 ± 0.034 U/mL), and treatments C and D being the lowest in SOD activity. SOD is a plant's first response to superoxide radicals, it's upregulation is prevalent in high-performing plants as higher metabolic activity generates more ROS which is mitigated by a higher production of SOD (Bano et al., 2022; Sakamoto & Suzuki, 2024). This is supported by Tomov et al. (2021), who found higher SOD activity in lettuce varieties under better nutrient regimes. Low SOD in Treatment D was likely due to the failure of antioxidant induction under severe nutrient deprivation (Bano et al., 2022).

5.0 Conclusion and Recommendation

This papar has been able to successfully test the plant growth and antioxidant properties of various groups of plants following hydroponic treatments given over a period of time. From the data, it can be concluded that group B which was given Bicgro solution, performed the best when it came to leaf area, leaf height, fresh weight, superoxide dismutase, and the lowest level of malondialdehyde which indicates minimal cellular damage. Treatment B demonstrated a healthy and larger leaf size and better protection against free radicals. In close second is treatment A which is the Masterblend solution, group A demonstrated the highest leaf number among the groups involved in the study and the highest catalase activity (CAT) value compared to the other groups. Group C which was the organic group ranked third in leaf area, leaf height, leaf size, leaf number, SOD and CAT, and it showed the third-best malondialdehyde value compared to the other groups. The worst performing group was the control group, which had the lowest value across all the metrics and showed the most cellular damage according to the malondialdehyde value. This paper was able to show that plants respond well with Bicgro hydroponic treatment which improved plant health, increased growth and vitality. Also, it can be concluded that while treatment C produced uniform results, it cannot be compared to the growth performance of inorganic treatments for the cultivation of lettuce in hydroponic systems.

Future studies should evaluate different electrical conductivity (EC) levels and fertigation schedules to determine the optimum nutrient concentration for maximising lettuce growth, yield, and quality in hydroponic systems. Further research should also investigate additional physiological and biochemical parameters such as chlorophyll content, photosynthetic efficiency, root development, nutrient uptake, and other antioxidant enzymes to provide a deeper understanding of the effects of nutrient treatments on lettuce physiology. In addition, large-scale greenhouse and commercial production trials are recommended to validate the findings obtained under controlled growth chamber conditions. Finally, future work should compare the long-term sustainability, nutrient use efficiency, economic feasibility, and environmental impact of inorganic hydroponic fertilisers and organic nutrient solutions in lettuce production systems.

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