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Sustainable Water Management: Developing a Hydroponic-Watering System to Support Epiphytic Plant Growth

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Abstract— *This study introduces an innovative hydroponic–epiphytic water system designed to address water conservation challenges in urban agriculture. The system involves repurposing water from a hydroponic setup to irrigate epiphytic plants, promoting sustainability and efficient water management. Expert opinions on the system's development and innovations were gathered using a structured evaluation based on key indicators. Notably, the mean scores were analyzed using an Inter-rater reliability assessment in order to determine the expert's opinion on the development and innovations of the hydroponic-epiphytic water system, and indicate strong acceptance in various aspects, including economic profitability, low initial cost, and compatibility with social values. However, identified areas for modification, such as time and effort savings and immediate benefits, offer valuable insights for refinement.*

The hydroponic–epiphytic system's components, meticulously detailed in the study, contribute to its structural integrity and water circulation efficiency. The chemical composition of the hydroponic solution, emphasizing nitrogen-rich urea, ensures precise nutrient delivery. The hydroponic growing medium, a blend of carbonized rice hull and coconut coir, provides an optimal environment for plant growth. The closed-loop water flow system minimizes wastage by recycling hydroponic water for epiphytic plants, aligning with sustainable gardening practices.

In conclusion, the hydroponic–epiphytic water system proves effective in meeting its objectives of innovation and water conservation. Expert evaluations enhance its credibility, and the identified areas for improvement offer a roadmap for optimization. Recommendations include exploring alternative energy sources, conducting extended studies for long-term observations, and a more comprehensive expert opinion study. This study contributes to the advancement of urban-friendly, sustainable water management practices in agriculture.

Keywords*— Hydroponic, conservation, epiphytes, agriculture, climate change*

I. INTRODUCTION

Background of the Study

The Philippines, like many of its Southeast Asian counterparts, boasts an agrarian landscape integral to its socio-economic fabric. A substantial segment of the rural populace relies heavily on agriculture for sustenance, encompassing four sub-sectors: agriculture, fisheries, livestock, and forestry. This collective sector engages 39.8% of the labor force and contributes a noteworthy 20% to the country's Gross Domestic Product (Perlas, 2019). Addressing the multifaceted challenges confronting the agricultural industry necessitates a strategic emphasis on sustaining the natural resource base, with a particular focus on water conservation. On a global scale, governments and farmers are increasingly dedicated to reducing water usage in plant irrigation, constituting a significant 70% of water consumption. Secretary Roy Cimatu of the Department of Environment and Natural Resources (DENR) advocates for the implementation of ordinances by local government units (LGUs) to foster water conservation practices, notably the collection and recycling of rainwater (De Leon, 2019).

In response to Secretary Cimatu's imperative on water conservation, this study endeavors to pioneer a water system that repurposes water from a hydroponic system to irrigate epiphytic plants. Hydroponic systems, involving plant cultivation in nutrient solutions with or without an inert medium for mechanical support, have gained recognition for their water-efficient nature. These systems utilize a small pump to deliver water directly to the roots, while excess water is collected and repurposed in an overflow reservoir for other plants within the system (Rahman et al., 2019). Hydroponics, an innovative method not widely acknowledged in the country, offers noteworthy efficiency in both space utilization and manpower for maintenance (Hiscock, 2017). Epiphytes, a distinct category of plants that thrive without soil, extract moisture and nutrients from the air and rain (Raine, 2018).

The strategic reutilization of non-recycled, nutrient-rich hydroponic waste solutions emerges as a promising avenue for mitigating environmental pollution (Kumar, 2014). Demonstrated successes in cultivating various crops using recycled hydroponic waste solutions underscore the viability of such an approach (Choi, Lee, & Ok, 2011; Bertoldi, 2009). In alignment with existing literature, this study aims not only to conserve water resources but also to maximize their utility by introducing urban gardening through the innovative repurposing of water from the hydroponic system for the irrigation of epiphytes. This process will be facilitated by an improvised water pump, serving as a sustainable and resource-efficient solution to water management challenges in the agricultural sector.

Objectives of the Study

This study, conducted from September 2019 to October 2019, aims to develop an innovation that conserves water by creating an urban-friendly hydroponic-epiphytic water system. Specific objectives include:

1. Develop an urban-friendly hydroponic-epiphytic water system that reuses water from hydroponic plants for watering epiphytic plants.
2. Determine expert opinions and evaluations on the development and innovations made in the water system.
3. Determine the Cost-analysis in the development and innovations of hydroponic-epiphytic water system.

Upon realization, this study is expected to contribute to water conservation, urban gardening practices, and overall water sustainability.

Review of Related Literature

Philippine Agricultural Problems. The Philippines, being an agricultural country, faces significant challenges in its agricultural sector. One pressing issue is the reduction in the size of farms due to rapid population growth. The expanding population necessitates the construction of more homes, leading to the conversion of agricultural land into industrial zones, shopping malls, and subdivisions (De Guzman, 2018). For instance, in Laguna, rice area decreased by over 50% from 1971 to 1992, accompanied by an annual decrease in rice production of approximately 21% (Moya et al., 1994). Out of the Philippines' 30 million hectares of land, 9.7 million are designated as agricultural (Cabildo, Subingsubing, & Reysio-Cruz, 2016).

Another challenge is the inadequacy of efficient irrigation systems. The poor performance of the country's irrigation system is attributed to optimistic technical and economic assumptions, inadequate water supply, inappropriate designs, and operational and maintenance difficulties, as noted by consultants from the Philippine Institute for Development Studies (PIDS) Dr. Christina David and Dr. Arlene Inocencio. Climate change further exacerbates agricultural difficulties. Variability and changes in temperature, CO2 levels, and rainfall patterns pose a considerable threat to crop production (Mall, Gupta, & Sonkar, 2016). Heatwaves, attributed to climate change, induce stress in both plants and animals, negatively impacting food production.

Prior Art Review. Challenges such as poor soil fertility, continuous cultivation leading to less natural soil fertility build-up, frequent drought conditions, climate unpredictability, rising temperatures, river pollution, poor water management, and excessive water wastage threaten conventional soil-based agriculture. Soil-less culture, or hydroponics, is gaining relevance globally as an alternative method to overcome these challenges (Sadare, 2013). Water plays a crucial role in ecosystems and economies, especially in agriculture. Changes in the water cycle due to climate, weather, and land-use alterations have intricate effects on economic and ecological systems (Ward & Pulido-Velazquez, 2008). Recent studies highlight water shortage concerns amid climate change, emphasizing the need to conserve limited water resources through the reuse of reclaimed wastewater for agricultural purposes (Kumar, 2014).

The Hydroponic System Process. Hydroponics, initially defined as "the cultivation of plants in water," has evolved to encompass plant cultivation without soil. It involves growing plants in nutrient solutions with or without supportive mediums like sand, clay, expanded gravel, vermiculite, rock wool, peat moss, perlite, coir, coco peat, and sawdust (Kumar, 2014). In hydroponic systems, plants' roots are suspended in nutrient-rich water, enabling them to grow without the need for soil. Hydroponics presents a viable option for home gardeners and commercial vegetable production, offering 20-25% higher yields than traditional soil-based systems, with productivity 2-5 times higher (Gashgari et al., 2018). Various hydroponic methods exist, such as Deep Water Culture (DWC), where plants grow in a water reservoir providing stability in the nutrient solution, and reducing the need for constant monitoring and maintenance (epicgardening.com). The study focuses on the intersection of agriculture and urban horticulture, specifically the hydroponic-epiphytic water system. This innovative water system enhances traditional planting methods by reusing water from the hydroponic system to irrigate epiphytic plants, with excess water returning to the hydroponic system's reservoir.

II. MATERIALS AND METHODS

Materials and Methods in the Production of the Hydroponic-Epiphytic Water System

1. Acquisition of Chinese Cabbage Seeds: Procurement of Chinese cabbage seeds from the Provincial Local Government Unit – Office of the Provincial Agriculturist Services (PLGU-OPAS) Biliran. Inquiries were made regarding tips and methods for cultivating hydroponic plants from the Provincial Agriculturist.
2. Growing Chinese Cabbage Seedlings: Cultivation of Chinese cabbage (Brassica rapa subsp. Chinensis) seedlings in soil until the roots were ready for transfer. The cabbage was grown using conventional sowing methods, watered daily, and exposed to an adequate amount of sunlight.
3. Design, Fabrication, Testing, and Evaluation of the Improved Water System: Measurement of dimensions to ensure the system's compatibility with hydroponic plants and overall sturdiness. Construction involved the use of materials such as bamboo, styrofoam cooler, wheels, air pump, and an electrically powered improvised water pump.
4. Measurement of Hydroponic System Base: The Styrofoam was measured to construct a wheeled bamboo container for convenience.
5. Attainment of Bamboo: Cutting down bamboo stems for the container, followed by cleaning and polishing for use.
6. Assembling the Container: Cutting bamboo stems to fit the Styrofoam dimensions and constructing a box-like structure by nailing the stems together.
7. Acquisition of Hydroponic Water Solution: Obtaining synthetic urea, an inexpensive nitrogen fertilizer (46-0-0 ratio), from the local PLGU-OPAS. A tablespoon of urea was diluted in the water, following the recommended solution for hydroponic growth by agriculturists.
8. Aeration System for Nutrient Solution and Oxygenation: Implementing an aeration system for the nutrient solution to ensure proper oxygenation. The deep water culture system, recommended for hydroponic plants with submerged roots, required 1 liter per minute of air for each gallon of nutrient solution (Hydroponics.com).
9. Transfer of Chinese Cabbage to Styrofoam Cups: Styrocups were filled with a 2:1 mixture of carbonized rice hull and coconut coir. Carbonized rice hull, derived from partially burned rice hulls, contains essential micronutrients vital for crop growth.
10. Transfer of Epiphytes to the Improved Water System: Relocating epiphytes to the developed water system.

Parts and Functions of the Hydroponic-Epiphytic Water System

1. Water Pump: The water pump is utilized to convey water under pressure from the water reservoir to the PVC pipe, which functions as the water sprinkler for the epiphytic plants.
2. PVC Pipe: the PVC pipe serves as the conduit for the pressurized water to reach the sprinkler system, facilitating even distribution to the epiphytic plants.

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3. Reservoir: Functioning as the growth medium for the hydroponic plants within the utility model, the reservoir contains essential nutrients required by the plants for optimal development.
4. Air Pump: Responsible for the oxygenation of the deep water, the air pump plays a crucial role in providing the necessary oxygen needed by the hydroponic plants submerged in the water.

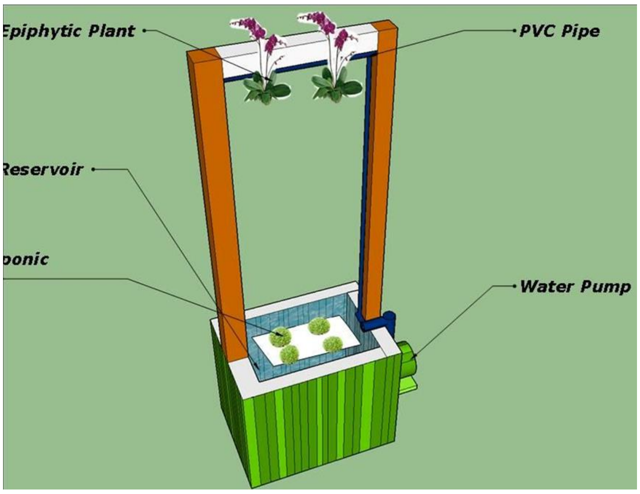

Figure 1
Hydroponic-Epiphytic Water System

Flow of Water in the Hydroponic-Epiphytic System

1. The hydroponic water, with diluted urea, is stored in the water reservoir.
2. Utilizing the improvised water pump, the water moves from the reservoir, flows through the PVC pipe, and irrigates the epiphytic plants. This process involves the recycling of hydroponic water for the watering of epiphytic plants.
3. Any excess hydroponic water from the epiphytic plants descends back into the water reservoir below, initiating the cycle anew.

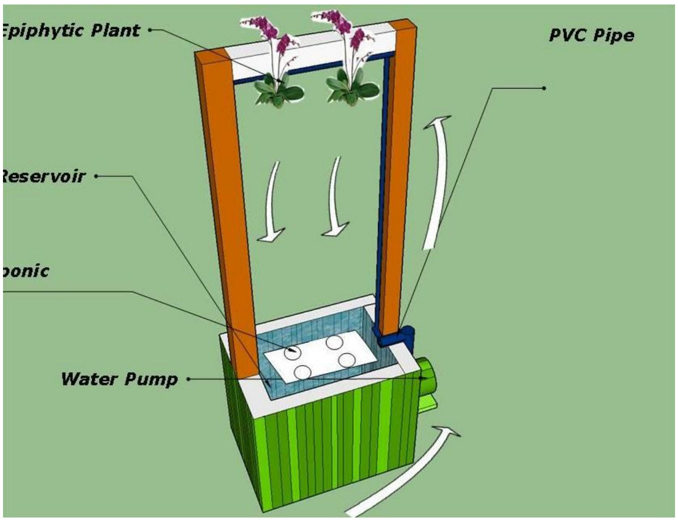

Figure 1
Water flow in the Hydroponic-Epiphytic Water System

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Process in obtaining Expert Opinion and Evaluation of the Hydroponic-Epiphytic Water System

1. The research team visited the Provincial Local Government Unit – Office of the Provincial Agriculturist Services (PLGU-OPAS) to consult with expert employees in the field. Mechanical engineers and research experts in the university were identified for their insights.
2. A comprehensive 2-hour survey was conducted, involving 4 agriculturists and 2 research experts.
3. The researchers employed the five attributes of innovations, based on the Theory of Diffusion of Innovations, as the foundation for evaluating the crafted model. These attributes are:

a. Relative Advantage: The innovation is technically superior to the technology it supersedes in terms of cost, functionality, and image.
b. Compatibility: The innovation aligns with existing values, skills, and work practices of potential adopters.
c. Complexity: The innovation is relatively difficult to understand and use.
d. Trialability: The innovation can be experimented with on a trial basis without undue effort and expense, providing incremental benefits.
e. Observability: The results and benefits of the innovation's use can be easily observed and communicated to others.

4. The experts were tasked with evaluating the model/prototype based on the indicators for each attribute. Data collected were collated, tallied, and analyzed using a 5-point rating scale.
5. The Level of Agreement was categorized as follows:

a) 4.3 – 5.0: Strongly Agree
b) 3.5 – 4.2: Agree
c) 2.7 – 3.4: Neutral
d) 1.9 – 2.6: Disagree
e) 1.0 – 1.8: Strongly Disagree

6. Inter-Rater Reliability assessment was utilized to determine the expert's opinion on the development and innovations of the hydroponic-epiphytic water system. The interpretation of the scores is as follows:

a. .79: Acceptable
b. .70 - .78: Needs Modification
c. Below .70: Not Acceptable

III. RESULTS AND DISCUSSIONS

Development of the Hydroponic – Epiphytic Water System

Table 1 illustrates the Parts and Specifications of the Hydroponic – Epiphytic Water System:

Table 1
Parts and Specifications of the Hydroponic–Epiphytic Water System

Parts	Specifications/Measurement
Base	15''L x 19.5''W
Water Reservoir	15''L x 15'' W
Orchid Beam	19.25'' x 4'' W
Support of the Orchid Beam	43'' L x 2'' W
Styro Cup	3.25''L x 3''d
Styro Cup Holder	12'' L x 10'' W

Table 1 meticulously outlines the integral components and their precise measurements constituting the Hydroponic – Epiphytic Water System. The foundation of the system, the Base, spans 15 inches in length and 19.5 inches in width, providing a stable platform for the entire structure. The Water Reservoir, measuring 15 inches by 15 inches, serves as the vital hub for the hydroponic solution, ensuring a consistent and regulated supply of nutrients. The Orchid Beam, with dimensions of 19.25 inches by 4 inches, plays a crucial role in supporting the growth of plants, while its supporting structure, spanning 43 inches in length and 2 inches in width, guarantees stability and durability. The incorporation of the Styro Cup, measuring 3.25 inches in length and 3 inches in diameter, facilitates the cultivation of epiphytic plants, enhancing the versatility of the system. The Styro Cup Holder, with dimensions of 12 inches by 10 inches, provides a secure placement for the cups, completing the framework of this innovative system. The precision in the measurements of each component ensures optimal functionality and efficiency, reflecting the meticulous design and engineering considerations. The collective synergy of these meticulously measured parts forms the backbone of the Hydroponic – Epiphytic Water System, creating an environment conducive to the flourishing of plants. Through this intentional design, the system not only addresses the specific needs of hydroponic and epiphytic cultivation but also underscores the importance of precision in the pursuit of sustainable and effective agricultural practices. Meanwhile, the chemical composition of urea is detailed in Table 2.

Table 2
The Chemical Composition of Urea (CH_4N_2O)

Element	Atomic Mass	Number of Atoms	Molar Mass
Carbon	12.01	1	12.01
Hydrogen	1.01	4	4.04
Nitrogen	14.01	2	28.02
Oxygen	16.0	1	16.0
		Total =	60.07

Table 2 unveils the precise chemical composition of urea (CH4N2O), breaking down its constituents into carbon, hydrogen, nitrogen, and oxygen. The Atomic Mass of each element, coupled with the Number of Atoms, facilitates the calculation of the Molar Mass, resulting in a total of 60.07 g/mol for urea. Notably, the nitrogen content dominates at 46.6%, constituting an optimal ratio for fostering plant growth. The strategic utilization of urea in the hydroponic water solution underscores the significance of its meticulously calculated composition. By diluting one tablespoon of urea in one gallon of water, the researchers ensure a precisely measured nutrient supply, aligning with the specific needs of the Hydroponic – Epiphytic Water System. The tailored chemical composition of urea, as elucidated in Table 2, plays a pivotal role in providing essential nutrients to plants. The calculated nitrogen percentage not only attests to the suitability of urea for hydroponic cultivation but also emphasizes the importance of precision in nutrient management. This deliberate approach to the chemical makeup of the hydroponic solution enhances the efficiency of nutrient delivery, contributing to the overall success of the system in fostering robust plant growth. Further, the hydroponic growing medium comprised carbonized rice hull (CRH) and coconut coir in a 75:25 ratio, as shown in Table 3.

Table 3
The Content of the Hydroponic Growing Medium

Substance	Percentage Present in the Mixture
Carbonized rice hull (CRH)	75%
Coconut coir	25%

Table 3 succinctly presents the composition of the hydroponic growing medium, with carbonized rice hull (CRH) and coconut coir contributing to the mixture in a proportion of 75% and 25%, respectively. This deliberate arrangement underscores the significance of each substance in creating an ideal environment for plant growth within the Hydroponic – Epiphytic Water System. Carbonized rice hull, constituting the majority of the medium, offers an organic foundation resistant to rapid decomposition, owing to its high silicon content. This resilience ensures prolonged stability and support for plant roots. Conversely, coconut coir, with its substantial water retention capacity, plays a pivotal role by absorbing up to 10 times its weight in water. This dual composition addresses the dual needs of stability and moisture retention crucial for the thriving of hydroponically cultivated plants. The meticulous selection and ratio of substances in the hydroponic growing medium, as depicted in Table 3, reflect a strategic approach to fostering an optimal growth environment. The integration of carbonized rice hull and coconut coir serves as a testament to the emphasis on organic, sustainable, and scientifically calibrated components within the Hydroponic – Epiphytic Water System. This tailored growing medium not only ensures the structural integrity of the system but also promotes the efficient delivery of water and nutrients to the plants.

Expert's Opinion and Evaluation

Table 4 presents the expert's opinion and evaluation of the development and innovations of the hydroponic–epiphytic water system.

Table 4

Experts' Opinion and Evaluation

Indicators	Mean	Interpretation
Relative advantage		
Economic profitability is an advantage of using this technology	0.875	Accepted
Low initial cost is an advantage of using this technology	1.0	Accepted
Decrease in some kind of discomfort is an advantage of using this technology	0.875	Accepted
Use of this technology advances the social prestige of the use	0.875	Accepted
Saving of time and/or effort is an advantage of using this technology	0.75	Needs Modification
The benefits of using technology are immediate a and that is an advantage of using this technology	0.75	Needs Modification
The use of technology is positioned as compatible with social/cultural values and beliefs	0.875	Accepted
Compatibility		
The use of technology is positioned as compatible with previously introduced ideas	0.75	Needs Modification
The use of technology is positioned as compatible with client needs	0.875	Accepted
Complexity		
The technology is positioned and should be perceived by potential users as easy	0.875	Accepted
Trialability		
There are mechanisms of the prototypes that enable the users to easily try the technology	0.875	Accepted
Observability		
The results and benefits of technology is easily visible by potential users.	0.75	Needs Modification

Table 4 provides a comprehensive insight into the expert evaluation of the hydroponic–epiphytic water system, employing a structured assessment based on key indicators. Notably, under the criteria of relative advantage, the mean scores indicate unanimous acceptance for economic profitability, low initial cost, decrease in discomfort, advancement of social prestige, and compatibility with social/cultural values and beliefs, with mean scores ranging from 0.75 to 1.0. However, the dimensions of saving time and/or effort, as well as immediate benefits, emerged as areas needing modification, with mean scores of 0.75. In terms of compatibility, the technology's alignment with previously introduced ideas necessitates adjustment (mean score 0.75), contrasting with the unqualified acceptance of its compatibility with client needs (mean score 0.875). The aspect of complexity garnered a positive reception, with the technology positioned as perceived ease of use receiving a mean score of 0.875. Similarly, trialability and observability received mean scores of 0.875 and 0.75, respectively, indicating acceptance with the stipulation of modifications in the latter case. The implications of these expert evaluations are multifaceted, suggesting that the hydroponic–epiphytic water system enjoys robust support in terms of economic viability, low cost, and social compatibility. The identified areas requiring

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modification, particularly in terms of saving time and/or effort and immediate benefits, signal opportunities for refinement in the implementation and communication of the technology. The accepted compatibility with client needs underscores the system's alignment with user expectations, while the call for modification in compatibility with previously introduced ideas prompts a nuanced reconsideration of contextual integration.

Cost-Analysis in the Production of Hydroponic – Epiphytic Water System

Table 5
Total Expenses of the Hydroponic-Epiphytic System

Material/ Item	***Amount***
Air Pump	P430.00
Water Pump	P706.00
Styrofoam	P240.00
Nylon with Break	P220.00
MTR Hose	P70.00
2x2 Wood	P108.00
PVC	P51.00
PVC Tee	P24.00
PVC Elbow	P24.00
PVC Cap	P8.00
Teflon	P28.00
TOTAL AMOUNT:	P1,909.00

After calculating expenses, the researchers compared the cost of the developed model with the cost of a commonly sold hydroponic system. The common cost of a hydroponic system is $109-$225, approximately P5,552.46-P11,461.50 in the Philippines. In contrast, the developed hydroponic-epiphytic system had a total expense of P1,909.00, affirming its low initial cost and economic profitability.

IV. CONCLUSIONS

In conclusion, this study delved into the critical intersection of water conservation, urban gardening, and sustainable agricultural practices in the Philippines. In response to the call for water conservation, this study sought to pioneer an innovative water system. The objectives of the study were systematically addressed. Firstly, the study successfully developed an urban-friendly hydroponic-epiphytic water system, meticulously detailing its components, measurements, and the strategic utilization of urea in the hydroponic solution. The integration of carbonized rice hull and coconut coir in a 75:25 ratio as the hydroponic growing medium showcased a deliberate and thoughtful approach to creating an ideal environment for plant growth. Secondly, expert opinions and evaluations were sought and obtained. The developed hydroponic-epiphytic water system received widespread acceptance for its relative advantages, compatibility with social/cultural values and beliefs, and perceived ease of use. Areas for modification, particularly in terms of saving time and/or effort and immediate benefits, were identified, indicating avenues for refinement in implementation and communication. Lastly, a cost-analysis revealed that the total expenses for the developed hydroponic-epiphytic system were significantly lower than the cost of commonly sold hydroponic systems in the market. This affirms the low initial cost and economic profitability of the developed system, making it an accessible and viable option for adoption.

Drawing from the insights gained through the literature review, data collection, and analysis, as well as the expert opinions on the hydroponic-epiphytic water system's development, several key areas for improvement and future attention have been identified. The following recommendations are proposed:

1. The current reliance on electricity for the improved water system presents an economic disadvantage. To enhance the technology's economic viability, future researchers are encouraged to explore alternative energy

sources. Integrating a solar panel system would not only contribute to a more sustainable and cost-effective operation but also align with the goal of reducing the system's dependence on conventional energy sources.

2. Considering the dynamic nature of plant growth, conducting an extended study over a more prolonged period is recommended. This approach would enable a more accurate and comprehensive observation of the development and growth of both hydroponic plants and epiphytes. The extended duration of the study will contribute to a more robust understanding of the system's long-term effectiveness.

3. To enhance the validity of expert opinions and evaluations, a more comprehensive study should be undertaken. This study could include additional features related to areas identified for improvement, such as the perceived advantages of saving time and effort, the immediacy of benefits, compatibility with previously introduced ideas, and the visibility of results and benefits to potential users. A thorough examination of these aspects will provide a more nuanced and accurate assessment of the system's strengths and areas needing refinement.

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