Enhancing Water Spinach Cultivation Efficiency through Deep Pipe Irrigation Utilizing IoT Technology

Dr. Selvi Lukman, S.T., M.T.
School of Computer Science
BINUS University
Bandung, Indonesia
selvi.lukman@binus.ac.id

Jonathan Aditya Sanusi
School of Computer Science
BINUS University
Bandung, Indonesia
jonathan.sanusi@binus.ac.id

Aaron Kenny Rijadi
School of Computer Science
BINUS University
Bandung, Indonesia
aaron.rijadi@binus.ac.id

Reynaldy Marchell Bagas Adji
School of Computer Science
BINUS University
Bandung, Indonesia
reynaldy.adji@binus.ac.id

Paulus Theodore Kumala
School of Computer Science
BINUS University
Bandung, Indonesia
paulus.kumala@binus.ac.id

Ranny, S.Kom., M.Kom.
School of Computer Science
BINUS University
Bandung, Indonesia
ranny@binus.ac.id

***Abstract*—The experiment comparing Internet of Things (IoT) based irrigation systems with traditional non-IoT systems, focusing on the growth of water spinach (Ipomoea Aquatica) and spinach, led to several key findings. Firstly, IoT-based irrigation systems have a positive impact on plant growth. Both water spinach and spinach grown using IoT-supported deep pipe methods showed faster growth compared to conventional approaches. Moreover, IoT improves irrigation efficiency by automatically watering plants when soil moisture levels fall below set thresholds, thus reducing water waste. This technology also provides significant time and labor savings for farmers, as automated sensor and software controls eliminate the need for continuous manual soil monitoring. Over time, the adoption of IoT-based irrigation systems can enhance crop quality through optimal environmental conditions that promote robust and productive growth. The experiment shows on day 9, water spinach began to enter a stagnant growth phase, where plant height remained relatively constant at 10.3 cm for the IoT irrigation method and 7.8 cm for the deep pipe non-IoT method. Meanwhile, spinach plants continued to exhibit steady growth during this period. As a result, the implementation of IoT irrigation systems has the potential to enhance overall efficiency, productivity, and crop quality in agriculture, offering farmers effective management of their crops.**

Keywords*—*deep pipe, IoT, ESP8266, Blynk, Arduino IDE, irrigation system, agriculture

I. INTRODUCTION (*HEADING 1*)

Water spinach (Ipomoea Aquatica) is a highly nutritious leafy vegetable with significant agricultural potential due to its rapid growth cycle and adaptability to various cultivation methods. Water spinach is also known for its ability to grow in diverse environmental conditions, both in wet and dry lands, and can be cultivated hydroponically or using conventional methods. This growth capability can be used for the integration of Internet of Things (IoT) tools to optimize the efficiency of water spinach cultivation [1].

Soil pH significantly influences water spinach cultivation. Optimal pH is required to ensure that plants absorb enough nutrients. Water spinach that grows in soil that has too high or too low pH will have difficulty absorbing essential nutrients, which can hinder growth and reduce yield. Research has found that the optimal pH for water spinach cultivation is between 5.5 and 6.5 [2].

The integration of IoT into plant irrigation using soil sensors has shown a significant increase in growth rates and minimizing water resource usage [3]. IoT devices can be used for real-time data collection, enabling farmers to monitor plant conditions. By analysing trends and patterns in the data, farmers can make informed decisions about irrigation, fertilization, and other cultivation practices. IoT devices can be integrated with actuators to automate tasks such as watering, fertilizing, and adjusting light levels based on predefined conditions [4].

Deep pipe irrigation is an irrigation system that uses vertical or near-vertical open pipes to deliver irrigation water to the deep root zone. This system is designed to provide water directly to the plant's root zone, allowing the plant to remain hydrated even during dry periods. Deep pipe irrigation allows for efficient use of water. This system also helps reduce weed growth and wild plants and enables quick and efficient water delivery without water wastage, even on steep slopes. Advantages of deep pipe irrigation compared to other traditional irrigation systems are: (1) the development of larger root volumes, (2) increased plant survival rates, (3) hand better plant growth [5].

The integration of IoT technology in agriculture has opened new opportunities to enhance the efficiency and productivity of agricultural land. IoT-based plant monitoring systems can overcome various challenges faced by conventional greenhouses, such as plant diseases, limited land space, and soil degradation. This technology enables real-time monitoring of plant health parameters and the necessary corrective actions. For instance, soil moisture sensors can measure soil conditions, and the ESP-8266 Wi-Fi module transmits the data to an IoT platform for remote monitoring. This allows farmers to efficiently manage irrigation and plant nutrient needs through an Android application, reducing labor costs and manual field interventions. The implementation of IoT in irrigation systems not only improves water usage efficiency but also ensures healthy plant growth with minimal intervention [6].

Therefore, this study aims to enhance the efficiency of water spinach cultivation through the integration of deep pipe irrigation supported by IoT technology. This research contributes to observing more effective planting methods using water spinach as the observation subject. By utilizing insights gained from previous research, this study seeks to advance agriculture through the application of technology in line with modern developments. This paper is further organized as follows. After the introduction, Section II will discuss related works, reviewing what other researchers have done. Next, Section III will explain the hardware and software installation, showing the setup of the experiments. Finally, Section IV will explain the results and discussion.

II. Related Works

A. Internet of Things in Agriculture (Heading 2)

The integration of Internet of Things (IoT) technology in agriculture has revolutionized crop monitoring and management. IoT devices, such as sensors and actuators, enable real-time data collection and automated control of agricultural processes. In the context of water spinach cultivation, A research using IoT sensors investigate soil moisture, temperature, pH levels, and other environmental factors crucial for optimal growth [3][6]. Data from these sensors is transmitted to a cloud system, allowing farmers to make informed decisions and automate irrigation and nutrient delivery.

Recent advancements in IoT technology have further enhanced its application in precision agriculture. For instance, the use of machine learning algorithms to analyse sensor data can predict plant health issues before they become severe, allowing for timely interventions [7]. Additionally, IoT systems can be integrated with Geographic Information Systems (GIS) to provide spatially explicit management recommendations [8].

B. Deep Pipe Irrigation

Deep pipe irrigation is a method designed to deliver water directly to the root zone of plants. This technique uses vertical pipes to ensure water reaches deeper soil layers, reducing surface evaporation and improving water use efficiency. Deep pipe irrigation is particularly beneficial in arid regions or areas with water scarcity, as it minimizes water loss and ensures that plants receive adequate hydration even during dry periods [5]. This method also helps in reducing weed growth and optimizing root development. Furthermore, studies have shown that deep pipe irrigation can significantly improve water use efficiency compared to traditional surface irrigation methods. The system also supports the use of reclaimed water, making it a sustainable option for irrigation in water-scarce areas [9].

C. Microcontroller ESP8266

The ESP8266 is a low-cost microcontroller with built-in Wi-Fi capabilities, making it ideal for IoT applications. This microcontroller can be programmed using the Arduino IDE, which provides a user-friendly environment for programming and debugging. The ESP8266 can connect to various sensors and transmit data wirelessly to a cloud platform or a local server. In agricultural applications, it is used to control and monitor irrigation systems, ensuring precise water delivery based on real-time soil moisture readings [1]. Additionally, the ESP8266's compatibility with a wide range of sensors allows for the monitoring of multiple environmental parameters simultaneously, further enhancing its utility in smart farming systems . Its low power consumption and ease of integration make it a popular choice for developing cost-effective and scalable IoT solutions in agriculture [10].

D. Arduino IDE

The Arduino Integrated Development Environment (IDE) is an open-source platform used for programming microcontrollers. This platform supports various boards, including the ESP8266, and provides an intuitive interface for writing, compiling, and uploading code. The Arduino IDE includes a vast library of pre-written code, simplifying the integration of sensors and actuators in IoT projects. For water spinach cultivation, the Arduino IDE can be used to program the ESP8266 to collect data from soil moisture sensors and control the irrigation system accordingly [1]. Moreover, the Arduino IDE's extensive community support and documentation make it an ideal choice for both novice and experienced developers working on agricultural IoT projects [11]. The availability of numerous libraries and examples for sensor integration further simplifies the development process [12].

E. Blynk Platform

Blynk is an IoT platform that enables users to build application interfaces to remotely control and monitor hardware via smartphones. Blynk supports various microcontrollers, including the ESP8266, and facilitates easy integration of sensors and actuators. With Blynk, users can create interactive dashboards displaying real-time data from sensors and control actuators through buttons, graphs, and other widgets. For water spinach cultivation, Blynk can be used to monitor environmental conditions and control the irrigation system automatically based on the collected sensor data [1]. The platform's user-friendly interface and extensive customization options make it suitable for developing personalized monitoring and control systems . Additionally, Blynk's support for multiple communication protocols ensures reliable data transmission and remote management capabilities [13].

F. Soil pH Management

Soil pH is a critical factor in water spinach cultivation, affecting nutrient availability and plant growth. The optimal pH range for water spinach is between 5.5 and 6.5, as it ensures maximum nutrient uptake and prevents deficiencies or toxicities [2]. IoT sensors can continuously monitor soil pH levels, and automated systems can adjust pH by adding appropriate amendments, ensuring that the soil remains within the optimal range for water spinach growth.

Maintaining proper soil pH levels is essential for maximizing yield and quality of the produce. Recent advancements in soil pH management include the development of real-time monitoring systems that provide alerts and recommendations to farmers via mobile applications, thereby facilitating timely corrective actions . These systems can also integrate data from weather forecasts to predict potential changes in soil pH and recommend pre-emptive measures [11].

G. Efficiency and Productivity Gains

The use of IoT and deep pipe irrigation significantly enhances the efficiency and productivity of water spinach cultivation. IoT systems provide precise control over irrigation, reducing water usage and preventing over-irrigation, which can lead to root diseases and nutrient leaching [4]. Deep pipe irrigation ensures that water is delivered directly to the root zone, promoting healthy root growth and reducing water wastage. These technologies together lead to higher crop yields, lower resource consumption, and increased profitability for farmers [3][6]. In addition, combining IoT with predictive analytics can optimize the scheduling of irrigation and other farm operations, further boosting productivity and resource efficiency [14]. The integration of renewable energy sources, such as solar-powered IoT devices, can also enhance the sustainability of these systems, reducing their environmental impact [15].

H. Soil Moisture

Soil moisture, commonly referred to as soil water, is the total amount of water present in the unsaturated zone of the soil. This includes both liquid water and water vapor. Soil moisture plays a critical role in various ecological and hydrological processes, such as plant growth, weather patterns, and the water cycle. Several metrics are used to measure soil moisture. These include plant-available volumetric soil moisture, which is the depth of water in a given soil depth, and total volumetric soil moisture, which is the volumetric percentage of water in a soil sample. Other measures include soil porosity and total water holding capacity, which indicate the fraction of soil that consists of water-filled pores and the maximum amount of water the soil can hold, respectively [16].

The importance of soil moisture extends to agricultural productivity, drought and flood forecasting, and environmental management. For example, it influences crop yields, forest fire predictions, and water supply management. Soil moisture levels can vary significantly based on factors such as weather conditions, soil type, and vegetation [16].

I. Water Spinach

Water spinach (Ipomoea aquatica), originating from Africa, Asia, and the southwestern Pacific Islands, has been highly valued for its medicinal properties since ancient times, potentially as early as 200 B.C. Traditionally harvested from the wild and actively cultivated, its global dissemination began with European contact in the late 1400s, when it gained recognition as a medicinal food. As Europeans traveled, they introduced water spinach and its various local names and cultural uses worldwide. Subsequent migrations from Asian countries further expanded its reach into new territories. Despite uncertainties about its exact domestication origins, various factors including culinary practices, geographic cultivation patterns, medicinal applications, genetic research, common names, and interactions with pathogens suggest that southeastern Asia likely served as the primary region for its initial cultivation. Despite its cultural and nutritional significance, water spinach has occasionally escaped cultivation, becoming an invasive species in natural environments [17].

J. Spinach

Spinach (Spinacia oleracea) is a leafy annual vegetable belonging to the family Amaranthaceae. It is renowned globally for its nutritional richness, including high levels of vitamins (such as A, C, and E), minerals, carotenoids (like lutein and zeaxanthin), and antioxidant compounds. Spinach exhibits a dioecious reproductive system, primarily wind-pollinated, with variations including monoecious forms. Cultivated spinach varieties differ in leaf morphology and adaptation to photoperiods and climate, with a significant portion of global production originating from regions like China and Denmark due to favorable agricultural conditions [18].

III. The Hardware and Software Installation

The development of an Internet of Things (IoT)-based irrigation system involves several critical stages to ensure the device operates optimally. First, soil moisture sensors are selected and integrated into the system to accurately detect soil moisture levels. These sensors are connected to a microcontroller (Node MCU ESP 8266), which serves as the brain of the device.

Next, software (Arduino IDE and Blynk) is developed to manage data collection from the sensors and make decisions based on this data. The algorithm within this software instructs the microcontroller to activate the automatic irrigation system when the soil moisture level drops below 30%. This software can also be equipped with additional features such as remote monitoring and integration with a smartphone application for ease of control. The software interface on the smartphone is presented in Figure 1.

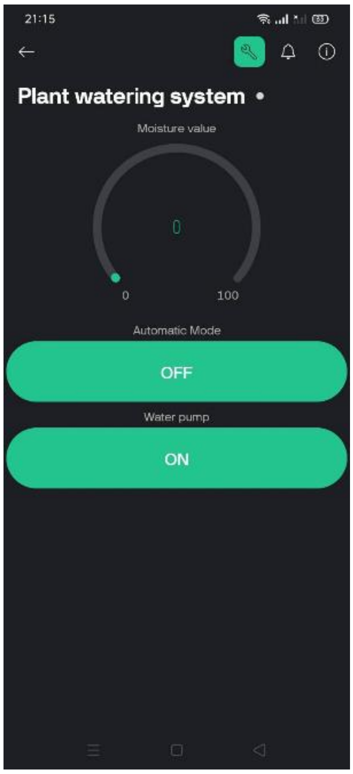

Figure 1. Software Interface on Smartphone

The next stage involves the installation of mechanical components such as water pumps, solenoid valves, and a network of pipes that will deliver water to the plants. The water pump will be activated by the microcontroller based on signals received from the soil moisture sensor. The design and explanation of the device are presented in Figure 2.

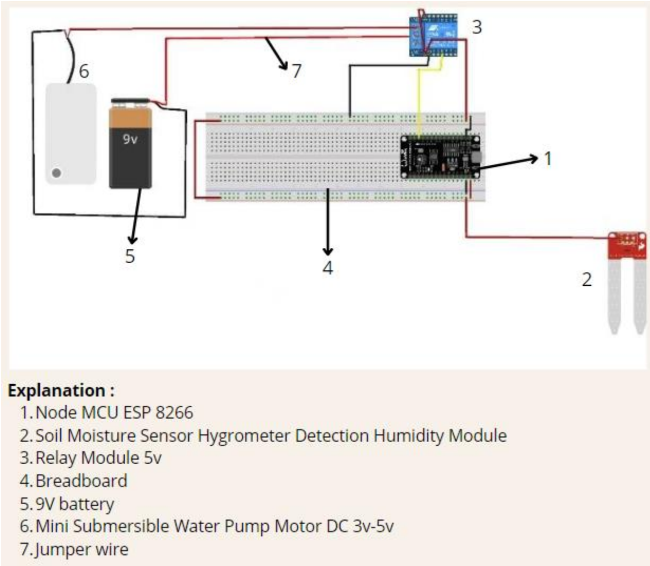

Figure 2. Device Design and Explanation

The IoT irrigation device is designed to water plants when soil moisture is detected below 30%. In contrast, the non-IoT irrigation method waters plants based on a fixed schedule of every two days. This method does not consider the actual soil moisture levels, or the water needs of the plants at that time. The working mechanisms of both the IoT and non-IoT irrigation systems are presented in the flowchart in Figure 3.

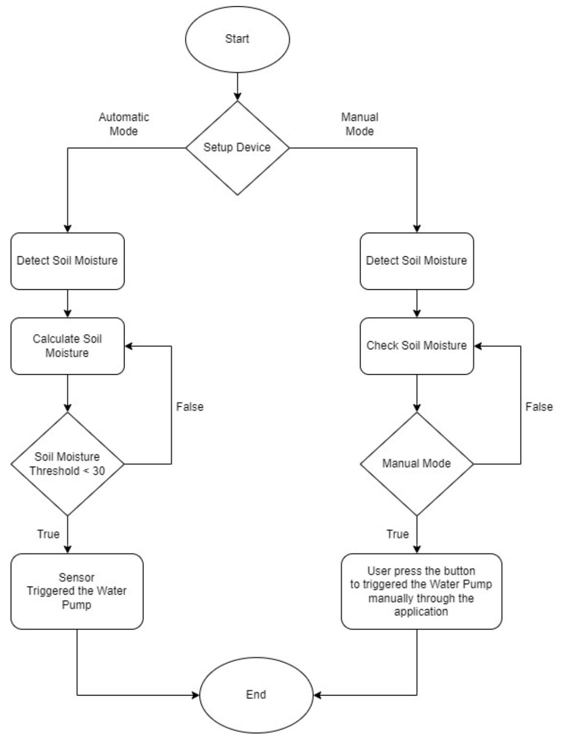

Figure 3. IoT and Non-IoT Irrigation Flowchart

The flowchart in Figure 3 illustrates the workflow of the IoT irrigation device. The developed device is designed to facilitate plant watering with two operation modes: automatic and manual. The process begins with device initialization, where the soil moisture sensor is inserted into the soil. Next, the microcontroller, breadboard, battery, and relay are placed in a location protected from water exposure. The pump is positioned at the water source to enable it to draw and distribute water effectively. Once the IoT irrigation device is set up, it allows the user to select the operation mode. In automatic mode, the device continuously detects soil moisture using a sensor. The moisture data is then calculated and compared to a predetermined threshold of 30%. If the soil moisture is below 30%, the sensor will trigger the water pump to automatically water the plants. If not, the device will continue to monitor soil moisture. Conversely, in manual mode, the user has full control over watering the plants. After soil moisture detection and checking soil moisture levels, the user can manually trigger the water pump through a connected application.


Figure 4. Experiment Setup

The initial phase of the experiment involves planting water spinach seedlings. The growing medium uses pots filled with a soil mixture, a deep pipe system, and an IoT-based automatic watering device. The deep pipe is placed in the center of the pot medium, and water spinach is planted around the pipe. Before being placed, the deep pipe is perforated with small holes along its length to ensure even water distribution within the soil. Each pot contains a deep pipe and three water spinach seedlings. The IoT device is implemented in one of the pot media. The implementation is carried out by inserting a soil moisture sensor near the plant. Then, a water hose is inserted through the deep pipe so that watering can be done directly into the soil. The water source used comes from a container that can hold water, so when the IoT water pump is activated, it draws water from this container. The detailed experimental setup is illustrated in Figure 4.

Figure 5. Initial Soil Moisture Value for Non-IoT Deep Pipe

Figure 6. Initial Soil Moisture Value for IoT Deep Pipe

In Figure 5 and 6, the measurements of soil moisture levels from each planting technique are depicted. Based on the measurement results, both soil media show similar moisture content. Soil moisture is one of the factors monitored by soil moisture sensors for IoT applications.

Figure 7. Experiment

The results of water spinach cultivation on day 16 after planting are shown in Figure 7. A noticeable height difference in water spinach is observed, where the IoT irrigation method shows greater growth compared to manual irrigation. Figure 7 also indicates that the soil appears moist under the Deep Pipe IoT condition. The irrigation process occurred as soil moisture was below the predefined threshold of 30.

IV. RESULT AND DISCUSSION

It is found that the use of IoT in growing water spinach with the deep pipe method has several advantages compared to normal watering. Soil moisture levels significantly influence the growth process of water spinach. With IoT, the plants grow faster due to more controlled watering facilitated by moisture sensors. In contrast, the non-IoT watering method results in slower plant growth. The growth data of water spinach, soil moisture levels, and soil pH are presented in Table 1.

Table 1. Growth Data of Water Spinach, Soil Moisture Levels, and Soil pH

Day	Deep Pipe IOT	Deep Pipe Non IOT	Moisture	Action	PH
	Average height (cm)	Average height (cm)			
1	0	0	27	Watered	6.5
2	0.1	0.1	60		6.5
3	0.1	0.1	45	Watered	6.5
4	0.9	0.4	60		6.5
5	4.2	3.4	40	Watered	6.5
6	7.2	5.8	53		6.5
7	8.1	6.4	42	Watered	6.5
8	9.5	7.2	65		6.5
9	10.3	7.8	40	Watered	6.5
10	11.3	8.2	70		5.5
11	11.3	8.5	40	Watered	5.5
12	11.4	8.8	60		5.5
13	11.4	8.8	50	Watered	5.5
14	11.5	8.8	60		5.5
15	11.5	8.8	40	Watered	5.5
16	11.6	8.9	50		5.5

For a clearer illustration of the growth comparison between Deep IoT and Deep Pipe non-IoT water spinach, Figure 8 presents the growth data of water spinach in centimetres.

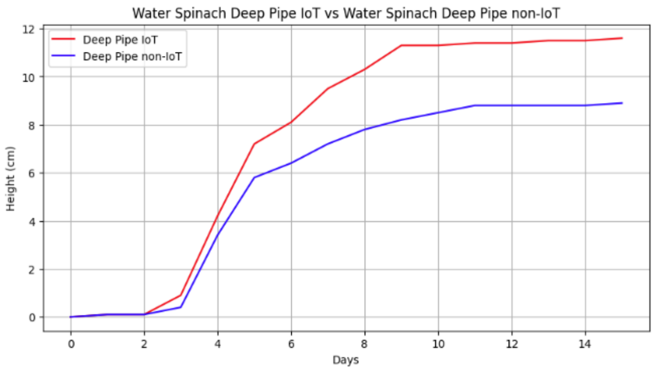

Figure 8. Water Spinach Growth

In Figure 8 above, the growth of water spinach using two planting methods is compared: Deep Pipe IoT and Deep Pipe non-IoT, over a period of 16 days. The results indicate that the Deep Pipe IoT method yields faster, and more consistent growth compared to the Deep Pipe non-IoT method. Significant growth in the Deep Pipe IoT method begins on day 5, reaching approximately 4.2 cm in height, further increasing to around 8.2 cm by day 7, and continuing to grow to about 11.6 cm by day 16. In contrast, the Deep Pipe non-IoT method shows slower growth, with significant increases observed starting on day 5 at approximately 3.4 cm, reaching about 8.9 cm by day 16. In both methods, there is a phase where growth is not as rapid, specifically from around day 9 to day 16, indicating an adaptation or adjustment phase in the water spinach growth cycle. From these results, it can be concluded that the Deep Pipe IoT method is more effective in supporting water spinach growth, yielding higher and more consistent results. The use of IoT technology in irrigation systems has proven to provide significant advantages in the efficiency and effectiveness of plant growth.

This research also finds that IoT-based irrigation can save water. Based on manually collected data, soil from water spinach plants irrigated using the deep pipe method does not dry out quickly. Although the topsoil appears dry, deep pipe irrigation delivers water directly to the root zone. Our data show that soil moisture never falls below 40%. We manually water every two days, maintaining soil moisture between 40%-50%. However, this method causes excess water to drain out since the soil can only hold up to 70% moisture the day after watering. In contrast, IoT-based irrigation activates when soil moisture reaches 30%, delivering 200ml of water, and maintains soil moisture for 4-5 days.

A similar experiment is conducted using spinach plants with manual watering without deep pipes and IoT, and with the use of deep pipe IoT. From this spinach experiment, it can be analysed that conventional planting and watering tend to be less effective compared to watering using deep pipes and IoT. The growth of manually watered spinach is slower compared to spinach grown with deep pipe IoT. For a clearer illustration of the growth comparison between manually watered spinach and deep pipe IoT spinach, Figure 9 presents the growth data of spinach in centimetres.

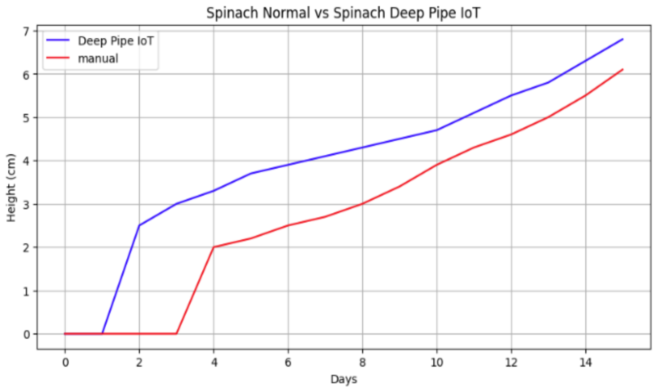

Figure 9. Spinach Growth

Figure 9 compares spinach growth using two cultivation methods: Deep Pipe IoT and manual irrigation, over a 16-day period. The findings reveal that the Deep Pipe IoT method achieves faster, and more consistent growth compared to the manual method. Significant growth with Deep Pipe IoT begins on day 2, reaching approximately 2.5 cm in height, then increasing to about 3 cm by day 4, and continuing to approximately 6.8 cm by day 16. In contrast, the manual method shows slower growth, with significant increases starting around day 4 at approximately 2 cm, reaching about 6.1 cm by day 16. Both methods experience a phase where growth slows, notably from around day 10 to day 16, indicating an adaptation or adjustment phase in the spinach growth cycle. These results suggest that the Deep Pipe IoT method effectively supports spinach growth with higher and more consistent yields. The integration of IoT technology in irrigation systems demonstrates significant advantages in the efficiency and effectiveness of plant growth, highlighting considerable potential for applications in modern agriculture.

V. Conclusion

The experiments comparing Internet of Things (IoT)-based irrigation systems with conventional non-IoT irrigation systems, along with observations of the growth of water spinach and spinach plants, yield several key conclusions. First, the IoT-based irrigation system positively impacts plant growth, with water spinach and spinach plants irrigated using the deep pipe method supported by IoT showing faster growth compared to those using conventional methods. Additionally, IoT enhances watering efficiency by promptly irrigating plants when soil moisture falls below the predetermined threshold, thus preventing water wastage. This system also offers significant time and labour savings for farmers, as the automatic control from sensors and software eliminates the need for continuous manual monitoring of soil conditions. Over time, the use of IoT-based irrigation systems can improve plant quality, as optimal environmental regulation supports healthy and productive growth. Consequently, implementing IoT-based irrigation systems has the potential to enhance overall efficiency, productivity, and quality in agriculture, benefiting farmers in managing their crops effectively.

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