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Effects of a TDS Sensor-Based Nutrient Automation System on Leaf Area and Plant Height of Lettuce (Lacctuca sativa L.) in Hidroponic Cultivation

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Kata Kunci :

Hidroponik; Sensor TDS; Otomatisasi Nutrisi; *Lactuca sativa*; Pertumbuhan Tanaman

Abstrak

Pemantauan nutrisi secara manual pada sistem budidaya hidroponik dinilai tidak efisien dan rentan menghasilkan data yang tidak konsisten, sehingga diperlukan sistem otomatisasi berbasis sensor untuk menjaga kestabilan konsentrasi nutrisi larutan. Penelitian ini bertujuan untuk menganalisis pengaruh sistem otomatisasi nutrisi berbasis sensor *Total Dissolved Solids* (TDS) terhadap luas daun dan tinggi tanaman selada (*Lactuca sativa* L.) pada sistem budidaya hidroponik. Penelitian ini menggunakan pendekatan eksperimen dengan membandingkan dua kelompok tanaman selada, yaitu kelompok perlakuan yang dibudidayakan menggunakan sistem otomatisasi berbasis sensor TDS dan kelompok kontrol yang dibudidayakan melalui pemantauan manual konvensional. Luas daun dan tinggi tanaman diukur pada masa panen empat minggu setelah penanaman. Hasil penelitian menunjukkan bahwa sistem otomatisasi memberikan pengaruh positif yang signifikan terhadap kedua parameter pertumbuhan. Rata-rata luas daun meningkat sebesar 64,24% dari 260,18 cm^2 menjadi 427,33 cm^2, dan rata-rata tinggi tanaman meningkat sebesar 19,71% dari 22,022 cm menjadi 26,355 cm. Temuan ini mengindikasikan bahwa sistem otomatisasi nutrisi berbasis sensor TDS secara efektif menjaga kestabilan konsentrasi nutrisi larutan, sehingga mendukung pertumbuhan vegetatif tanaman selada hidroponik secara optimal dibandingkan metode pemantauan manual.

Keywords :

Hydroponics; TDS Sensor; Nutrient Automation; Lactuca Sativa; Plant Growth

Abstract

Manual nutrient monitoring in hydroponic cultivation systems is considered inefficient and prone to producing inconsistent data, necessitating sensor-based automation systems to maintain the stability of nutrient solution concentration. This study aims to analyze the effect of a Total Dissolved Solids (TDS) sensor-based nutrient automation *system on leaf area and plant height of lettuce (*Lactuca sativa *L.) in a hydroponic cultivation system. This study employed an experimental approach comparing two groups of lettuce plants: a treatment group cultivated using the TDS sensor-based automation system and a control group cultivated through conventional manual monitoring. Leaf area and plant height were measured at harvest time four weeks after planting. The results demonstrated that the automation system exerted a significant positive effect on both growth parameters. The mean leaf area increased by 64.24% from 260.18 cm² to 427.33 cm², and the mean plant height increased by 19.71% from 22.022 cm to 26.355 cm. These findings indicate that the TDS sensor-based nutrient automation system effectively maintained nutrient solution concentration stability, thereby supporting optimal vegetative growth of hydroponic lettuce compared to manual monitoring methods.*

INTRODUCTION

The introduction The agricultural sector faces increasingly complex challenges amid global population growth and the progressive reduction of available agricultural land due to conversion into residential and industrial areas (Gultom & Harianto, 2022). This condition has driven the development of alternative cultivation methods that are more efficient in land utilization while capable of producing optimal yields. One rapidly evolving method is the hydroponic cultivation system, a soil-free planting technique that utilizes water, oxygen, and mineral nutrients as the primary growth medium for plants (Silva & Uchida, 2015). Hydroponic systems are particularly suitable for urban environments because they can be implemented on limited land and yield higher productivity compared to conventional agriculture.

Lettuce (*Lactuca sativa* L.) is one of the most widely cultivated horticultural commodities in hydroponic systems due to its relatively short growth cycle of 30–45 days, high economic value, and consistent market demand (Lestari et al., 2016). Lettuce is highly sensitive to fluctuations in nutrient solution concentration, making nutrient stability a determinant factor in the success of its cultivation. The success of lettuce growth in hydroponic systems is largely determined by the stability of nutrient solution concentration expressed in Total Dissolved Solids (TDS) units. Optimal growth of hydroponic lettuce is generally achieved within a TDS range of 560–840 ppm during the early growth phase and increases to 840–1200 ppm during the vegetative phase approaching harvest (Putri et al., 2025).

The primary challenge in hydroponic cultivation is the limitation in continuously and accurately monitoring and controlling nutrient solution concentration. Most conventional hydroponic systems still rely on periodic manual TDS measurement using handheld measuring instruments. This manual procedure is considered inefficient as it requires substantial time and effort, and is susceptible to producing inconsistent data due to temporal gaps in implementing corrective actions regarding nutrient solution conditions, potentially exposing plants to nutrient deficiency or excess over certain periods (Thakur et al., 2023).

With the advancement of Internet of Things (IoT) technology, the development of sensor-based monitoring and automation systems has become a highly relevant solution to overcome these limitations. TDS sensors are no longer solely utilized as local measuring instruments but are integrated with microcontrollers and actuator systems to form automatic control systems capable of maintaining nutrient solution concentration stability continuously (Harsono, 2020). Faisal et al. (2025) reported that the implementation of IoT-based monitoring systems using pH and TDS sensors in hydroponic systems significantly improved nutrient management efficiency and substantially reduced manual involvement.

Research conducted by Aini et al. (2025) demonstrated that the application of IoT-based TDS sensors significantly enhanced the growth and harvest yield of green lettuce (*Lactuca sativa* L.) in hydroponic systems, encompassing increases in plant height, leaf count, leaf area, fresh weight, and dry weight compared to conventional methods. Similarly, Adidrana & Surantha (2019) developed an IoT-based hydroponic nutrient control system that successfully maintained nutrient concentrations within the optimal range automatically. Although various studies have examined the influence of sensor-based nutrient monitoring on hydroponic plant growth, research that comprehensively evaluates the effect of TDS sensor-based nutrient automation systems on four growth parameters of lettuce simultaneously, namely leaf area, plant height, fresh weight, and dry weight, remains limited in the available literature.

Based on the aforementioned discussion, this study aims to analyze the effect of a TDS sensor-based nutrient automation system on the growth parameters of lettuce (*Lactuca sativa* L.) in hydroponic cultivation, encompassing leaf area, plant height, fresh weight, and dry weight. The findings of this study are expected to provide scientific contributions regarding the effectiveness of TDS sensor-based nutrient automation systems in supporting the improvement of hydroponic lettuce cultivation productivity.

METHODS

Materials And Equipment

The nutrient automation system developed in this study comprised a TDS sensor as the nutrient solution concentration measuring device, an ATmega328P-based Arduino Nano microcontroller as the main system controller, a relay module as the actuator controller, a DC 12-volt pump as the nutrient solution addition actuator, and a 12V 10A power supply as the primary power source for the entire system. Materials used included *Lactuca sativa* L. variety seeds, AB Mix nutrient solution, rockwool growing medium, and water as nutrient solvent. A digital TDS meter was used as a standard measuring instrument to validate TDS sensor readings

Research Design

This study employed an experimental approach comparing two separately cultivated groups of lettuce plants. The first group was the treatment group cultivated using the TDS sensor-based nutrient automation system, while the second group was the control group cultivated without the automation system using conventional manual monitoring methods. Each group consisted of nine individual plant samples. The hydroponic system utilized was the Deep Flow Technique (DFT), in which nutrient solution circulates continuously within a closed system.

Operation Of The Automation System

The nutrient automation system operates based on an on-off control mechanism. The TDS sensor continuously reads the total dissolved solids concentration in the nutrient solution and produces an analog voltage output that is converted to parts per million (ppm) units by the Arduino Nano microcontroller. When the TDS value is detected below the predetermined setpoint value, the Arduino Nano sends a control signal to the relay module to automatically activate the DC 12-volt pump to add nutrient solution to the system. The pump automatically ceases operation once the TDS value returns to the optimal range. In the control group, nutrient solution addition was performed manually based on periodic measurements using a handheld TDS meter.

Growth Parameters Observed

All growth parameters were measured at harvest time four weeks after planting. The parameters observed included the following. First, plant height was measured using a ruler from the base of the stem to the tip of the tallest leaf and recorded in centimeters (cm). Second, leaf area was determined through the gravimetric method using the following equation:

$$\text{Leaf Area} = \frac{Leaf\ Weight\ x\ Paper\ Area}{Paper\ Weight} \quad (1)$$

Where leaf weight is the mass of all plant leaves weighed in grams, paper area is the known area of the reference paper in cm², and paper weight is the mass of the reference paper in grams. Third, fresh weight was measured by weighing all fresh plant parts immediately after harvest before water evaporation occurred, and recorded in milligrams (mg). Fourth, dry weight was measured after all plant parts were dried in an oven at 60°C for 48 hours until the weight stabilized, then weighed and recorded in grams (g).

Data Analysis

The growth parameter measurement data were analyzed descriptively by calculating the mean value and percentage increase between the treatment and control groups. The percentage I ncrease was calculated using the following equation:

$$\text{Increase}(\%) = \frac{Mean\ with\ device - Mean\ without\ device}{Mean\ without\ device} \times 100\% \quad (1)$$

RESULT AND DISCUSSION

The measurement results of all growth parameters of lettuce (*Lactuca sativa* L.) in both treatment groups are presented in Table 1.

Table 1. Growth Data of Lettuce (*Lactuca sativa* L.)

Sample	**Leaf Area (cm^2)**		**Plant Height (cm)**	
	Without Device	**With Device**	**Without Device**	**With Device**
1	183,9	467,7	22,7	28,6
2	356,7	420,5	24,5	25,9
3	253,6	519,8	20,3	29,8
4	228,7	411,9	20,2	26,2
5	191,3	378,2	22,4	25,8
6	335,7	530,1	21,6	30,1
7	218,4	415,1	22,0	25,6
8	356,7	421,1	24,0	22
9	216,2	281,2	20,5	23,2
Total	2.341,6	3.845,9	198,2	237,2
Mean	260,1	427,3	22,0	26,3

The leaf area measurements revealed that the mean leaf area in the treatment group was 427.3 cm², significantly higher than the control group at 260.1 cm², representing a percentage increase of 64.2%. The highest leaf area value in the treatment group was recorded in sample 6 at 530.1 cm², while the lowest was recorded in sample 9 at 281.2 cm². This substantial increase in leaf area indicates that the automation system successfully maintained nutrient solution concentration within the range that optimally supports the photosynthesis process. Leaves with greater surface area possess a higher capacity for solar radiation absorption to facilitate photosynthesis, thereby producing more optimal vegetative growth (Vauzia et al., 2019). This finding is consistent with the results of Aini et al. (2025), who demonstrated that the use of IoT-based TDS sensors produced a significant increase in the leaf area parameter of hydroponic lettuce compared to conventional methods.

Individual variation within the dataset warrants brief acknowledgment. The leaf area value recorded for control sample 2 (356.75 cm²) exceeded that of treatment sample 9 (281.28 cm²). This localized inversion does not invalidate the overall treatment effect, as it is attributable to intrinsic biological variability, including genotypic differences among seed individuals, positional heterogeneity in radiation and solution flow distribution within the hydroponic infrastructure, and differential germination vigor (Asprillia et al., 2018). Such inter-individual variation is a recognized characteristic of biological experimental systems and does not preclude the drawing of valid group-level inferences from mean comparisons (Aini et al., 2025).

The mean plant height in the treatment group at 26.3 cm was higher than the control group at 22.0 cm, yielding a percentage increase of 19.7%. Plant height growth is strongly influenced by the availability of macronutrients, particularly nitrogen, which plays a critical role in chlorophyll synthesis and supports vegetative plant growth (Nugroho, 2015). The nutrient concentration stability maintained by the TDS sensor-based automation system ensures the continuous availability of nitrogen in sufficient quantities, thereby optimally supporting the vertical growth of plants. This 19.7% increase in plant height is consistent with the findings of Adidrana & Surantha (2019), who reported that IoT-based automatic nutrient control systems significantly enhanced vegetative growth of hydroponic plants.

It is noteworthy that individual data variation was observed in sample 8, where plant height in the control group at 24,0 cm was higher than in the treatment group at 22,0 cm. This reversal is interpretable through the lens of individual biological variation rather than systemic treatment failure. Germination vigor, which influences the rate of early root establishment and nutrient absorption capacity, varies among seeds even within a single batch due to subtle differences in seed maturity, storage conditions, and epigenetic programming (Asprillia et al., 2018). A control plant with exceptionally high germination vigor may therefore exhibit growth trajectories that temporarily or permanently exceed those of treatment group plants with below-average vigor, even in the presence of optimized nutrient delivery. This interpretation is consistent with the broader scientific understanding that within-group biological variation is an expected feature of agronomic field trials and does not compromise the validity of mean-level comparisons across groups (Aini et al., 2025).

A comparative summary of all growth parameters between both treatment groups is presented in Table 2.

Table 2. Summary of Growth Parameter Increases in Lettuce Plants

Parameter	Without Device	With Device	Increase (%)
Leaf Area (cm²)	260,1	427,3	64,2%
Plant Height (cm)	22,0	26,3	19,7%

Based on Table 2, the highest increase was observed in leaf area at 64.24% and plant height at 19.71%. This ranking of increases reflects that the nutrient automation system exerted the greatest impact on plant metabolic processes and biomass accumulation, as evidenced by leaf area parameter. This indicates that the nutrient concentration stability automatically maintained by the TDS sensor directly enhanced the efficiency of plant physiological processes, including photosynthesis, respiration, and assimilate translocation (Hasanah et al., 2020).

From an agronomic perspective, the 64.2% improvement in mean leaf area carries substantial commercial relevance for hydroponic lettuce production, where fresh weight yield and leaf presentation are primary determinants of market value. A broader photosynthetic surface also establishes the productive capacity for continued growth in longer cultivation cycles or subsequent replanting, contributing to the systemic efficiency of the hydroponic operation. These findings are consistent with those of Faisal et al. (2025), who emphasized that IoT-enabled hydroponic management platforms improve nutrient delivery precision and reduce operational labor, translating directly into enhanced agronomic outcomes. Collectively, the evidence presented in this study supports the adoption of TDS sensor-based automation as a scalable and operationally accessible strategy for improving lettuce productivity in hydroponic systems across a range of cultivation scales.

CONCLUSION

This study demonstrates that the implementation of a TDS sensor-based nutrient automation system produced significant and consistent improvements in both leaf area and plant height of hydroponically cultivated lettuce (*Lactuca sativa* L.) relative to conventional manual nutrient management. Mean leaf area in the treatment group reached 427.33 cm^2, representing a 64.24% increase over the control mean of 260.18 cm^2, while mean plant height increased by 19.71% from 22.022 cm to 26.355 cm. The disproportionately greater enhancement of leaf area compared to plant height indicates that lateral vegetative development is more acutely sensitive to nutrient supply continuity than apical extension, a finding with direct implications for optimizing yield parameters that depend on leaf surface area. The automated system achieved these outcomes by maintaining TDS concentration within the physiologically optimal range autonomously, precluding the nutrient shortfalls inherent in periodic manual monitoring. These results confirm that TDS-based automation represents an effective, scalable, and agronomically beneficial approach to hydroponic nutrient management and supports its broader adoption in precision horticultural production systems.

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