Solar-powered irrigation and monitoring system for okra cultivation

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ABSTRACT

Eco-friendly and cost-effective irrigation systems are essential for sustainable agriculture. Traditional irrigation systems are unsustainable due to the high cost of operation and environmental pollution associated with fossil fuels. A possible solution for farmers is the use of solar-powered irrigation systems. This research aims to develop a solar-powered irrigation and a real-time monitoring system for okra cultivation. The irrigation system was powered by a monocrystalline solar panel and controlled by a Node MicroController Unit ESP8266 microcontroller unit. A 12 V pneumatic diaphragm water pump was utilized to irrigate the okra plants efficiently. The real-time monitoring system using Blynk allowed for the remote monitoring of the system's performance. The irrigation system was deployed on an okra farm, and the results showed that the system could sustain the soil moisture level for the okra plants, with an average soil moisture sensor reading of over 80%. The system delivered power effectively, with an average voltage measurement exceeding 12 V, average current readings above 180mA, and average power readings exceeding 2 W. These results demonstrate that the solar-powered irrigation system is a viable and sustainable solution for farmers, researchers, and engineers to enhance the performance of conventional irrigation systems.

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1. INTRODUCTION

Water is required for drinking, irrigation systems, construction and power generation. Hence, there is a widespread necessity to transport high-quality water from its source to where it is needed. Water pumps have been used for decades, with most commercially available water pumps powered by electricity or diesel oil power [1]. Traditionally, national grid systems have supplied power generated mainly by burning fossil fuels, and it is challenging to distribute water to outlying locations that are not connected to a national grid station [2]. In addition, fossil fuel combustion produces carbon dioxide (CO_2), carbon monoxide (CO) and other greenhouse gases that can pollute the environment [3].

Meanwhile, solar photovoltaic (PV) technology is the best option [4]. Solar-powered water pumps for agriculture can support drip, sprinkler, pivot and flood irrigation methods [5]. Moreover, depending on the local conditions, a system may comprise filtration or fertilization equipment. Irrigation is rarely done daily due to crop, soil, and climate conditions. A storage tank fed daily by a smaller pump may be less expensive than a larger pump that operates only a few times a week [6]. Additionally, solar pumps can improve water accessibility. Groundwater is the only available water source in countries with economic water scarcity or when surface water must be transported over long distances [7]. At the crop farm level such as chili, tomato, and okra cultivation, PV technology can be a reliable energy source for irrigation water pumping in remote areas, especially in areas without electricity [8], [9].

However, solar power has a significant drawback because it is only available intermittently [10], [11]. Energy production peaks when the weather is sunny, but production ceases completely as soon as the sun goes down and the light fades [12]. Monitoring soil moisture for crops entails measuring either the soil water potential or the soil water content, and it has been utilized extensively for irrigation scheduling [13], [14]. Efficient irrigation scheduling applies irrigation water at the right time and quantity to maximize crop yield and mitigate adverse environmental impacts. The decisions of when and how much water to apply to a field through irrigation scheduling directly impact water use efficiency. Poor irrigation scheduling results in under-watering or waterlogging, reducing water use efficiency [15].

One of the crops that need irrigation scheduling is okra. Okra is a commercial vegetable crop grown extensively throughout Africa and Asia. It is a member of the Malvaceae family that is thought to have originated in Ethiopia and has since spread throughout the world's tropical, subtropical, and warm temperate regions [16]. Okra also contributes to the human diet by providing lipids, proteins, carbs, minerals and vitamins [17]. Moreover, its mucilage is excellent for medical and industrial purposes. As a result, young okra crops have reinvigorated interest in commercializing this crop.

The most significant issue with okra cultivation is a lack of rainfall, which significantly limits their production potential [16], [18], [19]. Sufficient water must be delivered to the soil to keep it moist. The okra crops may develop properly using all nutrients offered via soil throughout its development phase. When the okra is subjected to a reduction in water availability while growing, it negatively influences productivity, worsens when the scarcity is continuous and reduces output in the first harvest [20], [21]. Manual irrigation is the most prevalent type since it can be done by anyone physically capable [22]. Farmers channel water to okra crops using manual irrigation, which is labor-intensive and time-consuming [23]. This method is also the least efficient because it gives farmers less control over the water. Moreover, it is typically provided in greater volumes that are not beneficial to the okra plant and can increase farm runoff [24]. To solve the problem, this research aims to develop a solar-powered irrigation and monitoring system for okra cultivation using the Internet of Things.

The rest of the paper is organized as follows: Section 2 explains the research methodology used to develop a solar-powered irrigation and monitoring system for okra cultivation. Section 3 discusses the results and analysis of the proposed irrigation system. Finally, section 4 presents the conclusions and recommendations for utilizing the developed system.

2. DEVELOPMENT OF OKRA SOLAR-POWERED IRRIGATION AND MONITORING SYSTEM

Figure 1 depicts a block diagram of the okra solar-powered irrigation and monitoring system. Three subsystems were integrated into the Node MicroController Unit (NodeMCU) ESP8266 microcontroller: the irrigation system (green block), the solar power system (red block) and the monitoring system (blue block). The red block shows that the solar power system consisted of a monocrystalline solar panel, a solar charger controller and a rechargeable sealed lead-acid battery. This part harvests solar energy from the sun, converts it into a direct current power supply and stores it in the battery through the charge controller to prevent overcharging. The green block describes the irrigation system, which includes a capacitive soil moisture sensor and a digital humidity and temperature 11 (DHT11) sensor to measure soil moisture and air humidity, respectively. The monitoring system (represented by the blue block) consists of the Blynk application that acts as a monitoring application. The input data, such as soil moisture, humidity, temperature and water pump status, would be displayed on the application to allow users to monitor the data obtained on a mobile phone.

Figure 2 shows the okra solar-powered irrigation device. The schematic diagram of the solar-powered irrigation system is shown in Figure 2(a). The soil moisture sensor, a DHT11 sensor, a 12 V pneumatic water pump and a relay were connected to the NodeMCU ESP8266. In addition, the solar panel and charge controller ensured that the system was adequately powered. Figure 2(b) depicts a prototype of the monocrystalline solar panel that was mounted on a horizontal surface and tilted toward the sun to maximize the quantity of electricity produced at the site. Additionally, a 10A solar charge controller was fitted to regulate the flow of electricity from the solar panel to the battery. A sealed lead-acid battery was added to store the energy generated by the solar panel. The microcontroller was linked to the Blynk app, enabling farmers to monitor and control the system remotely.

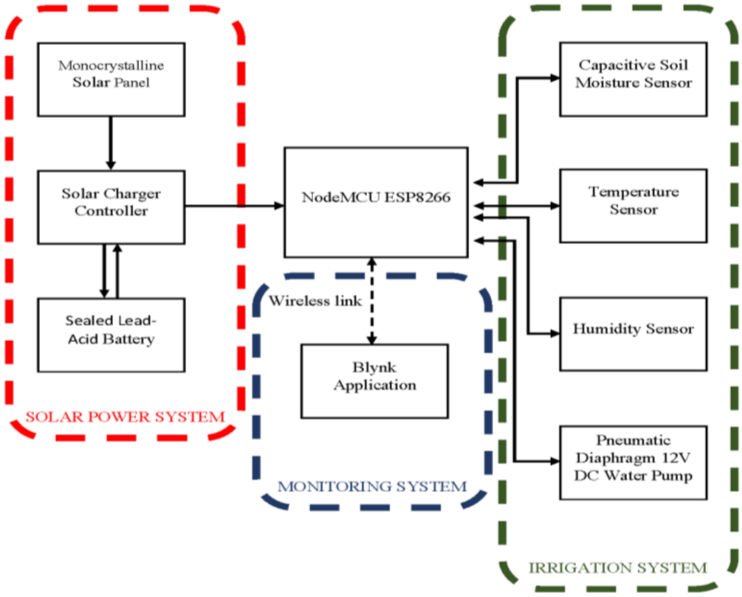
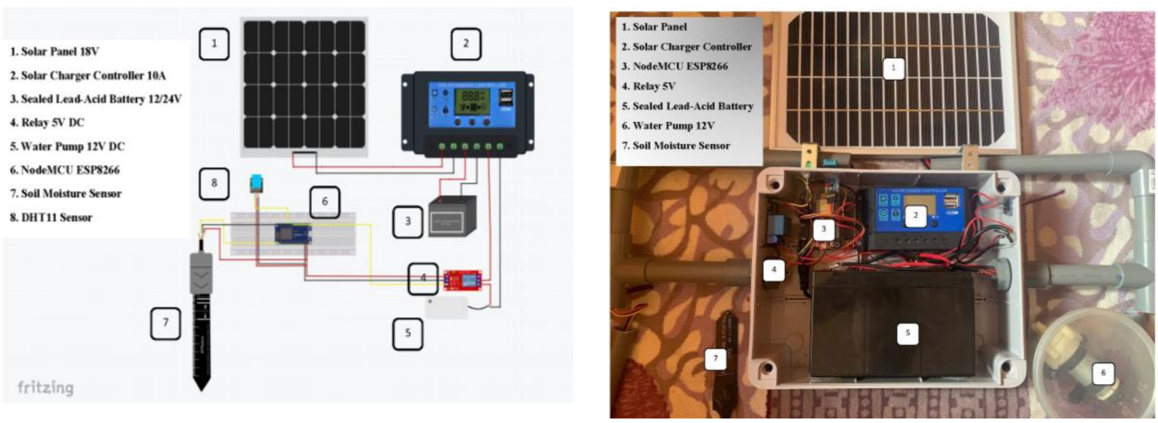


Figure 1. Block diagram of the okra solar-powered irrigation and monitoring system

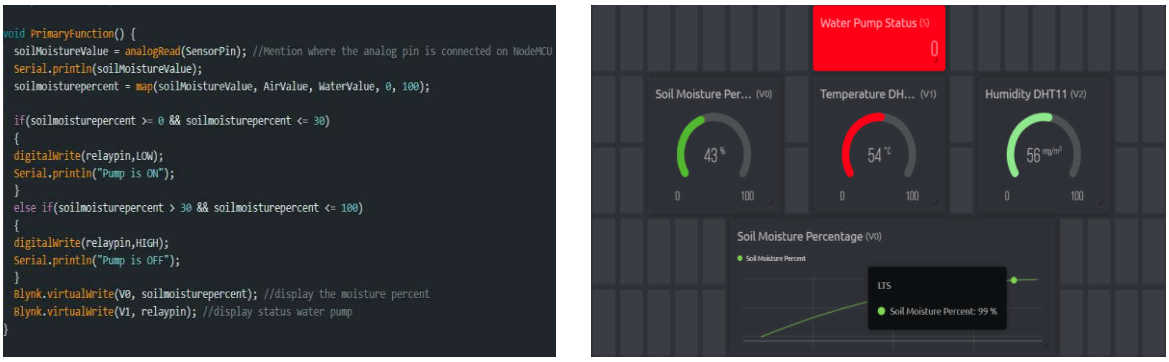


(a) (b)

Figure 2. The okra solar-powered irrigation device (a) a schematic diagram and (b) a prototype

Figure 3 shows the development of the real-time irrigation monitoring system for okra. The C++ programming language was used to construct the system’s software. The code snippets for water pump operation are shown in Figure 3(a). A "PrimaryFunction()" function reads data from a soil moisture sensor connected to an analog pin on a NodeMCU board. If the soil moisture was between 0 and 30%, the water pump was turned on by setting the relay pin to low [25]. If the soil moisture was between 30 and 100%, the relay pin was set to high, which turned off the water pump. As shown in Figure 3(b), the soil moisture gauge revealed the current soil moisture level, allowing the water pump to function when irrigation was necessary. The humidity and temperature gauges displayed the ambient humidity and temperature, which was essential for gauging the general health of the okra plants. The water pump status indicator indicated whether the water pump was currently on or off, enabling users to monitor the irrigation system and make necessary adjustments.

Figure 4 depicts the okra solar-powered irrigation device that was deployed in a small garden at Taman Tasik Semenyih, Selangor, Malaysia. Several phases were required to deploy the system, including site preparation, the installation of various components, and testing to verify the irrigation system's operation. Figure 4(a) shows the initial setup before the system was operated at the site. The first step was to prepare the site by picking a position in the garden that received adequate sunlight and had access to a water supply, as shown in Figure 4(b). The monocrystalline solar panel was mounted on the PVC electrical box to maximize the sunlight received. Then, the NodeMCU ESP8266, solar charger controller, sealed lead-acid battery, relay and all wiring were installed into a PVC electrical box to avoid water damage and protect the system. Finally, the system was tested to confirm that its components were operating as planned.



(a) (b)

Figure 3. The okra real-time irrigation monitoring system development (a) code snippets for water pump operation and (b) Blynk setup on the website

(a) (b)

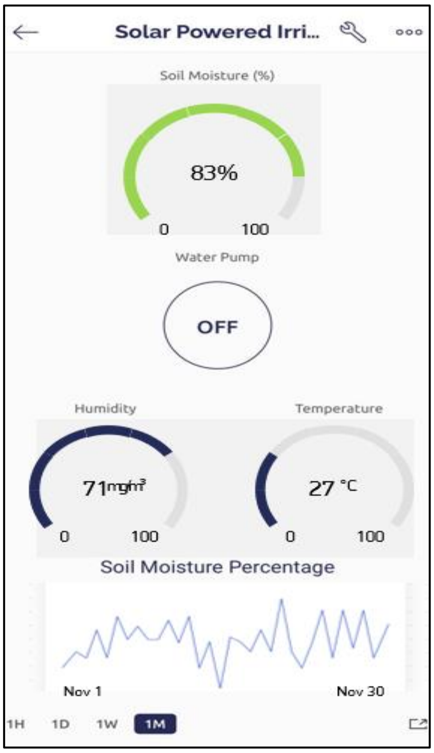
Figure 4. The okra irrigation device at the experimental site (a) inside view and (b) experimental setup

3. RESULTS AND DISCUSSION

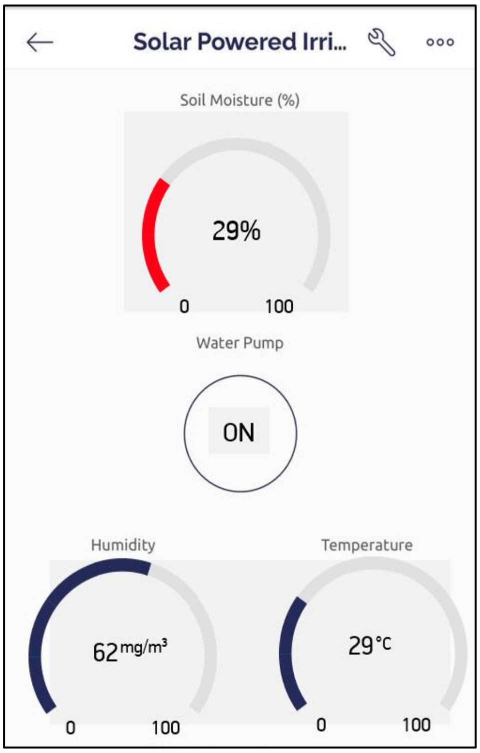
Figure 5 shows the display screens of the irrigation real-time monitoring system. Figure 5(a) displays the water pump off-state. It shows that the soil moisture percentage was 83% (indicated at the top of the figure). This was because the pump was controlled by the NodeMCU ESP8266 running on the Blynk application. The microcontroller utilized the soil moisture level to determine when to switch the pump on and off. With the soil moisture level at 83% and over 30%, there was no need for the pump to be running in this instance, indicating that the system was operating as intended and no action was required. The reading humidity and temperature were 71% and 27 °C, respectively, indicating that the environment was suitable for the okra plants to thrive.

The graph at the bottom of the figure reveals that soil moisture consistently remained above 30% throughout the month, and the water pump was turned off as expected. Figure 5(b) shows the sample output when the water pump was in the on-state. The soil moisture percentage was 29%, fulfilling the conditions of the programming setup in the microcontroller. The 62% humidity and 29 °C temperature recordings indicate that the DHT11 sensor was in adequate condition to detect the surrounding parameters.

The four-day soil moisture measurements for an okra plant are presented in Figure 6. The soil moisture of the okra plant was measured using a soil moisture sensor, which consistently reported readings above 70% throughout the four days. On Day 2, soil moisture was 81% at 8:00 a.m. and 71% at 1:00 p.m. At 5:00 p.m., it rose again to 90%. The readings increased because it started raining heavily after 1:00 p.m. Consequently, it was determined that the capacitive sensor could detect water inside the soil. This indicates that the plant received water continuously throughout the day as the soil absorbed water from the water tank to sustain plant development.



(a)



(b)

Figure 5. The okra real-time irrigation monitoring system displaying a water pump in (a) the off status and (b) the on status

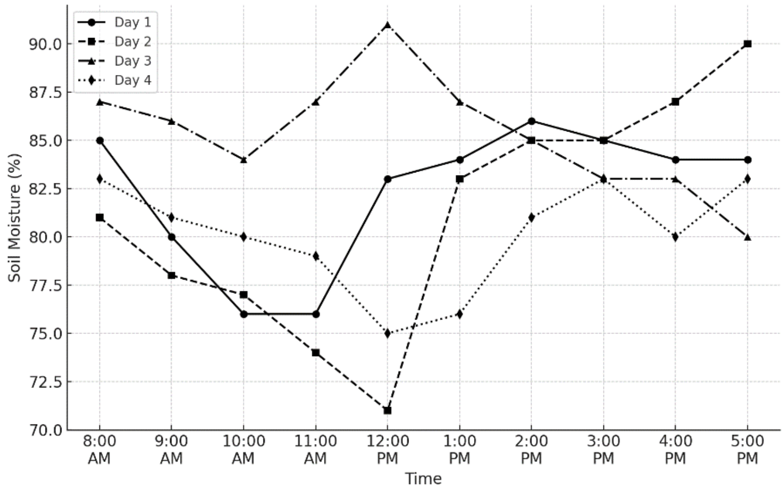
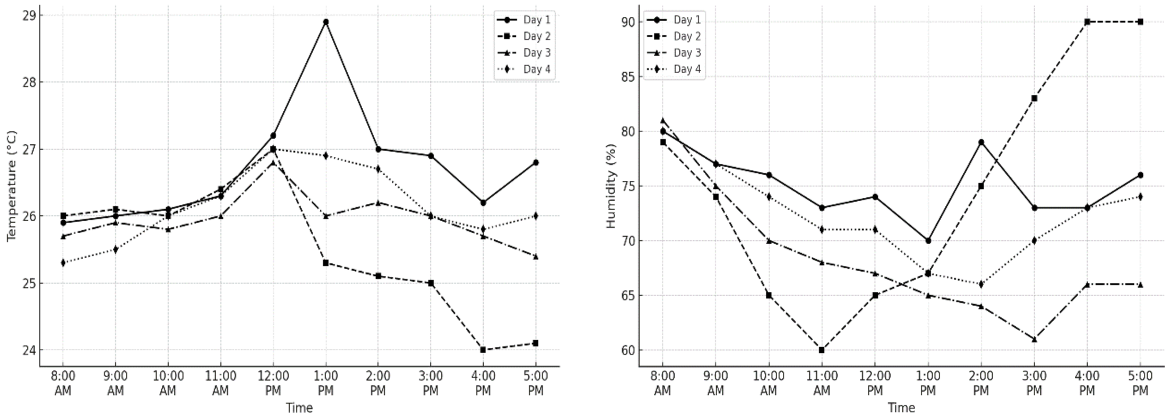


Figure 6. Soil moisture reading for experiments carried out over four days

The temperature and humidity readings recorded over four days are displayed in Figure 7. Measurements were taken at specific periods between 8:00 a.m. and 5:00 p.m. using a DHT11 sensor. The temperature fluctuated slightly throughout the four-day period, with very small variations occurring daily, as shown in Figure 7(a). On some days, the temperature peaked in the afternoon, while on others, it remained relatively constant. Overall, the recorded temperatures were moderate. As shown in Figure 7(b), on Day 2, at 8:00 a.m., the humidity was 79%, and the temperature was 26 °C. The humidity dropped, but the temperature rose until 1:00 p.m. The temperature was 24.1 °C, and the humidity was 90% at 5:00 p.m. The results indicate that the humidity reading was inversely proportional to the temperature reading, as the humidity decreased as the temperature rose and vice versa.

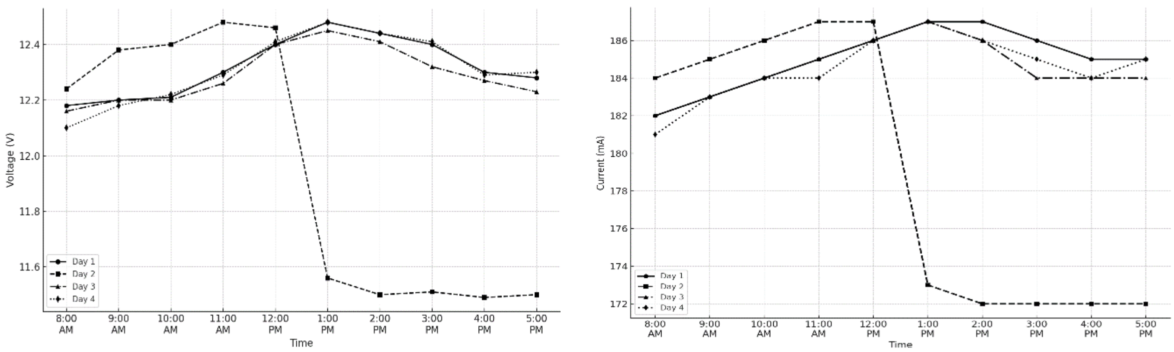


(a) (b)

Figure 7. Readings during four days of experiments (a) temperature and (b) humidity

Voltage and current readings were taken at various times for four days as shown in Figure 8. The solar radiation acquired from the solar panel resulted in a progressive increase in the voltage readings during the morning and throughout the day. As shown in Figure 8(a), at 8:00 a.m. on Day 2, the solar voltage was 12.25 V, which continued to rise throughout the morning. However, the voltage decreased starting at 12:00 p.m., reaching its lowest value of 11.48 V at 5:00 p.m. The voltage dropped because Day 2 was cloudy.

Figure 8(b) depicts the solar power current readings over four days. At 12:00 and 2:00 p.m. on Day 1, the solar current reached 187 mA before dropping to 185 mA at 5:00 p.m. At 8:00 a.m. on Day 2, the solar current was 184 mA and rose throughout the morning. It subsequently dropped sharply to 172 mA around 2:00 p.m. On Day 3, the solar current reached 187 mA at 1:00 p.m. and dropped to 184 mA around 3:00 p.m. On Day 4, the solar current started at 181 mA at 8:00 a.m. and peaked at 187 mA at 12:00 p.m. and 1:00 p.m. It then dropped to 184 mA at 4:00 p.m.



(a) (b)

Figure 8. Readings for (a) voltage and (b) current during four days of experiments

Figure 9 shows the solar power output measurements taken at various times over four days. The maximum power was around 2.31 W at 12:00 p.m. and 2.33 W between 11:00 a.m. and 12:00 p.m. on Days 1 and 2, respectively. Meanwhile, on Days 3 and 4, the maximum power output was around 2.33W at 2:00 p.m. and 2.33 W at 2:00 p.m., respectively. The four-day average power production was approximately 2.25 W.

Table 1 shows the okra plant growth over four weeks. In the first week, the seeds were planted in well-drained soil that had been changed with compost or other organic matter. Within a few days, the seedlings sprouted. The plant started to grow buds a few days into the second week. The okra fruit would eventually grow from these buds, so giving them enough water and food for healthy growth was essential. During the third week, the plant kept getting taller and bushier, and the buds began to get bigger. The leaves also got bigger and split more deeply. The okra plant started to grow flowers in the fourth week. Most of the flowers were yellow or white and very small. Once the flowers opened and pollinated, the okra fruit started to grow. Over the next few weeks, the fruit grew and ripened until it was ready to be picked.

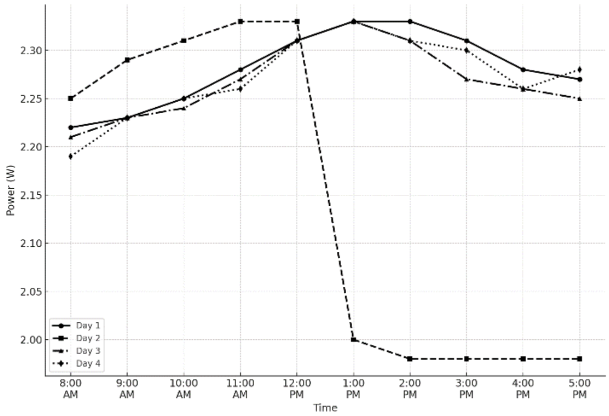


Figure 9. Solar power output readings over four days of experiments

Table 1. The growth of the okra plant

Week	1	2	3	4
Okra plant picture				
Okra growth	Seeds were planted.	The plant started to grow buds.	The plant kept getting taller and bushier, and the buds got bigger.	The plant started to grow flowers and the okra fruit started to grow.

The findings of this study show that it is possible to maintain the required level of soil moisture for the okra plantation using solar-powered irrigation and an IoT-based real-time monitoring system. The system successfully maintained soil moisture content above 30%, which is ideal for okra growth and ensured renewable energy supply for powering the irrigation system. These findings support the possibility of utilizing solar-powered systems as an efficient and renewable source of supply in contrast to oil-dependent irrigation systems, especially in remote zones where conventional electricity is scarce.

Following this study, prior research also propounds the usage of renewable energy in agriculture, particularly in enhancing water conservation and minimizing the adverse effects on the environment. Comparatively, the present study is innovative because it examined the impacts of solar power on okra yield, a valuable crop in the tropics and sub-tropics. The incorporation of IoT technology takes the usefulness of the system to the next level by providing farmers with a tool that allows them to control the irrigation process and thus optimize the use of resources or get better yield.

There is also a need to expand this study to other crops and bigger farms to understand whether this type of system will work in a broader context. It would be essential to note that long-term experiments are still needed to assess the lifespan and overall effectiveness of the system throughout multiple years of cultivation. Furthermore, there could be a continuation of the investigation with better sensors and integration of machine learning algorithms to reduce water consumption and energy use even more. Comparison with other renewable energy sources could also help in gathering more information on the best practices to adopt in agriculture concerning renewable energy. Therefore, this research highlights the ability to integrate solar energy with smart monitoring technology to advance sustainable agricultural practices. This approach not only favors organic farming but also offers some tangible strategies that are helpful to farmers in the innovation spaces.

4. CONCLUSION

In order to fine-tune the watering schedule, the irrigation system tested in this study employed a soil moisture sensor and a DHT11 sensor to check the soil moisture and temperature, respectively. Monocrystalline solar panels stored in a sealed lead-acid battery were used to convert solar energy into electricity. Using a smartphone and a specially designed website powered by Blynk applications, users can monitor the soil moisture percentage, temperature and humidity of crops. The monitoring system measured an average soil moisture level of 30%, which is ideal for okra growth. The system also recorded average solar panel outputs of 2.2 W and 12.3 V, which are sufficient for running the irrigation system. This implies that the solar panel can provide sufficient energy to the system to support the irrigation process. The system also recorded an average temperature of 28 °C and a relative humidity of 70%, which are excellent for okra cultivation. It has been shown in this research that the tested irrigation system can successfully introduce a controlled way of growing okra with low energy consumption. In addition, the user-friendly interface allowed users to monitor activities in real time using smartphones and web-based applications, making the implementation of smart technology practical for crop management.

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