



Commercial Production of High-Value Vegetables Using BPSU Automated Soilless Culture System

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ABSTRACT

Bataan Peninsula State University (BPSU) in the Philippines has developed an automated soilless culture system to enhance the commercial production of high-value vegetables in Bataan. Implemented in Limay, Pilar, and the BPSU-Abucay Campus, the project aimed to improve farm productivity and provide safe, quality produce through controlled greenhouse conditions. The automated temperatures were maintained between 27–30°C, and humidity levels ranged from 65–85%, resulting in healthy crop growth and an average yield of 169.92 kilograms of lettuce per month. The system generated a net annual income of ₱129,204.49 with a 74% return on investment. Findings demonstrate that the BPSU Automated Soilless Culture System offers a practical and sustainable approach to modern vegetable production.

INTRODUCTION

At present, the Philippines is facing pressure because of the current effects of climate change on the agricultural system. Climate change is a natural and urgent challenge that is already affecting people and the environment worldwide (Lenton et al., 2023; Van Bijsterveldt et al., 2023). The climate change phenomenon has been recognized for the complex effects that cause severe hydrological imbalance (Wang et al., 2023). This directly affects not only agricultural ecosystems but also human societies (Baltazar, 2024; Mondal et al., 2024).

With this, the demand for affordable and available food for every family table is a continuous challenge. There is a pressing need for an increase in the supply of food in the world is necessary, considering the increasing population (Li et al., 2023). The Philippines, which is considered to be one of the Asian countries with the fastest-growing population, requires the need to exploit all available technologies to increase food production and to sustain economic life (Park, 2023). In the global scenario, stated that the demand for food is expected to increase by 70% by 2050 (Mylan et al., 2023). However, the main challenge the world now faces is not so much growing the 70% additional food in 40 years but making 70% more food available on the plate. This could be higher if crop yields and the efficiency of agricultural production do not improve.

In this situation, adaptive farming techniques should be introduced in farming communities to combat and address the perennial problems encountered during a production period. The introduction of a hydroponics system in the local farming industry is important in sustaining and improving efficient production output. At the same time, making farming lucrative will inspire every farmer to engage in farming activities, which has proven the promising results of hydroponics and automation research output conducted in Bataan Peninsula State University, Philippines.

This established technology, with the worry-free soilless culture system and weather-based automated greenhouse system that controls operation and provides favorable conditions for the crops during production, can give an advantage to the farmers who can engage in the technology. This automated system could help solve problems with the current traditional practices of growing crops in the open field and other existing greenhouses.

The commercialization of the automated BPSU soilless culture system showcases the developed technology that can benefit the farmers and the consumers with the production of high-value vegetables. Likewise, this project will drum up the economic status of the community for better living.

LITERATURE REVIEW

In recent years, the demand for sustainable and efficient food production systems has increased rapidly as the world faces growing population pressures and environmental challenges that threaten agricultural productivity (Chen, 2025; Islam, 2025; Laghari et al., 2025). The Food and Agriculture Organization (FAO) estimates that global food production must rise by about 70% by 2050 to meet future demand, indicating the urgent need to adopt advanced farming technologies and controlled-environment systems. This growing concern has led

to numerous research efforts exploring modern techniques such as hydroponics, automation, and greenhouse-based farming to improve yield and strengthen food security in developed and developing nations (Dennison et al., 2025; Sadek et al., 2024).

Hydroponics and other soilless culture technologies have become promising alternatives to traditional agriculture because they maximize space, conserve resources, and enhance productivity (Rajendran et al., 2024). Studies have shown that hydroponic systems support faster plant growth and higher yields through direct nutrient delivery and controlled environmental factors, leading to consistent and safer production outcomes (Banboukian et al., 2025; Heo et al., 2024; Herrera-Arroyo et al., 2025). These systems also reduce dependence on arable land and help mitigate the effects of climate change by maintaining ideal growing conditions inside enclosed environments (Lakhier et al., 2025; Quirante & Politud, 2025). These hydroponics principles are aligned with the objectives of the BPSU Automated Soilless Culture System, which seeks to stabilize temperature, humidity, and nutrient levels to sustain high-value vegetable production in the Philippines.

Integrating automation into hydroponic systems represents an important advancement in making modern agriculture more efficient and precise (Lim et al., 2024; Rahman et al., 2024). Some studies indicated that sensors and IoT-based monitoring tools can automate irrigation, nutrient delivery, and climate control, minimizing human error and reducing operational costs (Rajaseger, 2023). In two related studies, it was found that sensor-controlled fertigation in greenhouse-grown strawberries improved yield and fruit quality by maintaining accurate water and nutrient levels (Bonelli et al., 2024; Hutchinson et al., 2025). These findings illustrate how automated systems, such as the BPSU model, can optimize microclimatic conditions, improve crop growth, and increase profitability for farmer-beneficiaries.

Beyond automation, recent developments in artificial intelligence (AI) and deep learning have further expanded the possibilities for Controlled Environment Agriculture (Ahmad et al., 2024; Ali et al., 2025). A study reviewed how deep learning algorithms can be used for environmental forecasting, crop stress detection, and yield optimization (Ojo & Zahid, 2022). Their findings show that predictive modeling allows for real-time adjustments, helping farmers maintain ideal growing conditions and improve decision-making. This technological integration explains the potential for the BPSU system to adopt similar intelligent features in the future, improving its adaptability and long-term sustainability.

Greenhouse design and structure are equally important in achieving energy efficiency and optimal yield (Narayanan et al., 2025; Song et al., 2025). A review by environmental engineers in 2022 emphasized that materials, ventilation, and architectural design significantly influence cost-effectiveness and climate regulation (Badji et al., 2022). These factors are particularly important in tropical countries like the Philippines, where high humidity and temperature fluctuations could pose several challenges. The BPSU automated system

demonstrates how thoughtful design and local adaptation can work together to create energy-efficient and context-appropriate greenhouse solutions.

Local studies in the Philippines have also demonstrated the growing promise of hydroponic farming. A 2025 study conducted in Nueva Ecija reported that hydroponic systems increased productivity, reduced water use, and provided a stable source of income for smallholder farmers, even with higher initial costs (Edrian P, 2025). These findings affirm the practicality of introducing automated soilless systems into local agriculture – one of the main goals of the BPSU project to empower rural farmers through accessible, technology-driven innovations. Similarly, one explored vertical hydroponics for onion production in the Philippines and found strong profitability and sustainable returns when technical and financial management were properly integrated (Armas et al., 2023).

In the Southeast Asian context, a study that analyzed the smart greenhouse hydroponic farming in Indonesia found it to be technically viable and economically beneficial (Harniati et al., 2023). Their study emphasized that features like real-time monitoring and climate automation can raise farmer income and product quality, especially when adapted to local energy and cost conditions. These results mirror the goals of the BPSU initiative, which combines automation with affordability to promote community-level adoption of advanced farming practices.

Finally, experimental work on modified hydroponic systems showed significant improvements in Pechay growth in terms of height, leaf number, and fresh weight under enhanced hydroponic setups (Galvan et al., 2021). Although their modification focused on magnetic treatment rather than automation, the study supports the broader principle that technological innovation in soilless farming can substantially improve plant performance. Taken together, these studies provide a strong foundation for the BPSU Automated Soilless Culture System, reinforcing its potential to boost agricultural productivity, support sustainable practices, and strengthen the economic resilience of Filipino farmers.

Hypothesis 1 (Production Efficiency)

H₀₁: The use of the BPSU Automated Soilless Culture System does not significantly enhance the growth performance and yield of high-value vegetables compared to traditional soil-based cultivation methods.

H₁₁: The use of the BPSU Automated Soilless Culture System significantly enhances the growth performance and yield of high-value vegetables compared to traditional soil-based cultivation methods.

Hypothesis 2 (Economic Viability)

H₀₂: The adoption of the BPSU Automated Soilless Culture System does not significantly increase the net income and return on investment of farmer-beneficiaries compared to conventional vegetable farming practices.

H₁₂: The adoption of the BPSU Automated Soilless Culture System significantly increases the net income and return on investment of farmer-beneficiaries compared to conventional vegetable farming practices.

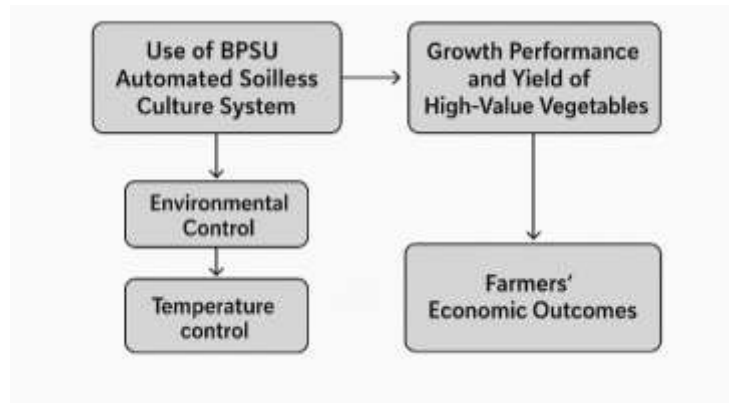


Figure 1. Conceptual Framework

The conceptual framework illustrates the relationship between the use of the BPSU Automated Soiless Culture System and its impact on growth performance and yield of high-value vegetables, ultimately influencing farmers' economic outcomes. The framework suggests that the automated system enhances vegetable production through improved environmental control, particularly temperature regulation, which provides optimal growing conditions for plants.

METHODOLOGY

Activities per Expected Output

a. Provided Worry-Free Control Systems for Greenhouse and Soiless Systems

1. The installed BPSU automation system will control the temperature and humidity inside the greenhouse by actuating the opening and closing of the valves for the foggers at the required minimum and maximum threshold while the rotation of the hydroponics solution at a pre-determined time interval during the production operation.
2. Before the actual production operation, the installed BPSU automation was first subjected to testing and calibration of the temperature and humidity sensors. The calibration equation was imputed in the device program for the correct opening signal to the fogger system when needed to maintain the desired temperature and humidity conditions inside the greenhouse. Also, the response signal from the device to the hydroponics solution valve was tested for functionality, and the GSM capability to transmit data to the farmer-beneficiaries' cellphones for 24 hours for online monitoring inside the greenhouse.
3. After the calibrations of the different components of the BPSU Automation, the device was set up in the desired settings as required by the high-value crops during the production period.
4. Monitored and observed the installed BPSU automation at the project site to evaluate the favorable weather conditions inside the greenhouse and the growth of the crop during the production period.
5. Observed and assessed the operation performance of BPSU automation to further improve the component system of the device in controlling greenhouse environmental conditions for successful crop production.

6. Adjusted and improved the BPSU automation based on the assessment results during the actual performance operation. The improved version was submitted for a patent application, and this will be subjected to technology incubation at the University to disseminate the BPSU automation technology developed in this project.

b. Proved that the Water and Fertilizer Resources Used were Optimized

1. The prepared and constructed hydroponic beds using a deepwater culture system have a dimension of 0.8 m width x 10.5 m length x 0.1 m depth with a population of 244 plants per bed and with an estimated hydroponic solution volume of around 0.5 m³ per bed. The capacity of the 12 m x 24 m designed greenhouse has sixteen (16) hydroponic beds with a total 3,904 plant population and a total 8 m³ hydroponic solution volume.
2. The SNAP hydroponics solution developed by the University of the Philippines, Los Baños was considered and used in this soilless production intended for leafy vegetable crops. The nutrient composition of the SNAP hydroponics solution provided the complete levels of micro and macro elements required for the crops.
3. The reared seedlings at 12 to 14 days old from the date of seed sowing with three to four true leaves, were transplanted at the prepared cup plugs with six slanted holes (0.002m x 0.03m) at the side and bottom part of the cup. During transplanting, the treated soilless medium and the seedlings were put together in the cup plug to hold the plant and root system, and transferred immediately to the soilless production beds.
4. Constructed a hydroponic solution reservoir tank with a capacity of 1.5 m³, where the SNAP hydroponics solution was properly mixed and loaded into this tank while maintaining mixture consistency. During the production operation, the hydroponic solution will be pumped out and go into the soilless system beds, where the seedlings are transplanted at the prepared soilless beds.
5. Monitored and recorded the growth of the crops from transplanting to harvesting, together with the EC, pH, and temperature of the hydroponic solution at the soilless beds. Also, measured the hydroponic solution consumption for every cycle of production aside from weighing the harvested crops.
6. Tabulated and analyzed the data collected during production to determine if the fertilizer (SNAP hydroponic solution) and water were efficiently utilized using the BPSU automated system.

c. Enhanced Production Capacity and Produce Healthy and Safe Vegetables

1. After transplanting, the BPSU automation controlled the temperature and humidity conditions inside the greenhouse and actuate the regular rotation of the hydroponics solutions to maintain a favorable environment inside the greenhouse for growing crops.
2. The established soilless culture system with BPSU automation, the production of high-value crops was scheduled per batch based on the market demand and maintaining a continuous production cycle.

3. During the production, the fresh high-value produce was harvested every week to offer and sell into the community. The collected data were analyzed using simple economic calculations.
4. The production was maintained for healthy and safe produce by observing cleanliness inside and outside the greenhouse. In addition, the installed double net door at the entrance of the greenhouse prevented and reduced insects and pests from possibly entering the greenhouse

d. Improved Farmer Beneficiaries' Production Capacity and Generated Higher and More Stable Income

1. Established a soilless system at the farmer's level, the farmer beneficiaries were trained and capacitated in the soilless culture system of production.
2. Recorded the daily time of engagement of the farmer beneficiaries in the soilless system of production.
3. Assessed and determined the additional benefit derived from the soilless project as a full-time regular farmer.

Production Aspect

a. Seedling Rearing. A separate nursery for seedling production was constructed near the established greenhouse to produce healthy seedlings that were transplanted and transferred to the soilless culture systems. This technique prevented and controlled the production area from infestation. The timing of reared seedlings in the production schedule was easily managed and executed in this process.

b. Operation of Soilless Culture System. The healthy and reared seedlings from the nursery with at least 3 to 4 leaves were used to transplant into the soilless culture system. The reared seedlings from the nursery were transplanted directly to the production bed using the soilless medium. After the transplanted seedlings, the BPSU automation will control the weather conditions inside the greenhouse at the predetermined temperature, humidity, and rotation of the hydroponic solution from the reservoir tank to the soilless production bed.

c. Harvesting. After 22 to 24 days, the high-value crops are ready to harvest. Proper care is required to prevent leaf damage and bruises during this activity. After harvesting and removal of dried leaves, washing was carefully done before the crops were packed into the prepared plastic bags or other packaging materials based on the requirements of the customer's demand in the market.

d. Market Strategies

Product. The high-value crop was the primary vegetable produced in this project, and other vegetable crops will be reared after the project duration based on the demand of the consumers. According to a study by Calderon et.al in 2009, High-value vegetables can command much higher prices, especially during the off-season, such as lettuce, bell pepper, and tomato. In the province of Bataan, these vegetables, bell pepper, tomato, and lettuce, are vegetables that can be found abundantly during peak season and can hardly be found during off-season, mainly because only a handful of farmers are really engaged in high-value vegetable production.

Place. The main target area where the product was sold to potential customers was at public markets and restaurants. Also, soon-to-be included hotels and designated “bagsakan” centers of the towns wherein the identified farmer-beneficiaries’ farms are located. Nearby towns were also be considered.

Even with the increasing number of shopping malls and commercial centers, the public market is still considered by many as the center of trade, from dry goods, basic household wares to fresh produce, and wherein consumers can look for cheaper products to augment their savings and stretch the value of their money.

BPSU, together with the Local Government Unit partner, assisted the farmer-beneficiaries in providing stalls in the municipalities to allow them to have their produce brought and sold. Other potential outlets are local supermarkets that have already been supplied with lettuce produced by the University in the past.

Pricing. The produce of the farmer-beneficiaries was priced according to the prevailing price range in the market. However, the products produced in the project were sold higher than the others due to the higher cost of production in the soilless system.

Promotion. BPSU conducted seminars and harvest festivals to help promote the produce of the farmer-beneficiaries. Trade fairs that BPSU participated in regularly were considered places for promotion. Part of the promotional activities is the promotion of the BPSU Automation technology, as well as to familiarize the target clientele with the advantages and operations of the soilless culture system of production

RESEARCH RESULTS AND DISCUSSION

Establishment of the Greenhouse and the Soilless System

The sites for greenhouses with a soilless culture system and automation were identified. This is located at BPSU-Abucay Campus, and the other two (2) are within the farmer beneficiaries selected and recommended area by our project partners, LGUs in Limay and Pilar, Bataan. Before the construction, preliminary activities were conducted in the proposed areas, like clearing, cleaning, leveling, lay-outting, provision of electrical supplies, and water supply.

As per approved project activities, the old greenhouse in BPSU-AC was repaired and rehabilitated. This old greenhouse was cleaned and removed damaged parts (nets, plastic, and other frames). The functional frames were restored and applied with rust-proofing, while unserviceable frames were replaced. Also, other component requirements of the greenhouse were assembled. The procured 0.008 mm thick UV plastic as roofing, and 16 holes per 100 mm² UV net protective side walls were installed. The piping system for 16 foggers was assembled in equal spaces inside the constructed greenhouse. The installation of the 75% shade net located at 2,500 mm above the ground to reduce the radiation light inside the greenhouse, especially during the noon time when the observed environmental temperature is high. The existing production bed was transformed into a soilless culture with a dimension of 800 mm width, 10,500 mm length, and 100 mm depth per production bed.

After the repair and rehabilitation of the old greenhouse and installation of the soilless components, the assembled BPSU automation was installed together with the sensor inside the greenhouse and connected to the electric water pump for hydroponics solution and at the pressured water tank that was actuated by the system with the given signal from the sensors when needed to adjust and control the environmental condition inside the greenhouse favorable for growing high-value vegetable crop.

At the farmer beneficiary level in Limay and Pilar, the fabricated frames for the 12,000mm x 24,000mm greenhouse were assembled, installed UV plastic roofing and sidewall net, assembled piping for foggers, constructed soilless culture bed, reservoir tanks, and BPSU automation. Aside from the complete setup of the soilless project, other agricultural supplies and materials were delivered to the farmer-beneficiaries, like seeds, seedling trays, SNAP hydroponics solution, mixing drums, and other agricultural supplies as the starting kit in this production project.

During the construction of the greenhouse, the project teams monitored and supervised the actual construction and assembly of the different structural components to ensure that the greenhouse structural design plan was properly and orderly followed. Other components of the soilless culture system were assigned to the farmer-beneficiaries as part of the associations' counterparts, like the labor for the construction of 16 units of soilless production beds and nurseries for seedlings, provision for the source of electricity, and labor for the construction of two (2) units of 1.5 m³ hydroponics solution and water reservoir. However, all these activities were executed and finished at the farmer's level, but it was delayed for 11 months due to the COVID-19 situation, particularly in the province of Bataan.

Capacity Building of Farmer-Beneficiaries

The ongoing project construction and establishment at the farmer-beneficiaries in Limay and Pilar, Bataan. The rehabilitated greenhouse in BPSU-AC was used for the farmer-beneficiaries training and seminar for the soilless culture system. Farmer beneficiaries were invited to attend the training/seminar following and observing the imposed health protocol in the area. The activity was conducted for three (3) days for every farmer beneficiary group. These three (3) days of training/seminar were done one day every week to explain and discuss the soilless culture system and monitor the whole production cycle of growing high-value crops from seeds to harvestable products.

The hands-on training was conducted for the farmer-beneficiaries and partner LGUs on the production, operation, and maintenance of the soilless system prior to the actual operation of the project. The following was given emphasis during the training: the hydroponic system, seedling preparation, soilless medium preparation, transplanting at the production bed, identification of pests and diseases for the seedlings and their control, operation of the automated system, proper harvesting and handling, packaging, and labeling of products, and storage requirements. The training was conducted on-site and successfully

executed, and delivered the expected knowledge and skills to the beneficiaries and LGU partners in the project.

Techniques of the soilless culture production system were explained and discussed during the said training. A total of twenty-six (26) farmer-beneficiaries were trained both in Limay and Pilar, Bataan. This equates to around 25 percent of the total farmer beneficiaries who were trained in the project, and the others were trained by their co-members during the actual production. After the construction and establishment of the greenhouse and soilless culture system at the farmer-beneficiary levels, the project team assisted and guided the farmer-beneficiaries during the actual production operations of the project.

Operation of BPSU Automation

The established greenhouse and soilless culture system, the fabricated and assembled BPSU automation control system was installed together with the sensors for temperature and humidity, and the 16 pieces of foggers were distributed at equal distances inside the greenhouse. Also, the electrical connections to the gate valve and to the electric water pump. The BPSU automation system was tested before the actual production and identified the range of the temperature from 27 - 30°C and 65 - 85 percent humidity levels suitable for the high-value crops planted.

a. Observed Temperature and Humidity Inside the Greenhouse

The developed heat inside the greenhouse is one of the major challenges in growing crops. The radiation heat from the sunlight trapped inside the greenhouse tends to raise the temperature, especially during the daytime period when the radiation is high. The presented Figure 2 below shows the recorded temperature and humidity from the collected time interval at 8:00 AM, 12:00 NN, and 4:00 PM, and at different heights from 0.2 m, 1.5 m, and 2.5 m above the ground where the observation points are located.

The recorded humidity located at 0.2 m and collected at 8 AM has an average of 79.52%, while the maximum and minimum values were 89.40% and 69.60%. The documented humidity at 12NN shows an average of 69.41%, 86.00% highest, and 59.40% lowest value; however, at 4 PM, the computed average value was 72.41% while the highest value is 82.00, and 58.6% lowest value. Results of the data showed that at 8 AM, the humidity is relatively higher as compared to the 12NN and 4 PM data, which means that the accumulation of moisture vapors from the crops and the hydroponics solution inside the greenhouse attributed to the presence of high humidity during this early morning. However, at 12NN the humidity decreases to 3% due to the developed heat inside the greenhouse that reduces the moisture air even with the presence of the foggers used in the automation system. And, at 4 PM the humidity level increases to around 10.10% due to the decrease in temperature inside the greenhouse. It is also depicted in the graph that the humidity inside the greenhouse is constantly fluctuating which suggested that high at 8 AM and low at 12NN while at 4 PM it starts to increase. Compared with the reference humidity recorded in the nearby synoptic station, the value of the average humidity is higher at 0.99% at 8 AM and 11.09% at 12 NN. At the same time, at 4 PM, it is 8.09%, which means that the surrounding air

moisture is higher than in the greenhouse. The relationship of humidity between 0.2 m, 1.5 m, and 2.5 m above ground at 8:00 AM shows that the humidity at 0.2 m, 1.5 m, and 2.5 m above the ground indicates a strong relationship between them, as statistically suggested.

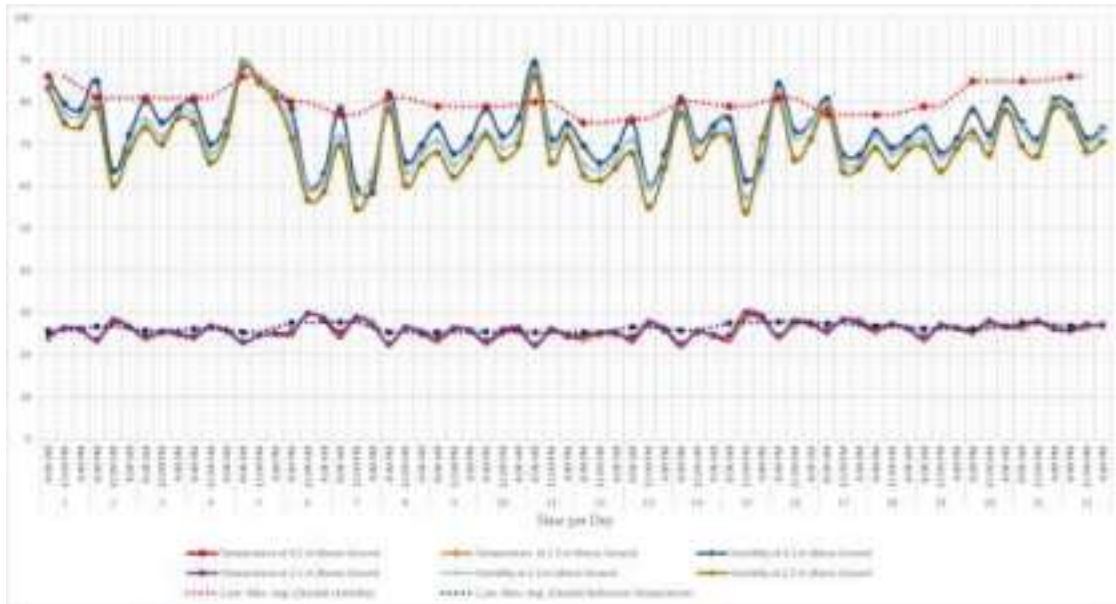


Figure 2. Graph of the temperature and humidity inside the greenhouse

However, the recorded humidity is located at 1.5m above the ground and collected at 8 AM, 12NN, and 4 PM as depicted in the graph. At 8 AM, the average humidity observed was 76.29% with the highest value of 88.90% and the lowest value of 65.30%. At 12NN, the gathered average humidity is 67.61% while the highest and lowest values are 86.10% and 57.50%. And, at 4 PM, the collected highest and lowest values of humidity was 81.30% and 61.50% while the average was 71.11%. The results suggested that the difference in humidity at 8 AM, 12 NN, and 4 PM was around 3.22%, 1.80% and 1.30% lower as compared to 0.2m, which means that a decrease in humidity level was observed. Although when comparing with the reference humidity at 8 AM, 12NN, and 4 PM, it was noted that around a 4.21%, 12.89%, and 9.39% difference outside the greenhouse. It was implied that at this level, the humidity is decreasing, especially during the noon time period, and slightly increasing in the late afternoon, even though the operation of the automation was applied inside the greenhouse during the noon period. This suggested that the higher heat accumulation at noon affected the humidity level. Thus, it is suggested that the humidity at 0.2 m, 1.5 m, and 2.5 m above the ground show a strong relationship between the different levels.

While the observed humidity at 2.5m above the ground gathered at 8 AM, 12NN, and 4 PM as presented in the graph. The average value computed was 74.61% but the highest and lowest value is 88.20% and 62.60% at 8 AM. At 12NN, the recorded highest and lowest value is 84.60% and 53.70% while the average is 64.68% at 4 PM the calculated average was around 69.84% while 80.70% for the highest and lowest value is 58.80%. The difference between 2.5m and 1.5m levels was recorded at 1.68%, 2.75%, and 1.27% while between 2.5m and 0.2m levels is

4.90%, 4.55%, and 2.57% for 8 AM, 12NN, and 4 PM which means that going at the upper level inside the greenhouse the humidity is decreasing as suggested in the data generated. When compared with the reference humidity it was found that around 4.21%, 12.89%, and 9.39% at 8 AM, 12NN, and 4 PM was the recorded difference which suggested that the humidity inside the greenhouse is lower than the environment. Also, it was observed that in the upper part of the greenhouse structure during the noon period, the temperature is higher than in the lower part due to the developed heat caused by the radiation from the sunlight. In addition, the location of the fogger or cooling system attached to the automation is lower than that level where the reduction of humidity was noted. Temperatures at 0.2 m, 1.5 m, and 2.5 m above the ground show a strong relationship between them in a positive direction.

b. Observed Hydroponic Temperature, Electric Conductivity (EC), acidity (pH), Growth of Crop

The graph depicted in Figure 3 below shows the observed hydroponic solution temperature, acidity (pH), electric conductivity (EC), growth of crops, and recorded temperature at 0.2m inside the greenhouse using a soilless culture system. The hydroponic solution temperature plays an important parameter in the growth of crops. In the experiment conducted, the observed temperature of the hydroponic solution at 8:00 am records an average hydroponic solution temperature of 23.1°C while the lowest is 22.1°C and the highest of 24.2°C. Thus, 12:00 pm has an average of 24.2°C while its lowest is 23.4°C, and 25.6°C is the highest. On the other hand, 4:00 pm records an average of 24.7°C and a lowest of 23.5°C while having a highest of 25.9°C which suggested that the hydroponic solution temperature during this period was maintained at a desirable level of temperature at a range of 24°C and below. However, in the later part where crops are about to harvest the recorded temperature was 25.2°C which resulted in the increasing environmental temperature. The data clearly shows a high significance between treatments and that the hydroponic solution temperature of the plot is highly significant to the temperatures above the ground.

The average temperature recorded at 8:00 am is 24°C, the lowest is 22.2°C, and the highest is 26.3°C. However, the average temperature recorded at 12:00 pm is 26.8°C, the lowest is 24.6°C, and the recorded highest temperature is 29.6°C while the average temperature at 4:00 pm is 26.15°C, with 24.4°C and 28.7°C is the lowest and highest temperature collected. The observed temperatures located at 0.2 m above the ground have minimal fluctuation which observed that the temperature at this level is stable due to the ground temperature.



Figure 3. Graph of the hydroponic solution temperature, electric conductivity (EC), acidity (pH), growth of crops, and temperature at 0.2m

The recorded data for the acidity of the hydroponic solution shows a smooth increase and decrease throughout the whole cycle, having the highest acidity collected on the last day, which means that the hydroponic solution becomes acidic. The average acidity at 8:00 am is 6.61 pH, while the lowest is 5.65 pH, and the highest of 7.44. However, 12:00 pm recorded an average acidity of 6.57 pH, its lowest is 5.62, while having a highest of 7.35. And 4:00 pm has an average of 6.56, while the lowest of 5.53 and the highest of 7.29. It was observed that when there is a lower temperature, the acidity rises slightly, and when the temperature increases inside the greenhouse, the acidity drops slightly. Comparing the recorded temperature at 0.2m and acidity shows a high significance. It implied that the temperature is one of the factors that affect the chemical composition present in the hydroponic solution, particularly the acidity (pH) level, which means that with an increase in the surrounding temperature, the solution absorbs the heat that forms H⁺ ions, resulting in a decrease in the pH level.

Moreover, the Electric conductivity showed a constant value for 22 days, having minimal movement. The average electric conductivity at 8:00 am is 1772 μ S, while the lowest is 1718 μ S, and 1845 μ S is the highest. The average electric conductivity at 12:00 pm is 1783 μ S, while the lowest is 1707 μ S, and 1860 μ S is the highest recorded electric conductivity. In addition, the average acidity at 4:00 pm is 1790 μ S while the lowest and highest electric conductivity are 1718 μ S and 1847 μ S. Hence, the EC of the plot beds was maintained at a range of EC levels during the noon time period when the automation is operating and controls the excessive heat that develops inside the greenhouse at the desired environmental parameters favorable to the crops.

The growth of the crops was measured, and the initial average height of the crops was 3.01cm when planted on the first day. The average weekly growth rate is 0.64cm per day, 0.82cm per day, and 0.71cm per day for the first, second,

and third weeks, with a recorded total average growth rate of 0.72cm per day. The total average height of the crops is 15.30cm which is equivalent to 47.66 grams per plant at 22 days growing period at the soilless bed while the hydroponic solution consumption was computed at 1.14 liters per plant. The resulting plant growth in the soilless culture system has almost recorded a uniform growth with an average of 0.72cm per day which means that the environmental requirements for the crops during this period were maintained. It clearly shows that there was a high significance between the growth of crops and the temperature at 0.2 cm above the ground.

However, when data collected at 8AM, 12NN, and 4PM were subjected to a correlation of the temperature at 0.2m to the hydroponic solution, acidity, electric conductivity, and growth of crops it was found that there is a highly significant correlation between which suggested that any changes of the environmental temperature inside the greenhouse will also change the status of the hydroponic solution, acidity, electric conductivity, and the growth of the crops will also be affected. It is important to control the temperature built-up inside the greenhouse using the BPSU automation during the noon time period where the accumulation of high heat can affect the growth of the crops.

However, during April and May the production it was experienced an increase in environmental temperature from the average of 26-31 °C from April to May 2022 as per DOST-PAGASA which affected the growth of the crops and triggered damage in the leaves. During this period, the operation of the automation was extended from 2 to 3 hours to 5 to 6 hours which was caused by the humid climate inside the greenhouse that burns the leaves of the lettuce due to the extended fogger operations. Based on these results, it was suggested that the additional exhaust fan was installed and attach to the automation device to address this issue inside the greenhouse when the environmental temperature abruptly increases.

Soilless Production Activities

In the prepared greenhouse and soilless culture system, the high-value lettuce seeds were reared at the nursery using the soilless medium for about 12-14 days with 2 – 3 true leaves were transplanted at the prepared seedling cup plugs using pumice to hold the plant roots. The transplanted seedlings at the cup plugs were placed in the soilless production bed inside the greenhouse with the prepared hydroponics solution. After the transplanting of seedlings, the BPSU automation was set up at the predetermined operating condition to control the temperature at 27-30°C and 65 to 85 percent humidity inside the greenhouse and the hydroponics solution rotation from 10 AM to 2 PM in the soilless culture system production bed.

Using the green rapid variety of lettuce seeds at the three sites and SNAP was used as a hydroponic solution with a uniform 22 days production period from seedlings to harvestable products was conducted. The recorded average harvested lettuce crop in Limay and Pilar, Bataan was 10.32 and 10.14 kgs while in BPSU-AC this is around 11.62 kg per soilless bed which is equivalent to an average of 10.62 kg/plot. The recorded consumption of hydroponic solution is

1.14 li/plant and the prevailing cost of SNAP hydroponic solution at Php 250.00 per 200 liters is equivalent to Php 1.425 per plant while Php 0.014 per plant for the cost of water. The computed energy consumption per plant in operating automation, foggers, and hydroponic solution rotation is Php 0.303 while the cost of labor from seedlings and growing crops was recorded at an average of 30.14 hours per production cycle, with an equivalent of Php 0.723 per plant. The total cost of production per plant is Php 2.465, while the cost of production per kilogram is Php 56.695. The sales of the produced crops are dependent on the requirements of the market. As the initial strategy, the production was scheduled every week to produce two soilless beds, while for the full production capacity, 4 soilless beds per week.

The total production capacity per month is around 169.92 kilograms at Php120.00 per kilogram, which is equivalent to Php 20,390.40 per month and Php 244,684.80 gross income for every year. The computed variable cost that includes labor, electricity, water, and SNAP is around Php 115,480.31 per year, while the recorded fixed cost, like the repair and maintenance, depreciation of the greenhouse, and other supplies, is only Php 60,000.00 per year. The total cost of operation is Php 175,480.31 per year. In the applied simple economic analysis, the net annual income derived from the project is around Php 129,204.49 per year, while the rate of return to capital is 74% which means that every single peso invested gains around 74% and it breaks even at 947.79 kilograms of harvested lettuce in the project. This scenario presented that the soilless project introduced to the farmer-beneficiaries is economically viable and profitable.

Marketing of the Crops Produced

In the marketing of products offered to the target clients as fresh, the farmer beneficiaries in Limay, Bataan, coordinated with the LGU and gave them space at the Municipal Hall, where they can display the lettuce crops produced through the initiatives of the Municipal Agriculturist. They sell the lettuce crops per piece together with the cup plugged at a price of Php 25 per piece and Php 120 per kg for the other harvest.

However, in Pilar, Bataan, the farmer-beneficiaries sell their produce directly to the target buyers with the assistance of their Municipal Agriculturist. The LGU helps them in the marketing of their lettuce products as one of the commitments prior to the implementation of the project. In BPSU-Abucay Campus, the lettuce crops were sold to the Restaurant in Samal at the weekly interval, while the other harvest was sold to the Balanga City market and to the BPSU employees. The harvest was scheduled based on the market demand at weekly intervals.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the implemented project, the project was properly coordinated with the DA-LGUs and barangay officials before the conduct of the project. The selected farmer beneficiaries were consulted and decided by the DA-LGU and Barangay officials, as per performance evaluation of the farmer group records, and was validated the area was validated for the greenhouse. The

compliance with the project requirements memorandum of agreement was signed and executed.

As part of the preliminary activities, the procurement of supplies and materials was conducted. The existing greenhouse in BPSU-AC was rehabilitated and restored to make it functional and to follow the requirements of the soilless culture system project. The established soilless production system in BPSU-AC serves as the training/seminar venue for the selected farmer-beneficiaries. However, the greenhouse and soilless system in Pilar and Limay, Bataan, were also established and constructed, but the programmed activities were affected and adjusted, causing delays in the procurement and delivery of supplies in the area. The constructed greenhouse has an area of 288 m² with 16 pieces of soilless beds and dimensions of 0.7m x 10.5m x 0.1m. The crop population per soilless bed is around 244 plants, while the total plant population is equivalent to 3,904 plants. Furthermore, the BPSU automation was installed in the identified three sites.

Even with the presence of COVID-19, the project team continuously pursued the implementation of the project while observing health protocol requirements. There were instances when the project was temporarily halted due to COVID-19-related restrictions, but the team remained motivated and committed to carrying out the approved work plan. The total number of farmer-beneficiaries trained in the soilless system conducted in BPSU-AC was 26 farmers, which is equivalent to 25 percent of the total members of the organization. This lower participation rate may be attributed to the effects of the pandemic, which limited mobility and attendance.

In the operation of the greenhouse with BPSU automation, the temperature and humidity were observed at 2.0m, 1.5m, and 2.5m above ground level, with observation times at 8 AM, 12 NN, and 4 PM. The collected data from the soilless beds were compared and analyzed. From the three observation points, the temperature readings showed that the automation effectively controlled the temperature inside the greenhouse between 27–30 °C, while humidity exceeded 85 percent during certain periods due to heat accumulation. It was also found that there is a strong correlation among the different observation points, confirming the efficiency of the automation system.

The hydroponic solution temperature was maintained at an acceptable level for crop growth, along with proper pH and EC levels as indicated in the experimental results with the intervention of the BPSU automation. The observed average crop growth rate was 0.72 cm per day, and the average weight per plant at 22 days was 43.52 grams. The production per month at four beds per week was equivalent to 169.92 kilograms, with a yearly harvest of 2,039.04 kilograms. At Php 120.00 per kilogram, this resulted in a yearly gross income of Php 244,684.80, while the total production cost amounted to Php 175,480.31, giving a net income of Php 129,204.49. The project achieved a 74% rate of return on capital and reached a break-even point at 947.79 kilograms of lettuce crops. In conclusion, the project demonstrated that the soilless culture system with automation is both technically and economically viable, providing a sustainable and efficient approach to crop production. Moving forward, it is recommended to continue

strengthening farmer training and participation, conduct regular monitoring and maintenance of the automation systems, and improve procurement and delivery processes to avoid delays. It would also be beneficial to explore other high-value crops suited for soilless production to further enhance productivity, profitability, and long-term sustainability of the project.

ADVANCED RESEARCH

The study also had its share of limitations. The implementation took place during the COVID-19 pandemic, which made it difficult to move around, gather participants, and deliver materials on time. These challenges affected the schedule and, at times, the consistency of data collection. The project was also limited to a few sites in Bataan, so the results may not fully reflect the conditions in other areas with different climates, soil conditions, or access to resources. For future research, it would be helpful to try the soilless culture system in more locations and with different types of crops to see how well it performs under various conditions. Long-term studies may also be done to look into the overall cost, yield performance, and possible use of renewable energy to make the system even more sustainable and practical for farmers.

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REFERENCES

- Ahmad, A., Liew, A. X. W., Venturini, F., Kalogeras, A., Candiani, A., Di Benedetto, G., Ajibola, S., Cartujo, P., Romero, P., Lykoudi, A., De Grandis, M. M., Xouris, C., Lo Bianco, R., Doddy, I., Elegbede, I., D'Urso Labate, G. F., García Del Moral, L. F., & Martos, V. (2024). AI can empower agriculture for global food security: Challenges and prospects in developing nations. *Frontiers in Artificial Intelligence*, 7, 1328530. <https://doi.org/10.3389/frai.2024.1328530>
- Ali, Z., Muhammad, A., Lee, N., Waqar, M., & Lee, S. W. (2025). Artificial Intelligence for Sustainable Agriculture: A Comprehensive Review of AI-Driven Technologies in Crop Production. *Sustainability*, 17(5), 2281. <https://doi.org/10.3390/su17052281>
- Armas, K. L., Lorenzo, Engr. G., & Cruz, C. D. (2023). Financial Viability of Business Models For Engineered Vertical Hydroponics Systems For Sustainable Onion Production in The Philippines. *Journal of Applied Engineering and Technological Science (JAETS)*, 4(2), 864–872. <https://doi.org/10.37385/jaets.v4i2.2040>
- Badji, A., Benseddik, A., Bensaha, H., Boukhelifa, A., & Hasrane, I. (2022). Design, technology, and management of greenhouse: A review. *Journal of Cleaner Production*, 373, 133753. <https://doi.org/10.1016/j.jclepro.2022.133753>

- Baltazar, R. G. (2024). Forecasting the Impact of Climate Change on Rice Crop Yields under RCP4.5 and RCP8.5 Scenarios in Central Luzon, Philippines, Using Machine Learning Algorithms. *International Journal of Agriculture and Natural Resources*, 51(1). <https://doi.org/10.7764/ijanr.v51i1.2494>
- Banboukian, A., Chen, Y., & Thomas, V. M. (2025). The challenges of controlled environment hydroponic farming: A life cycle assessment of lettuce. *The International Journal of Life Cycle Assessment*, 30(7), 1691–1704. <https://doi.org/10.1007/s11367-025-02463-6>
- Bonelli, L., Montesano, F. F., D'Imperio, M., Gonnella, M., Boari, A., Leoni, B., & Serio, F. (2024). Sensor-Based Fertigation Management Enhances Resource Utilization and Crop Performance in Soilless Strawberry Cultivation. *Agronomy*, 14(3), 465. <https://doi.org/10.3390/agronomy14030465>
- Chen, X. (2025). The role of modern agricultural technologies in improving agricultural productivity and land use efficiency. *Frontiers in Plant Science*, 16, 1675657. <https://doi.org/10.3389/fpls.2025.1675657>
- Dennison, M. S., Kumar, P. S., Wamyil, F., Meji, M. A., & Ganapathy, T. (2025). The role of automation and robotics in transforming hydroponics and aquaponics to large scale. *Discover Sustainability*, 6(1), 105. <https://doi.org/10.1007/s43621-025-00908-4>
- Edrian P, M. M. (2025). The viability of hydroponic agriculture in tropical developing regions: A case study of Nueva Ecija, Philippines. *Asian Journal of Agriculture and Rural Development*, 15(2), 202–213. <https://doi.org/10.55493/5005.v15i2.5406>
- Galvan, J. P. D., Adorio, M. D., Simon, M. R. A., & Razote, R. P. (2021). Growth and yield performance of pechay (*Brassica napus* L.) in hydroponics system as influenced by magnetic field. *International Journal of Agronomy and Agricultural Research*, 19(1), 1–8.
- Harniati, -, Trisnasari, W., & Saridewi, T. R. (2023). Smart Greenhouse Technology for Hydroponic Farming: Is it Viable and Profitable Business? *International Journal on Advanced Science, Engineering and Information Technology*, 13(4), 1333–1341. <https://doi.org/10.18517/ijaseit.13.4.17916>
- Heo, J., Baek, J., Subah, Z., & Ryu, J. H. (2024). Evaluating crop growth between hydroponics and aquaponics with different light inputs. *Frontiers in Horticulture*, 3, 1413224. <https://doi.org/10.3389/fhort.2024.1413224>
- Herrera-Arroyo, R., Martínez-Nolasco, J., Botello-Álvarez, E., Sámano-Ortega, V., Martínez-Nolasco, C., & Moreno-Aguilera, C. (2025). Smart Hydroponic Cultivation System for Lettuce (*Lactuca sativa* L.) Growth Under Different Nutrient Solution Concentrations in a Controlled Environment. *Applied System Innovation*, 8(4), 110. <https://doi.org/10.3390/asi8040110>
- Hutchinson, G. K., Nguyen, L. X., Rubio Ames, Z., Nemali, K., & Ferrarezi, R. S. (2025). Sensor-controlled fertigation management for higher yield and quality in greenhouse hydroponic strawberries. *Frontiers in Plant Science*, 15, 1469434. <https://doi.org/10.3389/fpls.2024.1469434>

- Islam, S. (2025). Agriculture, food security, and sustainability: A review. *Exploration of Foods and Foodomics*, 101082. <https://doi.org/10.37349/eff.2025.101082>
- Laghari, F., Ahmed, F., Ansari, B., & Silveira Ferreira, P. J. (2025). Agricultural Land, Sustainable Food and Crop Productivity: An Empirical Analysis on Environmental Sustainability as a Moderator from the Economy of China. *Sustainability*, 17(5), 1980. <https://doi.org/10.3390/su17051980>
- Lakhiar, I. A., Yan, H., Syed, T. N., Zhang, C., Shaikh, S. A., Rakibuzzaman, Md., & Vistro, R. B. (2025). Soilless Agricultural Systems: Opportunities, Challenges, and Applications for Enhancing Horticultural Resilience to Climate Change and Urbanization. *Horticulturae*, 11(6), 568. <https://doi.org/10.3390/horticulturae11060568>
- Lenton, T. M., Xu, C., Abrams, J. F., Ghadiali, A., Loriani, S., Sakschewski, B., Zimm, C., Ebi, K. L., Dunn, R. R., Svenning, J.-C., & Scheffer, M. (2023). Quantifying the human cost of global warming. *Nature Sustainability*, 6(10), 1237-1247. <https://doi.org/10.1038/s41893-023-01132-6>
- Li, S., Roger, L. M., Kumar, L., Lewinski, N. A., Klein-Seetharaman, J., Putnam, H. M., & Yang, J. (2023). High-frequency imagery to capture coral tissue (*Montipora capricornis*) response to environmental stress, a pilot study. *PLOS ONE*, 18(3), e0283042. <https://doi.org/10.1371/journal.pone.0283042>
- Lim, D., Keerthi, K., Perumbilavil, S., Suchand Sandeep, C. S., Antony, M. M., & Matham, M. V. (2024). A real-time on-site precision nutrient monitoring system for hydroponic cultivation utilizing LIBS. *Chemical and Biological Technologies in Agriculture*, 11(1), 111. <https://doi.org/10.1186/s40538-024-00641-6>
- Mondal, S. K., Su, B., Huang, J., Zhai, J., Wang, G., Kundzewicz, Z. W., Wang, Y., Jiang, S., Jiang, H., Zhou, J., & Jiang, T. (2024). Climate Change Will Aggravate South Asian Cropland Exposure to Drought by the Middle of 21st Century. *Earth's Future*, 12(5), e2023EF003872. <https://doi.org/10.1029/2023EF003872>
- Mylan, J., Andrews, J., & Maye, D. (2023). The big business of sustainable food production and consumption: Exploring the transition to alternative proteins. *Proceedings of the National Academy of Sciences*, 120(47), e2207782120. <https://doi.org/10.1073/pnas.2207782120>
- Narayanan, R., Madas, S. R., & Singh, R. (2025). Towards Sustainable Greenhouse Design: A Numerical Study on Temperature Control in Multi-Span Hoop Structures. *Sustainability*, 17(19), 8712. <https://doi.org/10.3390/su17198712>
- Ojo, M. O., & Zahid, A. (2022). Deep Learning in Controlled Environment Agriculture: A Review of Recent Advancements, Challenges and Prospects. *Sensors*, 22(20), 7965. <https://doi.org/10.3390/s22207965>
- Park, J. A. G. C. and T. (2023). Transforming Philippine Agriculture through Agriculture 4.0. *Precision Agriculture Science and Technology*, 5(4), 201-214. <https://doi.org/10.22765/PASTJ.20230016>

- Quirante, Z. A., & Politud, E. R. R. (2025). Mainstreaming Low-Cost Hydroponics Using Fermented Plant Juice for Sustainable Lettuce Production in Urban Farming. *International Journal of Multidisciplinary: Applied Business and Education Research*, 6(9), 4675–4698. <https://doi.org/10.11594/ijmaber.06.09.35>
- Rahman, M. A., Chakraborty, N. R., Sufiun, A., Banshal, S. K., & Tajnin, F. R. (2024). An AIoT-based hydroponic system for crop recommendation and nutrient parameter monitorization. *Smart Agricultural Technology*, 8, 100472. <https://doi.org/10.1016/j.atech.2024.100472>
- Rajaseger, G. (2023). Hydroponics: Current trends in sustainable crop production. *Bioinformation*, 19(9), 925–938. <https://doi.org/10.6026/97320630019925>
- Rajendran, S., Domalachenpa, T., Arora, H., Li, P., Sharma, A., & Rajauria, G. (2024). Hydroponics: Exploring innovative sustainable technologies and applications across crop production, with Emphasis on potato mini-tuber cultivation. *Heliyon*, 10(5), e26823. <https://doi.org/10.1016/j.heliyon.2024.e26823>
- Sadek, N., Kamal, N., & Shehata, D. (2024). Internet of Things based smart automated indoor hydroponics and aeroponics greenhouse in Egypt. *Ain Shams Engineering Journal*, 15(2), 102341. <https://doi.org/10.1016/j.asej.2023.102341>
- Song, S., Jeon, J., & Yoon, S. (2025). Optimizing Energy Efficiency and Light Transmission in Greenhouses Using Rotating Low-Emissivity-Coated Envelopes. *Energies*, 18(7), 1613. <https://doi.org/10.3390/en18071613>
- Van Bijsterveldt, C. E. J., Herman, P. M. J., Van Wesenbeeck, B. K., Ramadhani, S., Heuts, T. S., Van Starrenburg, C., Tas, S. A. J., Triyanti, A., Helmi, M., Tonneijck, F. H., & Bouma, T. J. (2023). Subsidence reveals potential impacts of future sea level rise on inhabited mangrove coasts. *Nature Sustainability*, 6(12), 1565–1577. <https://doi.org/10.1038/s41893-023-01226-1>
- Wang, Y., Meili, N., & Fatichi, S. (2023). Evidence and Controls of the Acceleration of the Hydrological Cycle Over Land. *Water Resources Research*, 59(8), e2022WR033970. <https://doi.org/10.1029/2022WR033970>