Automated vs. Semi-Automated Hydroponics: Quantifying Automation Effects on Plant Growth

Original Scientific Paper

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Abstract *– The issue of hydroponic farming is the ongoing requirement to maintain and control the artificial growing environment to enable optimal plant growth. The quality of the plants growing on the farm can be significantly impacted by changes in the climate, natural light, and fertilizer solution at any time during the plant's growth cycle. According to studies, every 3°C increase in ambient temperature from the optimal range reduces crop productivity by 10 to 40%. Therefore, by automatically supplying ideal growth conditions throughout the growing cycle, IoT-based automation is crucial to achieving optimal plant growth. In this work, lettuce is grown simultaneously in two distinct hydroponic Nutrient Film Technique (NFT) systems, one of which is fully automated and the other semi-automated. In terms of plant growth metrics, such as plant elevation, maximum plant length, maximum plant breadth, and weight of both fresh and dry-farmed lettuce, this paper compared a fully automated farm and a semi-automated NFT farm for growing lettuce. The outcomes demonstrate that the ariel weight of fresh and dry lettuce and root weight of fresh and dry lettuce had average improvements of 10.4 gm, 0.7 gm, 0.11 gm, 0.7 gm, and 3, respectively in the fully automated setup. Findings also demonstrated that IoT-based automation enhances the growth of lettuce plants on farms when comparing a completely automatic hydroponic farm to a semi-automatic hydroponic farm, in terms of plant height, width, and total leaf count.*

Keywords: *hydroponics, automation, IoT, nutrient control, dosing, weather control*

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1. INTRODUCTION

For many nations around the world, farming is an essential component of their economies. However, the capacity of conventional soil-based farming (SBF) to produce crops has been negatively impacted by the recent linear increases in population, urbanization, and food demands, as well as the concurrent drop in the amount of land and water available for farming. The disparity between the availability and demand of food is gradually widening, over time [1]. One of the biggest problems SBF has is that there are not enough resources to meet the growing demand for food, such as fertile land and water, which are essential for farming. Therefore, using the resources at hand, a smart agriculture technique is required that can produce higher yields than SBF. The majority of traditional farming's issues can be resolved with hydroponics, a branch of precision farming [1, 2].

Traditional agriculture faces challenges like climate change, soil degradation, water scarcity, labour shortages, and pathogen contamination, which impact crop yields and farming practices. Hydroponic farming addresses these issues by using soil-less systems that conserve water, eliminate soil-related problems, and allow for precise climate control. Automation and IoT technologies enhance labour efficiency, while controlled environments reduce exposure to pathogens, ensuring safer produce. This makes hydroponics a sustainable alternative to traditional farming [3]. Throughout the crop's growth cycle, HF must continuously monitor and maintain artificial climate conditions to replicate traditional weather and soil conditions. Manually monitoring and controlling weather, light, and nutrient conditions could lead to human error and a divergence from the ideal requirements. Taking this into account, to attain the required crop quality, the process of maintaining the artificial growing environment must be automated. One such method is the Internet of Things (IoT), which enables the HF to employ sensors, controls, and actuators to maintain its ambient conditions [3-6]. By continuously monitoring growth parameters and sending on/off signals to actuators connected to devices whenever any parameter goes outside of the ideal range, IoT technology enables precision agriculture in HF.

The research questions that motivated the basis of this study were: i. Effectiveness of the manual and semi-automated farm in maintaining artificial growth environment, ii. The effectiveness of a fully automated IoT farm in maintaining the artificial growth environment and iii. The difference is the crop quality harvested from semi-automated and fully automated farms. The objective of this study is to experimentally compare and study the effectiveness of IoT automation on the hydroponic farm for maintaining the growth parameters and the eventually harvested crop products. This study compares the crop production quality attained in two types of hydroponic farms: a fully automated hydroponic farm setup (FAHS), where the IoT setup maintains all climate conditions without the need for human intervention, and a semi-automated hydroponic farm setup (SAHS), where sensors are installed for remote farm monitoring but the farm owner is still responsible for controlling and maintaining the conditions [6]. A comparison of the following growth parameters was conducted after a 30-day growth cycle of lettuce crops planted simultaneously in FAHS and SAHS: Plant Elevation (PE), Maximum Plant Breadth (MPB), Ariel Weight of Fresh Lettuce (AW-FL), Root Weight of Fresh Lettuce (RW-FL), Ariel Weight of Dry Lettuce (AW-DL), Root Weight of Dry Lettuce (RW-DL), and Total Leaf Count (TLC). Following that, an analysis of the data from SAHS and FAHS was conducted to investigate the effects of semi-automation and complete automation on plant development [7].

The structure of this paper is as follows: The FAHS and SAHS systems utilized in this study are introduced in Section 1. In the second section, a thorough analysis of previous research papers that compare various automated HFs has been provided. Section 3 discusses the experimental setup's approach as well as the comparison parameters. The experimental analysis and comparison of the observed growth parameters are presented in Section 4. This section compares the quantitative findings for the growth metrics for both mediums, Finally, section 5 concludes the study's findings and future directions.

2. LITERATURE REVIEW

An extensive review of the literature on automated and semi-automated farms was conducted, focussing on evaluating the efficacy of artificial vs substrate media for hydroponic farms. Experimental analysis has been carried out by researchers and developers to investigate the impact of varying degrees of automation on the quality of hydroponic crop production.

To produce lettuce, the research work [12] compared the performance of conventional soil-based growing farms and commercial hydroponic farms. An analysis was conducted on the productivity of lettuce in hydroponic systems and alternative soil-based systems, as well as the financial advantages of a greenhouse farm. Even though the hydroponic farm used less than 50% of the water utilized by the soil-based farm, the output acquired by the former was 134% of the yield obtained by the latter throughout two growth cycles of lettuce grown in identical greenhouses. The hydroponic farm's initial investment and overall running costs [8] were, respectively, 21.76 times and 47% greater than those of the conventional farm. The hydroponic farm produced lettuce with superior overall quality and performance than the traditional farm, despite the automated farm requiring higher capital and operational costs.

The growth performance of a crop of romaine lettuce in a fully automated hydroponic setup was compared to that of a crop grown in an uncontrolled, non-automated hydroponic plant by the authors in their study [9]. The following metrics were used to measure and assess the plant growth in a single harvest cycle, or 30 days: plant height, maximum leaf length and width, and the weight of the farmed plant. The controlled and automated arrangement produced a greater yield and better-quality growth in terms of weight, height, and leaf count, according to the growth findings collected from both setups. The parameters recorded in the automated setup remained in the optimal range throughout the 30-day development cycle, while the non-automated configuration required manual interference to keep the growth environment parameters (temperature, humidity, pH, and TDS) in the optimal range.

A low-cost Arduino system was used in [3] to track and maintain the aquaponics setup's growth parameters automatically. The farm's irrigation, humidity, and temperature controls were automated to maximize growing production and make frugal use of the resources at hand. When compared to the traditional arrangement, the results showed a boost in leaf yield of over 40% in the automated farm and a 400-fold increase in cultivable area density in the automated setup.

Using fuzzy logic and IoT technologies, a hydroponic farm with parameter monitoring and precision system was put into operation. Fuzzy logic was used to ensure a steady supply of water and nutrients while monitoring the nutrient levels and intake of the bok choy and lettuce crops [5, 6]. An automated vertical hydroponic farm utilizing robotic technology and IoT was established in the study [4]. The height and width of the leaf crop cultivated in the automated vertical farm were compared in detail with a traditional vertical farm that did not have any robotic automation. The automated farm's average plant height and height were found to be 12.08 cm and 5.5 cm, respectively, while the conventional farm's average plant height and height were 10.58 cm and 3.9 cm, respectively. The findings indicate that automation has a greater impact on plant development than conventional growth media.

In their investigation [7], scientists grew lettuce plants in two distinct media: a soil-based substrate medium and a hydroponic system based on NFT. Based on the length of the development cycle, leaf length, leaf count, and leaf perimeter, the crop's growth results in both media were compared and examined [7]. The results from the AquaCrop simulator were also checked and validated with the substrate medium's actual growth outcomes. According to the data, growing lettuce in a hydroponic medium yields a higher quality and quantity of crop than growing it in a substrate media, and it does it in a way that is resource-competent and sustainable. The study brought to light the difficulty of hydroponic farming, which is that automated farms use about 70 times more energy than the substrate medium.

An analysis of the benefits and drawbacks of automated hydroponic farming with traditional agriculture can be found in [10]. The benefits of automated hydroponics included: (i) yields that were 11 times higher than those from conventional media; (ii) no stubble is produced; this prevents pollution from burning stubble; and (iii) improved crop quality in terms of plant height and weight. The study identified the following difficulties with the hydroponic medium: (i) a hydroponic farm's energy consumption was roughly 82 times greater than that of a traditional soil medium; (ii) a hydroponic farm required a larger initial investment and ongoing maintenance costs than a soil-based medium [10]. Smart Grow, an automated hydroponic system with minimal operating costs, was introduced in [11] as a solution to the drawbacks of high investment and operational expenses for hydroponic farms. The farm's fundamental growth characteristics, including pH, EC, and water levels, may be tracked by the system. The growth characteristics were then examined and the Smart Grow system was contrasted with the conventional soil medium. The ensabi planted in Smart Grow and soil medium had an average height of 12 cm and 9 cm, respectively.

The literature review made it clear that HF and conventional SBF had been the subject of extensive prior research, as well as the effects of both growth media on plant growth [4-7, 9, 12-14]. It is also evident that a significant amount of study on the effects of automated and manual hydroponic farms on plant development has not yet been conducted thus creating a research gap. The results of this study will aid in the subsequent investigation of how various IoT automation levels in a hydroponic farm affect plant development.

3. PROPOSED AUTOMATED AND SEMI-AUTOMATED HYDROPONIC NFT SETUP

We have grown lettuce crops for one growth cycle, or thirty days, in this comparative study using an IoT-based fully automated hydroponic system (FAHS) and semi-automated setup (SAHS). The two configurations were running concurrently using the algorithm implemented in the study [7] to give the crop on both farms the same environmental conditions.

The lighting and climate automation suggested in [6, 8] and the nutrient control and automation from the setup used in [7, 11] were used to create the hydroponic farm structure to reach 100% automation. The nutrient film technique (NFT) is the foundation of the hydroponic system developed for this investigation. The system includes water pumps, an air conditioner, a humidifier, artificial lighting, a water tank, a pH up/down solution, polyvinyl chloride (PVC) hydroponic pipes, and a nutrient solution container. Plants in NFT have their roots immersed in water that has dissolved fertilizer solution. The plant's roots acquire all the nutrients needed for their growth from the water supplied by the hydroponic system. The concentration of nutrients in the water passing through the pipes is essential to the hydroponic plant's growth, and the pH of the water affects how much of the nutrients the roots can absorb.

Additionally, this hydroponic system was fitted with sensors and actuators to allow automated, human-free nutrient supply, watering, and environment management. The DHT11 temperature and humidity sensor, the pH sensor track the pH level of the nutrient water passing through the NFT system, the ultrasonic sensor monitors the water level in the irrigation tank, and the TDS sensor records the TDS level of nutrient water were the sensors utilized in FAHS. Actuators automatically monitor and maintain the growth parameters in the ideal range based on sensor data, which functions as a feedback loop. When any of the farm's development parameters deviate from their ideal range, actuators allow us to continuously manage them without the assistance of a human. Actuators were utilized in FAHS to run water pumps, humidifiers, and air conditioners. Fig. 1 shows the FAHS block structure, and Table 1 provides information on each sensor, including its ideal ranges.

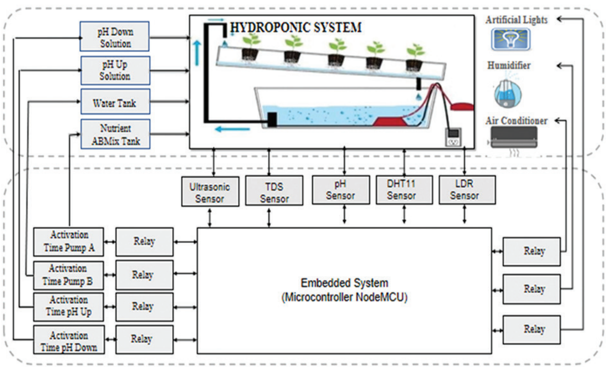


Fig. 1. Block Diagram of Fully Automated Hydroponic Setup (FAHS)

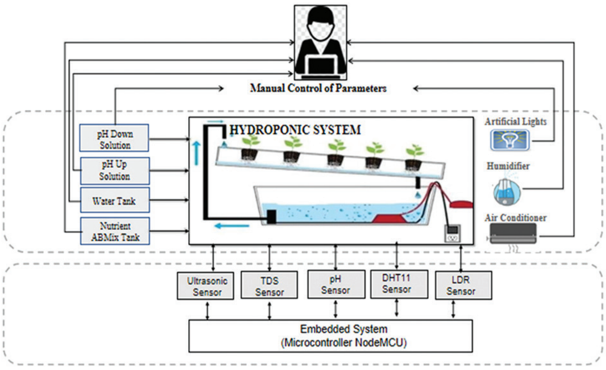


Fig. 2. Block Diagram of Semi Automated Hydroponic Setup (SAHS)

The next stage was to put in place semi-automated (SAHS), in which a human source will manage all parameter handling rather than actuators. All of the actuators in the FAHS are removed (Fig. 1), and the manual device control is moved to a human source, providing us with the necessary semi-automated configuration for comparative analysis. As shown in Fig. 2, the NFT-based hydroponic system, NodeMCU Micro-controller, and sensor configurations were the same in SAHS and FAHS. The growth parameters are continuously monitored by the sensors in SAHS. If any of the parameters deviates from the required ideal range, the micro-controller unit uses WiFi to send a warning message to the mobile application. Via the Android app, the person in charge of the farm can view the warning message and take appropriate action. The person as mentioned earlier is responsible for managing the outside world in this system. For example, SAHS will issue an alarm via the mobile app if the DHT11 sensor detects a temperature higher than 260C (Table 1). To return the temperature to the ideal range, the person will have to manually turn on the air conditioner. This temperature sensing and decision-making process—which for FAHS involves turning on the air conditioner—will be automated. Without any assistance from a human, the air conditioner will turn on automatically when the micro-controller unit sends the relay attached to it the on signal. Thus, there are no delays in FAHS when managing growth parameters.

Table 1. Sensors Deployed In FAHS And SAHS

Functionality	Sensor	Growth Parameter & Optimal Range for Lettuce Crop
Climate Monitoring & Control	DHT11	Temperature: 20 to 25^{0}C Humidity: 40% to 75%
Irrigation and Nutrient Control	pH Sensor	pH level of the Nutrient Water in NFT 5.7 to 6.5
	TDS Sensor	TDS of the Nutrient Water in NFT 1-10 Days: 550 - 850 ppm 11 - 20 Days: 680 - 900 ppm 21 - 30 Days: 800 - 900 ppm
	Ultrasonic Sensor	Water Level in the Irrigation Tank Water level > = 85%

4. EXPERIMENTAL ANALYSIS OF THE PROPOSED SETUP

The lettuce crop was grown for one growth cycle, or thirty days, in both the fully automated hydroponic setup (FAHS) and the semi-automated hydroponic setup (SAHS), to conduct the experimental analysis. To monitor the progress of plant growth, a variety of metrics were periodically recorded during the lettuce's growth phase. On days 5, 10, 15, 20, 25, and 30 of the growth cycle, three parameters—current plant elevation, current plant breadth, and current leaf length—were recorded [Table 2]. On the day of harvest, or day 30, other parameters—such as the aerial weight of dry lettuce, root weight of dry lettuce, and total number of leaves in the final harvest—were recorded [Table 3].

Using a weighing instrument, the plants were immediately weighed after being picked from both setups to examine the properties of fresh plants. The total number of lettuce leaves gathered in each setup was counted to get the total Leaf Count (TLC) metric. To conduct additional research, the aerial parts of each plant, or the leaves and stems, were separated from their roots and weighed individually once again using a weighing apparatus to determine the following parameters: Ariel Fresh lettuce weight (AW-FL) and fresh lettuce root weight (RW-FL). The aerial and root parts of the lettuce gathered from both setups were dried in an oven set at 500 °C for five hours to examine the weight parameters of dry lettuce. The aerial weight of dry lettuce (AW-DL) and root weight of dry lettuce (RW-DL) were measured following the drying process.

Table 2. Measured Values of Plant Growth Parameters for FAHS and SAHS for 10 plants taken on the days 5, 10, 15, 20, 25 and 30 of the growth cycle

Days	Mean Plant Elevation (Cm)		Mean Plant Width (Cm)	
	FAHS	SAHS	FAHS	SAHS
Day 5	2.5	2.3	3.4	3.2
Day 10	7.8	7.2	4.5	3.3
Day 15	12.5	11.3	7.3	4.8
Day 20	19.3	15.7	10.8	6.7
Day 25	24.8	20.7	13.9	9.8
Day 30	28.9	22.3	16.7	11.9

4.1. RESULT ANALYSIS AND DISCUSSION

Calculating the plants' agronomic parameters was the first step in the experimental investigation. The average plant height and average plant breadth for ten plants growing in automated (FAHS) and semi-automated (SAHS) farms were measured on days 5, 10, 15, 20, 25, and 30 of the growth cycle, as shown in Table 2. Following the completion of the growth cycle, the plants were harvested, and measurements were made of the following parameters for ten plants each from FAHS and SAHS [Table 3]: Fresh lettuce (AW-FL), dry lettuce (AW-DL), fresh lettuce (RW-DL), and total leaf count (TLC) are the weights measured at the air, on the root, and on the surface.

The mean plant height and mean plant width in FAHS were 28.9 cm and 16.7 cm, respectively, and in SAHS they were 22.3 cm and 11.9 cm, according to the results shown in Table 2. It follows that for plants cultivated in the automated farm, there was an average improvement of 6.6 cm in plant height and 4.8 cm in plant breadth.

Similarly, Table 3 results show that when comparing the automated setup to the semi-automated configuration, there was an improvement of 10.4 gm in AW-FL, 0.7 gm in AW-DL, 0.11 gm in RW-DL, 0.7 gm in RW-FL, and 3 in Total Leaf Count. The ideal development environment that the plants were given for their growth was the root cause of the superior growth quality in FAHS compared to SAHS. In the semi-automated configuration, all the growth parameters were managed manually, while in the automated arrangement, the IoT system carried out the entire process of temperature, humidity, light monitoring, irrigation, and nutrient regulation automatically. This causes a variation in the efficiency and precision of the growing conditions given to the plants, which enhances the growth quality in FAHS. Fig. 4 shows the comparative analysis of agronomic characteristics between FAHS and SAHS.

Table 3. Sensor Values of Ambient Parameters for FAHS and SAHS for days 20 to 30 of the plant growth cycle

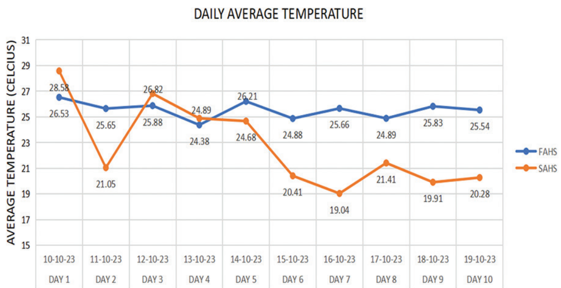
DAY	AVG. TEMP (CELCIUS)		AVG. HUMIDITY(%)		AVG. pH		AVG. TDS (PPM)	
	FA	SA	FA	SA	FA	SA	FA	SA
20	26.5	28.6	42.5	45.7	5.9	5.8	810	823
21	25.7	21.0	45.4	50.9	5.7	6.0	850	783
22	25.9	26.8	47.8	39.8	5.6	5.7	834	793
23	24.4	24.9	41.8	36.9	6.0	5.2	856	910
24	26.2	24.7	42.4	58.2	5.9	5.5	879	854
25	24.9	20.4	44.2	39.1	6.0	6.1	894	869
26	25.7	19.0	43.4	55.8	5.3	4.9	872	813
27	24.9	21.4	41.8	59.5	6.0	5.4	852	784
28	25.8	19.9	46.2	44.9	5.9	5.5	885	790
29	25.5	20.3	46.3	35.9	5.6	5.8	823	834
Mean	24.54	22.71	44.18	46.97	5.7	5.9	855.5	825.3

Table 4. Measured Values of Plant Growth Parameters for Fully automated(FA) and Semi automated(SA) for 10 plants taken on the 30th day of growth cycle

Plant No.	AW - DL (grams)		AW - FL (grams)		RW - DL (grams)		RW - FL (grams)		TLC (leaves)	
	FA	SA	FA	SA	FA	SA	FA	SA	FA	SA
1	3.0	1.9	58.4	46.1	0.35	0.13	3.6	2.3	24	19
2	3.2	1.8	57.9	47.9	0.43	0.18	3.7	2.5	23	22
3	3.1	1.9	57.3	47.4	0.42	0.21	3.9	2.7	25	24
4	2.9	2.2	58.3	47.8	0.29	0.19	2.9	2.4	22	23
5	2.8	2.4	56.9	47.5	0.24	0.17	4.2	2.9	22	20
6	2.6	2.0	57.4	46.7	0.26	0.26	3.5	2.5	24	18
7	3.0	2.3	56.6	46.2	0.31	0.23	3.1	2.5	21	18
8	2.6	1.9	58.2	45.9	0.29	0.21	3.6	2.1	27	19
9	2.9	2.3	55.3	47.3	0.31	0.19	3.3	2.6	26	21
10	3.1	2.9	57.5	47.3	0.33	0.21	2.9	2.3	21	22
Mean	2.9	2.2	57.4	47.0	0.3	0.19	3.5	2.8	23.5	20.6

Every three hours, sensors collected data on the temperature, humidity, pH, and TDS of the nutrient water on the farms over the thirty-day growth cycle of the lettuce plant. This data was then uploaded to the ThinkSpeak platform for analysis. The sensor data obtained from both farms during days 20 to 30 of the growth cycle is shown in Table 3, and Fig. 3 displays the comparative analysis. It is evident from the sensor data in Tables 3 and Fig. 3 as well as the optimal ranges in Table 1 that the automated setup was successful in keeping the temperature, humidity, pH, and TDS within the required optimal ranges of 20 to 25 °C, 40 to 70%, and 800 to 900. With FAHS, there was likewise minor difference between the ambient parameters and the ideal values.

Conversely, the SAHS sensor data shows that there were times when the parameter was outside of the ideal range. Considering the scenarios for day 22, the average humidity of the SA farm was 39.8% which was not in the ideal range, and the next day the average humidity reduced to 36.9%. This clearly shows that the farm owner took no corrective actions to rectify the humidity levels to their ideal range. For example, SAHS's average temperature was 24.68 °C on day 5, 20.41 °C on day 6, and 19.41 °C on day 7. From day 5 to day 7, the farm's mean ambient temperature consistently dropped. Parameters in SAHS frequently and noticeably deviate from the optimal range. For instance, the farm's average humidity was below 40% on days 3, 4, 6, and 10, which is outside of the recommended range. In contrast, no day in FAHS saw any agricultural parameter fall outside of its ideal range. The reason for this was that FAHS was self-sufficient for maintaining its parameters in the intended range; whenever temperature, humidity, pH, or TDS deviated from the required range, the appropriate actuators would quickly activate and fix the errors. Conversely, in SAHS, human resources had to turn on the relevant equipment manually to fix deviations. The quality of plant growth for FAHS and SAHS, as examined in Fig. 4, showed similar outcomes.



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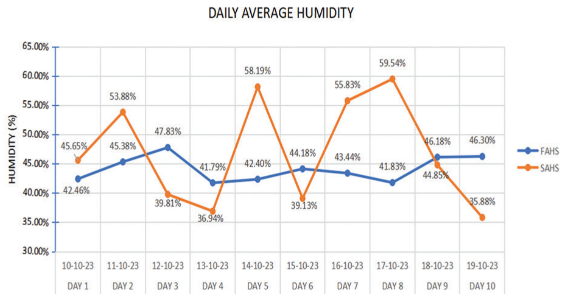

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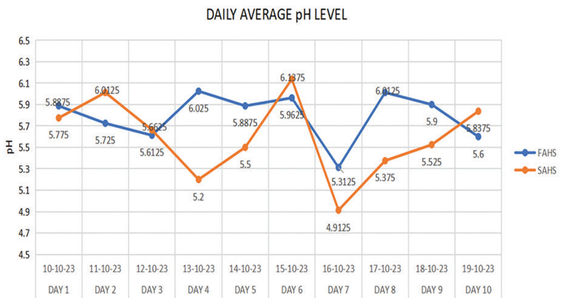

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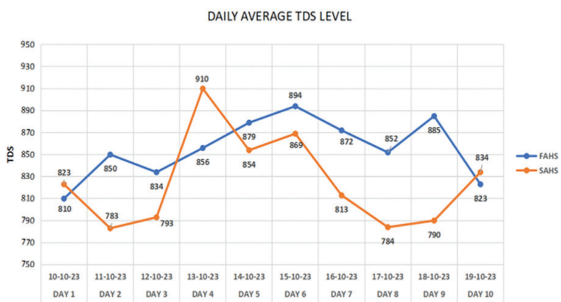
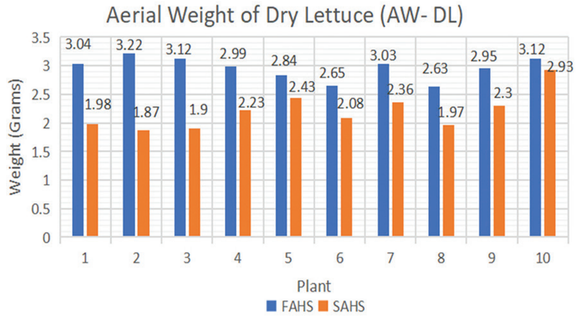


(d)

Fig. 3. Comparative analysis of the ambient conditions maintained automatically for FAHS and manually for SAHS setup with respect to (A) Temperature, (B) Humidity, (C) pH level and (D) TDS for days 20 to 30 of the plant growth



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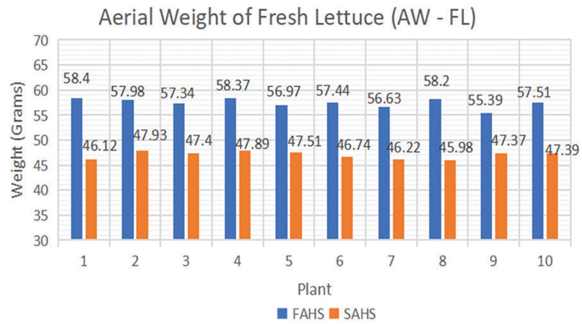

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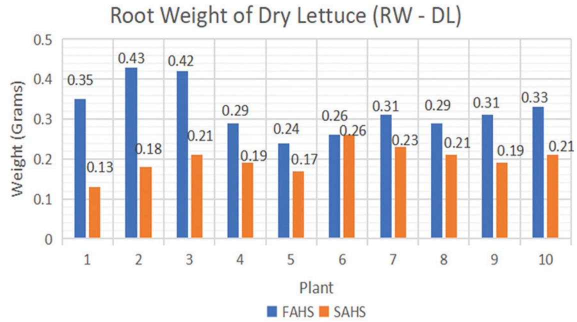

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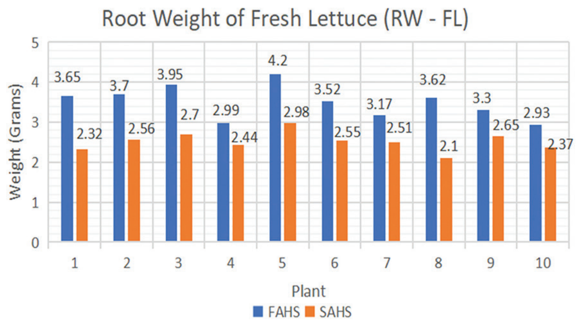

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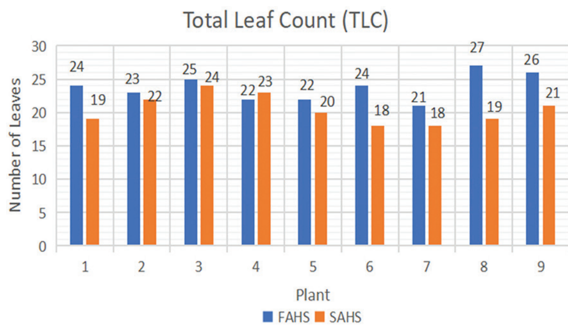

Fig. 4. Comparative Analysis of the plant growth parameters for 10 plants taken from FAHS and SAHS each in terms of (A) AW - DL, (B) AW - FL, (C) RW - DL, (D) RW - FL and (E) TLC

Hence, we can say that fully automated hydroponic systems surpass semi-automated ones in terms of precision, efficiency, and scalability. They continuously monitor and adjust environmental conditions, ensuring optimal plant growth and higher yields while minimizing resource waste. Automation reduces labour costs by minimizing manual intervention and allows for easy scalability of operations. Additionally, these systems provide valuable data for fine-tuning processes, leading to improved long-term productivity and efficiency.

Thus, the practical relevance of automated IoT hydroponic farms is that they offer precise control over environmental variables like temperature, humidity, and nutrient level s, optimizing plant growth and yield. This precision reduces resource wastage and labour costs while increasing productivity and crop consistency. Real-time monitoring and remote control capabilities enhance efficiency and allow for proactive management, minimizing risks of crop failure.

Compared to semi-automated systems, which require more manual intervention and oversight, fully automated IoT farms provide greater scalability, reliability, and potential for integration with data analytics and AI for predictive maintenance and decision-making. Thus, they represent a leap forward in sustainable, high-yield agriculture with lower operational overheads.

5. CONCLUSION

New and smart agricultural practices are a key priority in view of population growth, reduced land and water resources available to agriculture and growing demand for food. Hydroponics, a technology used in vertical farms, allows plants to be grown without any soil nutrients. This will decrease the reliance on arable land and water resources for agriculture. As hydroponics creates an artificial growth environment, they require automation technology to keep and preserve it in the correct range. In this experimental study, researchers compare the effects of automation on plant growth.

The practical implications of this research are significant for the agricultural industry. By comparing plant growth in fully automated IoT-based hydroponic farms with semi-automated manual hydroponic farms, we gain insights into the impact of automation on crop productivity and resource efficiency. This can inform farmers, agricultural businesses, and policymakers about the potential benefits of adopting advanced automation technologies in hydroponic farming.

Moreover, the findings may guide investment decisions in agricultural technology, helping stakeholders prioritize resources for implementing automation solutions that maximize yield and sustainability. Additionally, this research opens avenues for future studies to explore the optimization of automation parameters, such as fine-tuning environmental controls and nutrient delivery systems, in order to further enhance plant growth and resource utilization efficiency in hydroponic farming. We compared the growth outcomes of the two farms using agronomic criteria related to both quantity and quality. By examining the agronomic factors, it was determined that the cases of AW-FL, AW-DL, RW-DL, RW-FL, and TLC had average improvements of 10.4 gm, 0.7 gm, 0.11 gm, 0.7 gm, and 3, respectively. Additionally, they compared the efficiency of the automated technologies in maintaining the artificial growth conditions for both farms. The increased quality of lettuce crops in FAHS resulted from the continuous monitoring, management, and maintenance of all critical environmental factors within optimal limits by automated farms.

The semi-automated farm was neglected multiple times during the night, causing temperature, humidity, pH, or TDS levels to deviate from ideal ranges and impact the quality of lettuce growth. The comparison research has clearly shown that the automated process has a favorable effect on the quality of plant growth while making efficient use of the resources at hand and reducing waste. For this reason, the answer to every issue with conventional agricultural methods is a hydroponic farm outfitted with sensors and actuators to automate farm management.

The results of a study comparing automation's effects on lettuce growth in automated versus semi-automated hydroponic farms have broad implications for agriculture beyond lettuce and hydroponics. Insights gained from the study can be applied to various crops with similar growth patterns and environmental requirements, facilitating crop adaptability across different systems. Additionally, understanding how automation influences growth parameters like plant weight and height can inform practices in both hydroponic and soil-based farming systems.

The findings can guide the adoption of automation strategies in precision agriculture, enhancing efficiency and sustainability across diverse farming methods. By optimizing resource use and minimizing environmental impact of automation, farmers can work towards more sustainable food production practices. Ultimately, the study contributes to advancing agricultural technology and practices, providing valuable insights that can be translated into improved crop outcomes and resource management strategies in agricultural systems worldwide.

Future research could focus on optimizing automation parameters and assessing long-term effects on plant health, nutritional content, and resistance to pests and diseases. Exploring the economic viability and scalability of automated systems across different regions and crop varieties is also essential. Ultimately, this research contributes to advancing agricultural practices towards more efficient, sustainable, and resilient food production systems, addressing pressing challenges in food security and environmental sustainability.

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