Water and Fertilization Management Prototype for Eggplant

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Water and fertilization are critical components in farming, as different crops and plants require specific watering and fertilization schedules to thrive. Effective water and fertilization management can significantly support farmers, particularly when implemented through automated hardware systems (Aijaz et al., 2025; Lakhiar et al., 2024; Xing & Wang, 2024; Et-taibi et al., 2024; Kaur et al., 2024). Such technology reduces manual labor, provides more time for farmers to manage their crops, and ensures consistent plant care.

According to Ricciardi et al. (2018), smallholder farmers, particularly older individuals in developing countries, produce the majority of the world's food. However, older farmers are less likely to adopt new technologies that could sustainably increase agricultural productivity while safeguarding the environment. This underscores the importance of encouraging younger generations to engage in agriculture. Technological solutions, such as automated systems, can help bridge the gap created by an aging farming population. For instance, in Japan, Hiroki Iwasa, a former IT engineer with limited farming experience, developed computer-controlled greenhouses that manage every aspect of the growth environment, including humidity, carbon dioxide, nutrients, water, and temperature (Kaneko, 2017). This approach highlights how technology can make farming more appealing and efficient for younger farmers while ensuring optimal crop growth.

The present study focused on developing a water and fertilization management system specifically for eggplant cultivation, targeting small vegetable farmers. The prototype consists of a water pump that automatically switches on and off and includes a timer setting to regulate both the duration and frequency of water delivery. By automating irrigation and fertilization, the system reduces manual labor and ensures consistent plant care. Irrigation, defined as the application of water at required intervals and amounts, is essential not only for farm productivity but also for promoting proper seed germination, maintaining soil fertility, and supporting plant growth and development (Kelley et al., 2025).

Fertilization strategies also play a key role in crop productivity. Moncada et al. (2020) states that fertilized spring seedlings and transplants are initially treated with soluble fertilizers mixed with water, later transitioning to granular vegetable fertilizers as the plants grow. Optimal water management combined with crop-specific fertilizer rates can increase productivity while reducing non-point source nutrient pollution, making it both environmentally sustainable and economically beneficial (Hashemi et al., 2024; Feng et al., 2020; Abd–Elrahman et al., 2022).

Globally, smallholder farmers provide the food relied upon by up to 70% of the world’s population, yet they remain financially vulnerable and increasingly affected by climate variability (Joshi, 2024). While traditional irrigation methods have long been used to water crops, modern technology allows for more efficient and precise watering and fertilization, easing farmers' workload and enhancing crop management. Recent studies by Mohammadi et al. (2019) show that root water and nitrate uptake under optimal irrigation conditions (So treatment) exceeds that of conventional methods, with application efficiency improving by 9–15% depending on the treatment. This underscores the value of automated water management systems in maximizing resource use.

The primary objective of this study was to develop a functional prototype for water and fertilization management of eggplant, enabling small vegetable farmers to efficiently manage irrigation and nutrient application while reducing labor and increasing productivity.

Theoretical Framework

Water Management

Water is a fundamental resource in agriculture, essential for crop growth and livestock production. With global population growth accelerating, efficiently managing available water resources has become crucial to meeting the increasing demand for food. Effective water management remains a significant challenge, but recent technological advancements have improved monitoring and management practices in agriculture (Parra-López et al., 2025; Alharbi et al., 2024; Antu et al., 2024). Applications of the Internet of Things (IoT), wireless sensor networks, and cloud computing have enabled smarter, more automated approaches to agricultural water management. By addressing water management holistically, these technologies aim to maximize water use efficiency, enhance crop yield and quality, and reduce the need for extensive human intervention (Abdelmoneim et al., 2025; Mansoor et al., 2025; Nsoh et al., 2024).

Uhlenbrook et al. (2022) emphasizes that knowledge of water availability and usage is critical not only for agriculture but also for environmental management, societal needs, navigation, and transportation. Accurate forecasting of water supply and demand has long been a challenge worldwide. By predicting incoming water volumes in reservoirs, farmers and managers can make informed decisions regarding water distribution and usage. A systems-based perspective further enhances water management by considering the interactions between subsystems, the dynamic changes over time, and the broader impacts of interventions. This approach prevents the isolation of water management subsystems, allowing farmers to optimize irrigation through automation while remotely monitoring and controlling their farms, thereby improving efficiency and responsiveness.

Fertilizer Management

Fertilization is another critical aspect of farming that directly impacts crop productivity and environmental quality. Proper fertilization ensures that crops receive adequate nutrients during peak growth periods, based on the soil’s inherent nutrient-supplying capacity. Mismanagement of fertilization can lead to economic losses, soil degradation, and contamination of groundwater and surface water. Over-fertilization, in particular, can cause eutrophication, whereby excess phosphorus in freshwater promotes algal blooms that deprive other species of oxygen and sunlight, disrupting aquatic ecosystems (Xing et al., 2025).

Fertilizer application practices often vary among regions and even among farmers within the same area. In irrigated plantations, fertilizers are most effective when applied 12–24 months before or after the peak growing season. However, in regions where subsidies encourage high fertilizer usage, nutrient overabundance is common, leading to environmental degradation and reduced water quality. Achieving a dynamic balance in nutrient application is therefore essential for sustainable agricultural productivity and environmental protection.

Related Prototypes

Crop irrigation and fertilization using purified wastewater. A pioneering prototype developed by ENEA and the University of Bologna, in partnership with the Hera Group and Irritec, integrates purified wastewater for crop irrigation and fertilization (ENEA, 2022). This system conserves water, provides nutrients that can partially replace chemical fertilizers, and enhances the sustainability of the water purification process. The prototype, part of the Value CE-IN project funded by the Development and Cohesion Fund and the Emilia-Romagna Region, was tested at the Cesena purification facility on 120 crops, including 66 peach trees and 54 industrial tomatoes. This innovation demonstrates how wastewater can be repurposed to increase resource efficiency and reduce the environmental footprint of agriculture.

Embedded system for greenhouse irrigation and fertilization. Mite-Baidal et al. (2019) developed a prototype that leverages embedded systems and hardware-software codesign to automate greenhouse irrigation and fertilization. The system reduces manual labor while improving efficiency and precision. Soil moisture sensors trigger irrigation or fertigation through nebulizers, ensuring plants receive the right amounts of water and nutrients. The system also measures soil nitrogen, phosphorus, potassium, and other mineral levels, while a solar panel provides sustainable energy. An ultrasonic sensor monitors water levels in tanks for optimal rationing.

Farmers access real-time data via a smartphone application, with all information stored on a cloud server for record-keeping and analysis. This prototype automates critical processes, reduces costs, and allows farmers to provide optimal care for greenhouse crops while maintaining detailed daily records.

Research Framework

This section describes the methods employed in conducting the study, including the research design, methodology, and the technical aspects involved in system modeling.

Design

This study employed an experimental research design, which provides a structured framework of protocols and methods developed to conduct scientific investigations involving two sets of variables. In this setup, the first set of variables remains constant and serves as the basis for comparing changes observed in the second set. This approach allows researchers to test hypotheses systematically and objectively. Moreover, the use of an experimental design enables researchers to carry out their research aims with greater clarity, transparency, and control over influencing factors.

Respondents

The study utilized a quota sampling method to ensure an unbiased selection of participants and improve the generalizability of the findings. Quota sampling is a non-probability sampling technique wherein researchers select participants who accurately reflect the characteristics of the target population. Participants are chosen based on specific traits or attributes relevant to the study.

A total of 15 vegetable farmers from Sariaya, Quezon, Philippines, were selected as respondents. The researchers recognized that additional data could further enhance the comprehensiveness and validity of the study's results. Among the respondents, the majority were 41 years old and above (40%), followed by those aged 36–40 years (33.33%). In terms of farming experience, most had been engaged in farming for 2–3 years (60%), while 33.33% had four years or more of experience in the field.

Instrument

The primary research instrument was a questionnaire designed to gather data on farmers' perspectives regarding water and fertilizer efficiency. Respondents rated their familiarity with the sub-variables using a Likert scale. The third section of the questionnaire assessed the prototype machine's quality, focusing on its functional suitability, usability, reliability, and maintainability. This section aimed to measure respondents' satisfaction with the developed prototype's performance.

The Likert scale was used to quantify the participants' responses, providing a standardized way for them to indicate their level of agreement or disagreement with each statement. This approach facilitated the collection of numerical data suitable for statistical analysis, allowing the researchers to identify patterns and trends in participants' perceptions of the prototype machine's quality and usability.

Before distribution, the questionnaire underwent two validation procedures: content validation and concurrent validation. Content validation involved the review and feedback of three experts, an MIT professor, an IT instructor, and an ICT NCII competencies assessor, to ensure that the items were clear, relevant, and aligned with the study's objectives. These validation processes established the reliability and accuracy of the instrument, thereby enhancing the credibility, rigor, and integrity of the study's findings.

Statistical Treatment

The data collected were analyzed using frequency, percentage distribution, weighted arithmetic mean, and ranking. These statistical tools allowed the researchers to summarize responses, interpret trends, and draw meaningful conclusions from the gathered data.

Ethical Considerations

The study adhered to the ethical principle of informed consent, ensuring that all respondents participated voluntarily. Participants were provided with sufficient information about the study's purpose, procedures, and potential implications to make an informed decision about their involvement. The researchers emphasized that participation was entirely voluntary, free from any form of coercion or undue influence, in accordance with standard ethical research practices.

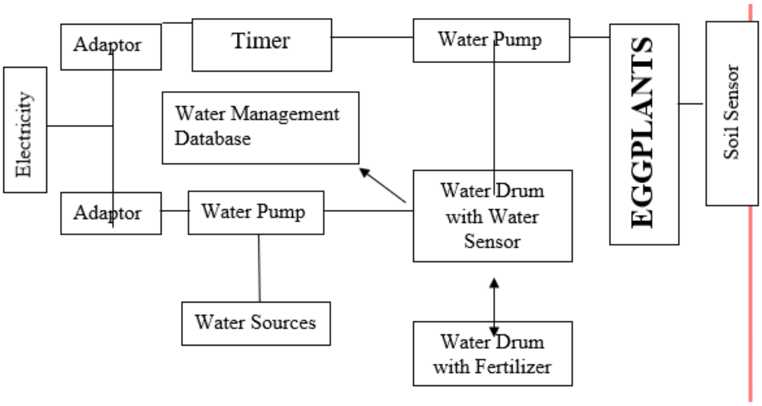
Modeling

Figure 1 presents the flow diagram of the developed hardware. The diagram illustrates the process of the automated water and fertilizer management system designed for vegetable farmers. The system operates using a switch timer connected to an electrical source, which automatically activates the machine. Through this timer, farmers can set the specific duration for which the water pump will operate and the length of time allotted for fertilization of the eggplants.

Once activated, the system records in its database the date, time, and duration of the water pump’s operation. The electrical power is then transferred to the water pump motor, enabling the distribution of water through the connected pipes. The water drum is equipped with a water level sensor that monitors the water volume. When the water level reaches a critical point, the pump connected to the water source automatically activates to refill the drum. Once the desired water level is reached, the pump automatically shuts off to prevent overflow.

Figure 1

Flow diagram



The fertilizer drum is connected to the water pump through a hose, allowing the system to mix and distribute fertilizer as needed. When the eggplants require fertilization, the system channels the water-fertilizer mixture through the pipes, ensuring that the plants are efficiently watered and nourished. This automated process reduces manual labor, conserves resources, and promotes consistent plant growth.

Procedures of the Different Phases

Machine design. The machine developed for the water and fertilization management of eggplants for vegetable farmers is a prototype model. It operates through a switch timer, a device that can automatically turn on and off various types of electrical equipment at preset times. Using this instrument, farmers can set the duration for which the water pump operates and the time allotted for fertilizing the eggplants.

Analysis. The machine operates using a switch timer connected to a power source. Farmers set the desired duration for irrigation and fertilization, after which the timer automatically activates the system. The power is then transferred to the water pump motor, which drives the flow of water through the connected pipes.

The water drum plays a crucial role in regulating water supply. Its water sensor detects when the level is critically low, triggering the source pump to refill the drum automatically. Once the optimal level is reached, the pump switches off. Meanwhile, the fertilizer drum releases fertilizer through a hose connected to the pump when needed, ensuring that water and nutrients are evenly distributed to the eggplants.

The soil sensor continuously monitors the moisture level in the soil. When the soil becomes sufficiently wet, the sensor automatically shuts off the water pump to prevent over-irrigation. This process ensures efficient use of water and fertilizer, reduces manual labor, and promotes healthier plant growth through precise and automated control.

Testing. The testing phase aimed to measure the functionality and performance of the water and fertilization management prototype to determine its effectiveness and reliability. After the development of the machine, the researchers conducted a series of demonstrations and operational tests to verify whether all components functioned as expected. Each hardware component was individually tested to ensure compatibility and proper integration within the system.

In addition, the researchers simulated real-world scenarios to evaluate how the machine would perform under typical farming conditions. These test cases allowed the researchers to identify potential issues, assess operational efficiency, and confirm that the system could perform its intended tasks, automated watering and fertilization, effectively and consistently.

The testing approach involved systematic verification and validation of the machine's operation. The researchers first implemented the prototype in a controlled environment to detect possible technical problems and make necessary adjustments. This proactive approach allowed them to identify and fix issues promptly, thereby improving the overall performance and stability of the system.

Furthermore, the researchers considered potential risks associated with electrical and mechanical components, as well as regulatory and safety aspects of the design. A well-defined testing plan was followed to ensure that any malfunctions, incompatibilities, or safety hazards were immediately addressed. This ensured that the prototype met both functional and safety standards before being deployed for actual use.

Deployment and Maintenance. The researchers developed a comprehensive implementation plan for the deployment of the machine prototype. The deployment phase included a review and approval process to verify that the system operated as intended after completing all required testing stages. Once all evaluations were successfully passed, the prototype was deemed ready for real-world application by the end users.

The deployment of a hardware prototype provided valuable user feedback prior to large-scale implementation. Users were encouraged to test the prototype and provide insights into its usability and effectiveness. Based on these comments, the researchers made necessary refinements before final acceptance. This iterative process continued until the users, primarily the farmers, were satisfied with the prototype's performance and functionality.

Regarding maintenance, the researchers emphasized the importance of preparing solutions for potential technical issues that may arise after deployment. Ensuring the farmers understood how to manage minor problems was crucial to prevent panic or misuse. Post-deployment, the researchers conducted an evaluation of the hardware's performance to confirm that all systems were functioning efficiently and to plan for future improvements.

Technical Framework

This section describes the technical framework of the study, encompassing the design, structure, and functional flow of the system, as well as the interactions between its hardware and software components.

Materials

Table 1

Hardware specifications

Hardware	Specification
Adapter	12V AC Adapter Charger Power
Timer	SINOTIMER AC 12V Digital TIMER SWITCH
Water Pump	Pressure Diaphragm Self Priming Water Pump 6L per minute 12v
Water Hose	Transparent Silicone Rubber Hose
Nozzle	BB Plastic Stopper nozzle
Water Container	Water container 150 liters
Water Sensor	Arduino Nano
Wire	Jumper wires
Mixer	Mini Washing Machine
Soil Sensor	Arduino Uno

Adapter. The adapter was used to connect the system to the main electrical source, allowing the switch timer and water pump to operate efficiently.

Switch timer. The researchers used a switch timer capable of automatically turning on and off various electrical equipment at preset times. This was the first essential component required for the machine's operation, as it controlled the activation and deactivation of the water pump and fertilization process.

Water hose connector. A water hose connector was utilized to securely connect hoses to different pressurized air and water outlets. This coupling ensured stable and leak-free connections between the hoses and other components of the system.

Water pump motor. The water pump motor is an electromechanical device that generates pressure to move water from one point to another. It is an essential part of the system's water control mechanism, responsible for transferring water efficiently from the source to the distribution pipes and ultimately to the plants.

Water hose. A transparent silicone rubber hose was used to transport water between plants. The transparency of the hose allowed the researchers to observe the flow of water during operation, ensuring consistent distribution across the system.

Water sensor. A water sensor was installed to monitor the water level in the storage container. This sensor detects when the tank requires refilling, enabling the automatic activation of the source pump when water levels fall below the critical threshold.

Water container. A 150-liter water container served as the main water reservoir for the system. It stored the water used for both irrigation and fertilization processes throughout the experiment.

Washing turbine. A mini washing machine turbine was repurposed to mix the fertilizer with water inside the drum. This component ensured proper blending of the fertilizer solution before it was distributed to the plants.

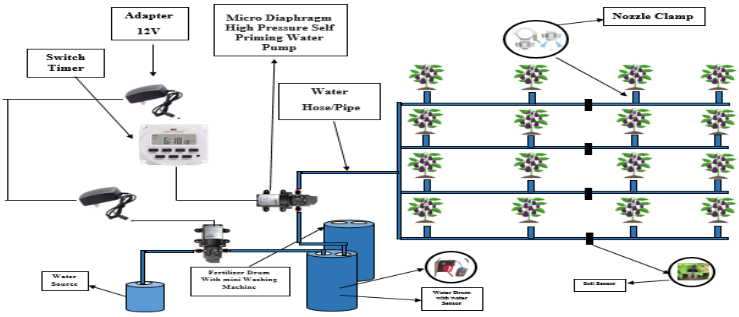
Arduino Uno. The Arduino Uno microcontroller was used to operate the soil moisture sensor. It monitored the soil's moisture content and automatically turned off the water pump when the soil was sufficiently wet, optimizing water usage and preventing over-irrigation.

Modelling

Figure 2 illustrates the machine design of the prototype

Figure 2

Machine design of the prototype



The machine developed for water and fertilization management of eggplants is a prototype model designed specifically for vegetable farmers. The system operates using a switch timer, a device that can automatically turn on and off various electrical equipment at preset times. Using this timer, farmers can set the duration for which the water pump operates and the time allotted for fertilizing the eggplants.

The water drum is equipped with a water level sensor that monitors the water volume. When the water level drops to a critical point, the pump connected to the water source automatically activates to refill the drum. Once the desired water level is reached, the pump automatically shuts off to prevent overflow. The fertilizer drum is connected to the water pump via a hose, enabling fertilizer to be applied to the plants as needed. Additionally, a soil moisture sensor is integrated into the system to automatically switch off the water pump when the soil is sufficiently wet, preventing overwatering and conserving resources.

In terms of design, the prototype has a rectangular shape, measuring 45 inches in length and 30 inches in width, providing a compact and functional layout suitable for small to medium-scale vegetable farms.

Figure 3

The circuit diagram

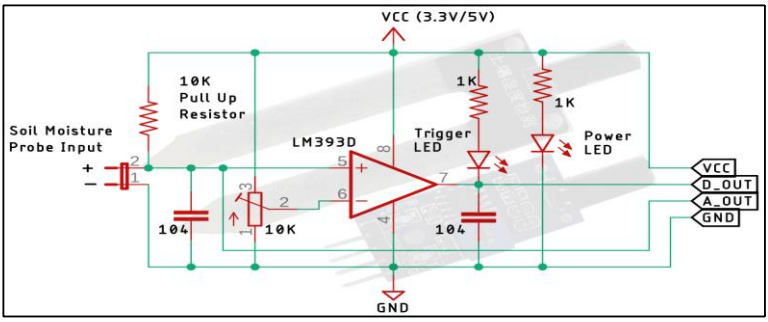


Figure 3 shows the circuit diagram. The circuit diagram depicts the electrical flow within the soil sensor, demonstrating how the sensor detects soil moisture and sends signals to automatically activate or deactivate the water pump to maintain optimal soil conditions.

Figure 4 shows the water sensor used in the system. The purpose of the water sensor is to automatically refill the water container from the main water source. When the sensor detects that the water level has dropped (the sensor sinks), the water pump activates to refill the container. Once the water level reaches the required height (the sensor floats), the water pump automatically stops, preventing overflow and ensuring consistent water availability.

Figure 4

Water sensor

Figure 5

Soil sensor and switch timer

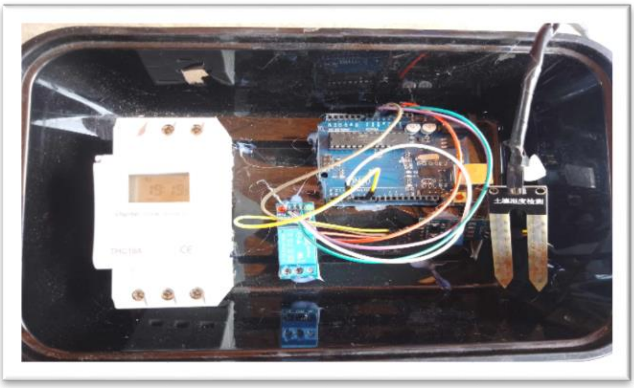


Figure 5 shows the soil sensor and switch timer used in the system. The soil sensor is designed to prevent excessive watering by detecting the soil's moisture level and automatically stopping the water pump when the soil is sufficiently wet. The switch timer allows farmers to control the operation duration of the water pump. It has three settings: ON, which manually turns on the water pump; AUTO, which automatically controls the water pump based on the preset schedule; and OFF, which manually disables both the soil sensor and the switch timer, stopping the system entirely.

Figure 6

Water management database

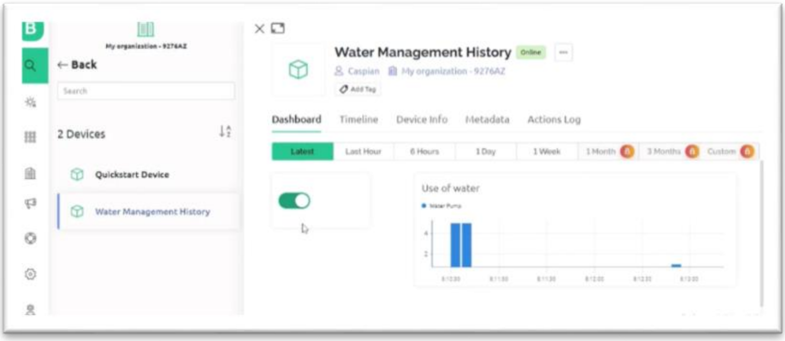
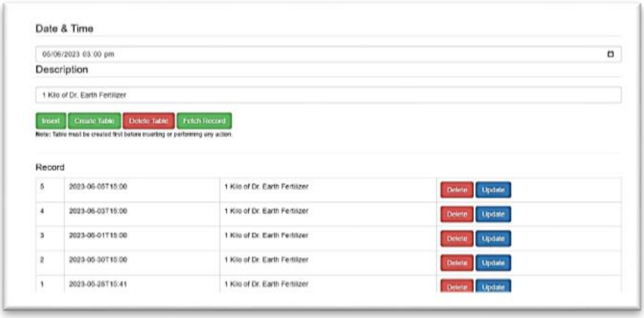


Figure 6 illustrates the water management database, which logs the exact date and time of each water pump operation, allowing for accurate monitoring and analysis of irrigation activities.

Figure 7

Fertilization Management Database



Date & Time

06/06/2023 03:00 pm

Description

1 Kilo of Dr. Earth Fertilizer

Note: Table must be created first before inserting or performing any action.

Record

5	2023-06-05T15:00	1 Kilo of Dr. Earth Fertilizer	Delete Update
4	2023-06-03T15:00	1 Kilo of Dr. Earth Fertilizer	Delete Update
3	2023-06-01T15:00	1 Kilo of Dr. Earth Fertilizer	Delete Update
2	2023-05-30T15:00	1 Kilo of Dr. Earth Fertilizer	Delete Update
1	2023-05-28T15:41	1 Kilo of Dr. Earth Fertilizer	Delete Update

Figure 7 illustrates the fertilization management database, tracking both the timing of fertilizer application and the quantity used, providing an accurate record of resource usage for effective farm management.

Table 2

Data analysis

Time and Date	Water consumption	Fertilizer consumption
2023-05-28 / 15:41	16 liters of water used by the machine	1 kilo of Dr. Earth Fertilizer
2023-05-30 / 15:00	16 liters of water used by the machine	1 kilo of Dr. Earth Fertilizer
2023-06-01 / 15:00	16 liters of water used by the machine	1 kilo of Dr. Earth Fertilizer
2023-06-03 / 15:00	16 liters of water used by the machine	1 kilo of Dr. Earth Fertilizer
2023-06-05 / 15:00	16 liters of water used by the machine	1 kilo of Dr. Earth Fertilizer

Table 2 displays the recorded data on the date and time of water pump and fertilizer usage, including the quantity of water and fertilizer applied to the plants.

Table 3

Risk analysis

High	Average	Low
Short Circuits	Poisoning	Soil sensor ate by rats
Pump getting explode	Electrocuted	Soil sensor gets burn
	Water sensor gets stock by tree branch	
	Over heating	

Table 3 presents the risk analysis of the system. High-risk factors include the possibility of a short circuit and the potential explosion of the water pump. Moderate risks involve hazards such as poisoning from fertilizer exposure, electrocution, blockage of the water sensor by tree branches, and overheating. Low-risk factors include the soil sensor being damaged by rats or being burned due to prolonged exposure to sunlight.

Table 4

Cost benefit analysis

Materials, Tools & Equipment	Quantity	Price	Total
Water Sensor	1	350	350.00
Adapter	3	300	300.00
Switch Timer	1	450	450.00
Water Pump	2	380	760.00
Water Hose	1 (10 meters)	100	100.00
Water Hose connectors	25	500	500.00
Water Container	2	150	300.00
Water Turbine	1	250	250.00
Arduino Uno	1	680	680.00
Soil Sensor	1	70	50.00
Total Costs		**Php 3,740**	

As shown in Table 4, the Water and Fertilization Management Prototype was developed at a total cost of Php 3,740, covering all necessary materials, tools, and equipment. The most significant contributors to the cost were the water pump (Php 760), Arduino Uno (Php 680), and water hose connectors (Php 500), which are essential components for the automation and connectivity of the system.

The relatively low overall cost demonstrates that the prototype is affordable and feasible for small-scale vegetable farmers. By investing in this system, farmers can potentially reduce labor costs and improve efficiency in watering and fertilization. The cost-effectiveness of the prototype, combined with its functionality and automation features, makes it a practical solution for improving farm productivity while remaining budget-friendly.

Table 5

Water efficiency overall mean score

Indicator	Mean	Interpretation
Water Efficiency	3.89	Strongly Agree
Fertilizer Efficiency	3.81	Strongly Agree
Overall Prototype Machine	**3.85**	**Strongly Agree**

As indicated in Table 5, the overall assessment of the prototype's efficiency yielded a mean score of 3.85, also verbally interpreted as "strongly agree," demonstrating that the system performs effectively in both watering and fertilization management.

In terms of water efficiency, the respondents generally strongly agreed that the prototype effectively manages water usage, with an overall mean score of 3.89, which is verbally interpreted as "strongly agree."

For fertilizer efficiency, the weighted mean was 3.81, indicating that most respondents were familiar with the system's fertilization process and found it effective.

Figure 8

Overall mean score of hardware prototype machine

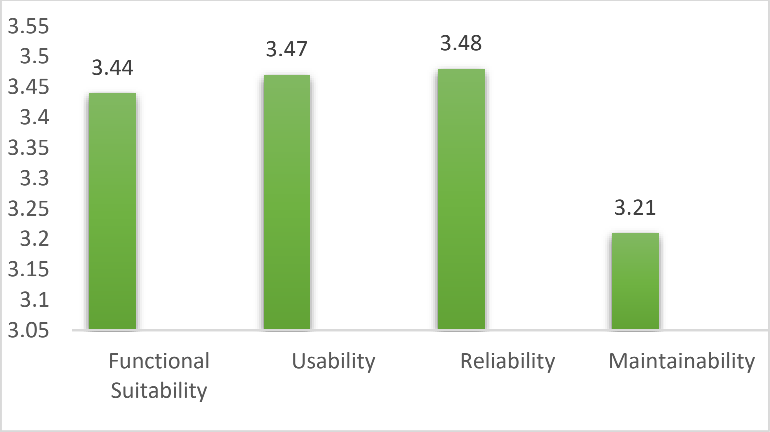


Figure 8 presents the overall mean score for the hardware prototype, which was 3.4, verbally interpreted as “strongly agree.” This indicates that the respondents generally found the prototype to be effective and satisfactory. Most of the sub-variables received strong agreement ratings, reflecting positive perceptions of the machine’s performance, usability, and reliability.

In terms of functional suitability, the prototype received an overall mean score of 3.44, suggesting that the respondents agreed that the machine performs its intended functions effectively. For usability, the mean score was 3.47, indicating that the system is user-friendly and easy to operate. The reliability of the prototype was rated at 3.48, reflecting respondents’ confidence in the machine’s consistent performance during operation. All these scores fall under the “strongly agree” category, demonstrating that the prototype meets the expectations of the users in terms of functionality and practical application. However, in terms of maintainability, the prototype received the lowest overall mean score of 3.21, which is verbally interpreted as “agree.” This suggests that while the machine is generally effective, some respondents perceived potential challenges in maintaining or servicing the hardware. This finding highlights an area for improvement, emphasizing the need for clearer maintenance guidelines, easier access to components, or enhanced durability to ensure long-term usability.

Overall, the results demonstrate that the hardware prototype is well-designed, reliable, and user-friendly, but addressing maintainability concerns could further enhance its overall effectiveness and acceptance among farmers.

Conclusion

Compared to traditional methods, the prototype allows for faster and more consistent watering and fertilization of plants, minimizing manual labor while improving resource management. The system's automated features enable farmers to schedule irrigation and fertilization, reducing the risk of over- or under-application. The hardware prototype was deemed acceptable and effective based on the evaluation conducted by the researchers. These results indicate that while the system performs its intended functions effectively, is easy to use, and operates reliably, there is still room for improvement in maintainability to enhance long-term usability and user satisfaction.

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