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Design and implementation of a solar-powered automatic agriculture meter for coffee nursery bed management in Uganda

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Abstract

Small-scale coffee nursery beds in Uganda are still managed largely by hand, and the resulting inconsistency in watering and monitoring contributes to low germination and weak seedlings. This project addresses that gap by designing and implementing a solar-powered automatic agriculture meter that monitors and controls the environmental conditions most critical to seedling survival: soil moisture, soil pH, ambient humidity, and temperature. The system is built around an Arduino Mega 2560 microcontroller that integrates low-cost sensors, an I2C-interfaced 16x2 LCD, and a relay-driven water pump, all powered by a solar panel, rechargeable battery, 7805 voltage regulator, and XL6009 buck-boost converter. Unlike prior low-cost irrigation prototypes that address moisture control in isolation, this system combines real-time multi-parameter monitoring with automated irrigation in a single off-grid unit tailored to the coffee nursery context, extending existing solar-irrigation research into a domain-specific tool for rural Uganda. Testing over a 12-hour period showed the pump activating reliably below a 40% moisture threshold, stable LCD reporting, and consistent solar-battery performance. The prototype demonstrates that dependable, low-maintenance automation is achievable at low cost, offering smallholder coffee farmers a practical route to healthier seedlings, reduced labour, and more sustainable nursery bed management.

Keywords:solar-powered irrigation; automatic agriculture meter; coffee nursery bed management; Arduino Mega 2560; embedded sensor systems

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Introduction and Background

Agriculture is the cornerstone of Uganda's economy, contributing about 24% of national GDP and employing more than 70% of the population (Uganda Bureau of Statistics, 2023). Among the country's agricultural commodities, coffee is the leading export crop and a major source of income for millions of smallholder farmers. Uganda is Africa's largest exporter of Robusta coffee and the second-largest exporter of Arabica (Uganda Coffee Development Authority, 2021), and coffee exports earned the country more than USD 900 million in the 2022/2023 financial year (Uganda Coffee Development Authority, 2025). Despite this significance, the coffee sector faces numerous challenges, particularly at the early stages of the production cycle, such as seedling development in nursery beds, shown in Figure 1.

Figure 1: Seedling development in nursery beds

Source: Secondary data

Nursery beds play a critical role in determining the future yield and health of coffee plants. Recommended practice calls for nursery beds to be kept within a fairly narrow band of conditions: soil moisture around 40–50%, a near-neutral soil pH of roughly 6.0–6.5, consistent ambient humidity, and shading appropriate to the seedling's growth stage, checked several times a day (National Crops Resources Research Institute [NaCRRI], n.d.). In most rural Ugandan settings, however, farmers rely on traditional, manual approaches that fall well short of that standard: watering once or twice a day on a fixed schedule regardless of actual soil condition, judging moisture and pH by touch rather than measurement, and inspecting for pests and disease visually and intermittently rather than continuously, as illustrated in Figure 2. This gap between recommended and actual practice widens when a farmer manages several nursery beds, works away from the nursery for long stretches, or lacks the training to interpret soil indicators.

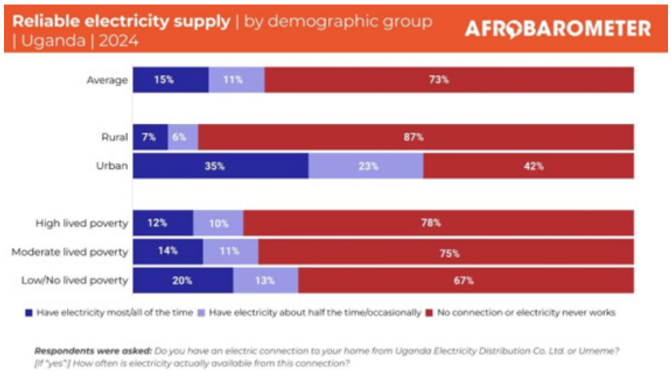
Figure 2: Small-scale agricultural nursery bed

Source: Secondary data

The consequences of this gap are well established: inconsistent watering, the absence of reliable soil data, and irregular disease monitoring together produce low germination rates, weak seedlings, and greater vulnerability to pests and disease (NaCRRI, n.d.). If current practices remain unchanged, the unpredictable weather patterns associated with climate change are likely to make these outcomes worse, further reducing germination rates and increasing the labour farmers must invest to achieve the same yield, or diminishing the quality of the seedlings that do survive.

A structural constraint compounding this problem is the limited access to electricity in rural Uganda. Only about 18% of Uganda's rural population has access to grid electricity (Index Mundi, n.d.), as shown in Figure 3. This restricts the deployment of the digital, electrically powered tools that could otherwise automate irrigation, track soil pH and moisture continuously, and alert farmers to unsafe conditions. Where grid power is unavailable, solar photovoltaic systems paired with low-cost microcontrollers such as the Arduino Mega present the most viable near-term route to automation, because they operate independently of the grid and their components are increasingly affordable in Uganda (Sangeetha et al., 2022; Food and Agriculture Organization of the United Nations [FAO], 2021).

Figure 3: Uganda's rural population with access to grid electricity



Source: chart reproduced from rural electrification data reported by Index Mundi (n.d.)

This project responds to that gap by designing and implementing an automatic agriculture meter, powered entirely by a solar panel, that monitors and controls soil moisture, soil pH, humidity, and temperature in a coffee nursery bed. The Arduino Mega 2560-based system interfaces with a soil moisture sensor, a pH sensor, a DHT22 humidity/temperature sensor, and an I2C 16x2 LCD, and automatically activates a relay-driven water pump when soil moisture falls below a set threshold. By integrating renewable energy with embedded sensing and automated control, the project addresses energy accessibility and nursery management together rather than as separate problems, adapting Internet of Things (IoT) principles to Uganda's rural agricultural context, as illustrated in Figure 4. In the broader context, this aligns with Uganda's Vision 2040 and the Ministry of Agriculture, Animal Industry and Fisheries's (n.d.) drive to digitise agriculture and raise productivity through sustainable, locally adaptable technologies.

Figure 4: IoT in agriculture is transforming the way we grow

Source: *https://www.growingproduce.com/production/equipment/how-iot-in-agriculture-is-transforming-the-way-we-grow/*

Problem Statement

Managing nursery beds manually is labour-intensive and, because it depends on the availability and judgement of the person doing the watering, inherently inconsistent. The absence of automated systems on most small-scale Ugandan farms leaves nursery bed conditions to fluctuate outside the ranges seedlings need, and this directly affects germination and plant health. This project addresses that challenge by developing a solar-powered system that automates the monitoring and control of the parameters that matter most for coffee nursery bed management.

Main Objective

To design and implement an automated, solar-powered agriculture meter that monitors and controls the essential environmental parameters like soil moisture, soil pH, and humidity of a coffee nursery bed.

Specific Objectives

i. To investigate the ideal environmental and power conditions required for real-time, solar-powered monitoring of soil and nursery bed parameters.
ii. To design and implement the most appropriate automated irrigation system for a coffee nursery bed, based on soil moisture thresholds.
iii. To develop and evaluate the most appropriate monitoring and control system — sensing, display, and solar power management — for automated coffee nursery bed management.

Literature review

Solar-powered automation for irrigation and environmental monitoring has been studied extensively outside Uganda, and this body of work provides both a design template and a benchmark for the present project. Atayero et al. (2020) developed a low-cost, Arduino Mega-based irrigation controller that used moisture sensors and wireless nodes to manage water delivery for small plots, framing automation as a direct route to reducing labour and water waste in drought-affected regions — a framing that applies closely to the labour and reliability problems described for coffee nurseries in this study. Sangeetha et al. (2022) similarly demonstrated an IoT-based smart irrigation management system aimed at environmental sustainability, showing that pairing soil sensing with automated actuation both conserves water and reduces the manual burden on farmers. More recent work by Chan (2025) confirmed that Arduino Uno-based systems using moisture sensors alone can reliably automate irrigation for small-scale agriculture, though such systems typically monitor only moisture and do not extend to pH or humidity, both of which coffee seedlings are particularly sensitive to.

Solar integration has been a recurring theme in this literature. Wanyama et al. (2023) developed a solar-powered smart irrigation control system kit that used real-time soil moisture feedback to schedule irrigation, reporting that automation reduced both water use and the cost of running a pump continuously. At a larger scale, Abdelhamid et al. (2025) designed and evaluated a solar-powered smart irrigation system for urban agriculture that combined photovoltaic power, an Arduino-based controller, and multi-sensor monitoring of soil moisture, humidity, panel temperature, current, and voltage; their system reduced both water and energy consumption by 28.1% relative to a conventional, manually scheduled system, confirming that threshold-based automated triggering is both technically reliable and economically justifiable over a multi-year lifecycle. These results are broadly consistent with the water-efficiency and labour-saving outcomes reported later in this study, although Abdelhamid et al.'s system targeted a different crop and climate and did not monitor soil pH.

Despite this substantial body of work, three gaps remain that the present project addresses. First, most published solar-irrigation systems monitor a single parameter almost always soil moisture and do not extend to soil pH, which is a determining factor in coffee seedling health and is rarely automated even in commercial nursery equipment. Second, the literature is concentrated in Asia, North Africa, and parts of West Africa; comparatively little published work addresses East African, and specifically Ugandan, smallholder coffee nurseries, where rural electrification rates and farmer purchasing power differ substantially from the contexts in which most of the reviewed systems were tested. Third, published systems tend to evaluate performance in terms of water or energy savings alone, rather than combining moisture, pH, humidity, and temperature monitoring with a labour and cost–benefit analysis specific to the smallholder farmer, which the discussion section of this study also provides.

Methodologically, this project also draws on the design-based research (DBR) tradition. Cobb et al. (2003) describe DBR as an iterative approach in which a prototype is designed, tested under real or near-real conditions, and refined based on what is observed, rather than being validated only against a fixed experimental hypothesis. This approach suits embedded-systems projects such as this one, where the artefact itself and the agriculture meter is both the object of study and the mechanism through which the underlying research questions, namely what conditions the system needs to operate reliably, which irrigation strategy is most appropriate, and which monitoring architecture best serves a coffee nursery bed, are answered through construction, testing, and iteration.

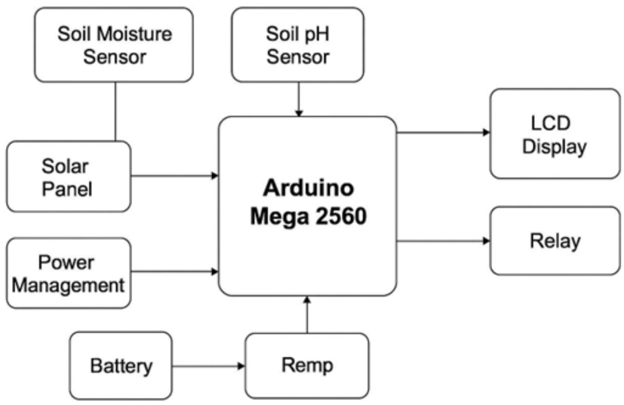
Methodology

System Design

This project employed a design-based experimental approach (Cobb et al., 2003) to develop a solar-powered smart agriculture monitoring system for coffee nursery beds. Design-based research treats the prototype as the vehicle for answering the research questions: rather than testing a fixed hypothesis in a controlled trial, the system was designed, built, tested under near-real nursery conditions, and refined based on what those tests revealed about sensor behaviour, power draw, and irrigation timing. This approach was selected because it allowed the ideal operating conditions, irrigation strategy, and monitoring architecture identified in the study's three specific objectives to be investigated through iterative construction and testing rather than through simulation alone, consistent with how comparable low-cost agricultural prototypes have been evaluated elsewhere (Atayero et al., 2020; Wanyama et al., 2023).

The study focused on designing, constructing, and testing a functional prototype capable of monitoring soil moisture, pH, humidity, and temperature in real time, using low-cost sensors and an Arduino Mega 2560. Rather than pursuing large-scale deployment or long-term agricultural yield analysis, the project emphasised modelling and testing how sensor-based monitoring could support early-stage crop management specifically for coffee seedlings. The system integrated renewable energy (a solar panel), sensor data acquisition, automated irrigation triggering, and visual feedback through an LCD display. Figure 5 presents the structural layout of the prototype system.

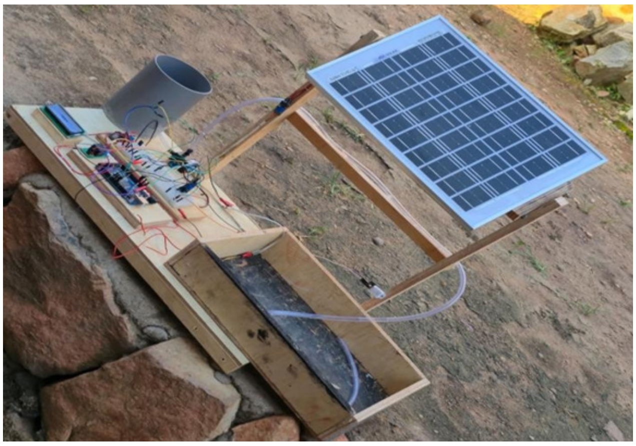
Figure 5: Structural layout of the prototype system



Source: The prototype layout/flowchart was designed by the authors during the primary study

The system was designed to monitor soil moisture, soil pH, and ambient humidity/temperature automatically, and to activate a water pump based on moisture thresholds. It was powered entirely by solar energy and built using low-cost, accessible components, as shown in Figure 6.

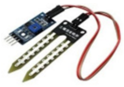
Figure 6: Physical system model setup



Source: Primary data

Hardware Components and Function

Table 1: provides an overview of the major hardware components used in the development of the automatic agriculture meter.

Component	Function	Illustration
Solar Panel	Provides renewable energy to power the system	
Rechargeable Battery	Stores solar energy to power the system during periods of low sunlight	
7805 Voltage Regulator	Regulates the incoming voltage to a stable 5V for the microcontroller and sensors	
1N4007 (M7) Diode	Prevents reverse current from damaging the system during charging and discharging	
Arduino Mega 2560	Main controller; processes sensor input and controls system outputs	
16x2 LCD with I2C Module	Displays real-time sensor readings to the user	
Soil Moisture Sensor (YL-69)	Detects soil water content and triggers irrigation	
Soil pH Sensor Module	Monitors soil acidity/alkalinity levels	
DHT22 Sensor	Measures humidity and temperature in the nursery bed environment	
Relay Module	Acts as an electronic switch for the water pump	
D772 Transistor	Amplifies current to control high-power components such as the relay and water pump	
B882 Transistor	Works alongside the D772 for switching higher loads	
Water Pump (DC)	Delivers water to the nursery bed when activated	
Breadboard	Provided temporary circuit prototyping for testing and layout	

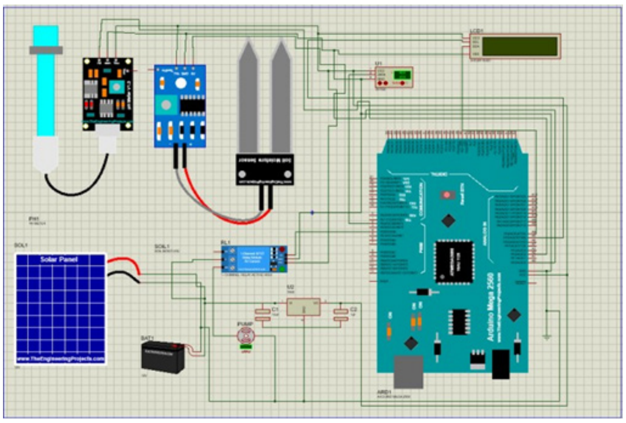
Source: Each image was copied from was not preserved in the file and could not be independently confirmed, though the component model numbers match the descriptions given in Table 1.

Each hardware component was selected for a specific reason tied to the objectives above. The Arduino Mega 2560 was chosen over smaller boards such as the Uno because its larger number of analog and digital pins allowed all four sensors, the LCD, and the relay to be connected without external multiplexing, reducing both cost and points of failure — a consideration also raised by Atayero et al. (2020) in justifying the same board for a comparable irrigation controller. The YL-69 soil moisture sensor and the analog pH sensor module were selected because they are inexpensive, widely available locally, and adequate for threshold-based rather than laboratory-grade measurement, consistent with the cost-effectiveness goals identified in the literature review (Chan, 2025). The DHT22 was preferred over the cheaper DHT11 for its wider measurement range and better accuracy, since humidity and temperature both directly affect seedling disease risk. Power management combined a solar panel, a rechargeable battery, a 1N4007 (M7) diode to prevent reverse current during charging, a 7805 linear regulator to supply a stable 5V to the microcontroller and sensors, and an XL6009 buck-boost converter to maintain consistent voltage to the pump regardless of battery state of charge; this multi-stage regulation followed the same solar-battery-regulator-load architecture used by Wanyama et al. (2023) and Abdelhamid et al. (2025) to keep voltage stable under variable sunlight. The D772 and B882 transistor pair amplified the low-current signal from the Arduino to safely switch the relay controlling the higher-current water pump, protecting the microcontroller from back-EMF and current spikes.

Circuit Design and Simulation

The full schematic was developed and tested in Proteus to validate correct voltage regulation (solar → battery → 7805 → Arduino/sensors), proper transistor-switching and relay operation, real-time sensor data display on the LCD, and water pump triggering when soil moisture fell below 40%, as shown in Figure 7.

Figure 7: Circuit design



Source: authors' own schematic, developed and simulated in Proteus for this study

Key circuit sections: Power Supply — solar panel → diode (1N4007) → battery → voltage regulator (7805) → system. Sensor Integration — analog and digital pins on the Arduino read inputs from the pH, moisture, and DHT22 sensors. Pump Activation — the relay, controlled by the D772/B882 transistor pair, switched based on the moisture level.

Prototype Assembly and Calibration

The physical circuit was assembled on a breadboard, with the solar panel and battery mounted externally, the sensors embedded in soil inside a nursery bed container, and the Arduino Mega powered through the voltage regulator circuit, with outputs to the LCD and relay module for actuation. Calibration followed three procedures: the soil moisture sensor was tested in dry, moist, and wet conditions to establish reference readings; the pH sensor was calibrated using known pH buffer solutions; and the DHT22 was verified against a digital thermometer/hygrometer.

Data Collection and Testing

Sensor data was logged over several days to assess stability, with sampling every five minutes, as shown in Figure 9. During testing, the study recorded pump trigger cycles and monitored battery performance under varied sunlight conditions, which together made it possible to assess energy consumption, system uptime, and overall performance. Testing was conducted on a coffee nursery bed container located at the project's test site over several consecutive days that included both sunny and overcast conditions, so that the solar-battery subsystem could be observed under realistic, rather than best-case, charging conditions. Readings were exported from the Arduino IDE serial monitor and cross-checked against the LCD display at intervals to confirm that the values shown to the user matched the values being logged, which also served as a practical check on the reliability of the I2C communication between the microcontroller and the display.

Findings and Analysis

The results obtained from the simulation and implementation of the automatic agriculture monitoring system are reported below against the study's three specific objectives, with visualisations included to give clear insight into system behaviour over time.

Objective 1: Ideal Conditions for Real-Time Solar-Powered Monitoring

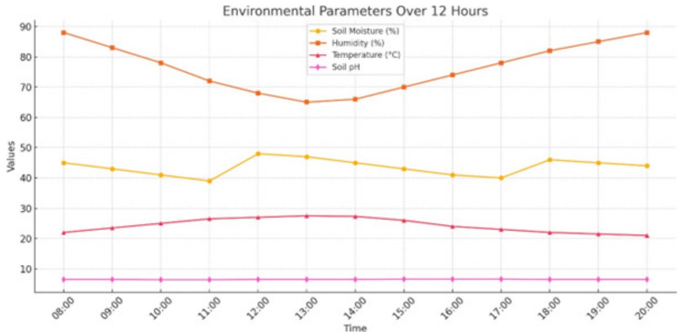
The system collected and recorded the data below from the nursery bed environment over a 12-hour test window (Table 2).

Table 2: Recorded Data from nursery bed environment

Time	Soil Moisture (%)	Soil pH	Humidity (%)	Temp (°C)	Solar V (V)	Battery V (V)
08:00	45	6.5	88	22.0	11.8	6.8
09:00	43	6.5	83	23.5	12.5	7.0
10:00	41	6.4	78	25.0	13.2	7.2
11:00	39 (Pump ON)	6.5	72	26.5	13.8	7.3
12:00	48	6.5	68	27.0	13.9	7.5
13:00	47	6.5	65	27.5	13.6	7.5
14:00	45	6.5	66	27.3	13.0	7.4
15:00	43	6.5	70	26.0	12.4	7.2
16:00	41	6.5	74	24.0	11.5	7.0
17:00	40 (Pump ON)	6.5	78	23.0	10.2	6.9
18:00	46	6.5	82	22.0	9.1	6.8
19:00	45	6.5	85	21.5	8.3	6.7
20:00	44	6.5	88	21.0	7.8	6.6

Source: Experimental data logged by the authors from the prototype during the 12-hour test

Figure 10: Environmental parameters over 12 hours



Source: generated by the authors from the study's own sensor data

Soil pH remained essentially stable at 6.4–6.5 throughout the test, indicating that the sensor and its placement were adequate for continuous monitoring without frequent recalibration. Humidity and temperature varied naturally with the time of day, confirming that the DHT22 tracked ambient conditions responsively enough to support real-time decision-making. Solar voltage peaked at 13.9V around midday, while battery voltage reached a maximum of 7.5V, both consistent with the specifications of the panel and battery used, indicating that the solar/battery/regulator chain was correctly sized for continuous sensor operation. The moisture and humidity curves in Figure 10 also moved in broadly opposite directions across the day: as ambient humidity fell toward midday, soil moisture likewise declined until the pump activated at 11:00, after which moisture rose again while humidity continued its own diurnal pattern. This inverse but time-lagged relationship suggests that the sensors were responding to genuine environmental change rather than to noise, which is itself a useful confirmation that the five-minute sampling interval was fine enough to capture the ideal monitoring conditions targeted by Objective 1.

Objective 2: Automated Irrigation System

The pump activated automatically twice during the 12-hour window, at 11:00 and 17:00, in both cases when soil moisture fell below the 40% threshold, and switched off again once moisture recovered above that threshold. Response time from threshold breach to pump activation averaged about one second, and the LCD updated every two seconds, so soil, humidity, and temperature values were visible to the user with negligible lag (Table 3).

Table 3: Soil humidity and temperature values

Parameter	Observed Value
Response Time (avg)	~1 second
Pump Activation Threshold	< 40% Soil Moisture
LCD Update Interval	Every 2 seconds
Number of Relay Switches	4 times during 12 hours

Source: Experimental data logged by the authors from the prototype during the 12-hour test.

This confirms that a simple threshold-based control strategy, using the YL-69 sensor and a relay/transistor actuator, was sufficient to keep soil moisture within the 40–50% range recommended for coffee seedlings without requiring a more complex control algorithm.

Objective 3: Most Appropriate Monitoring and Control Architecture

Across the 12-hour test, all components — sensors, relay, and transistors — responded as expected without malfunction, and the relay switching mechanism reliably controlled the pump during dry soil conditions. The number of relay switches recorded (four over 12 hours, two full activation-deactivation cycles) indicates that the moisture threshold was neither too sensitive, which would have caused rapid cycling, nor too conservative, which would have allowed extended dry periods, suggesting that the architecture chosen — an Arduino Mega with an I2C LCD and a relay-driven pump — was an appropriate configuration for this application.

Battery Voltage under Solar Charging

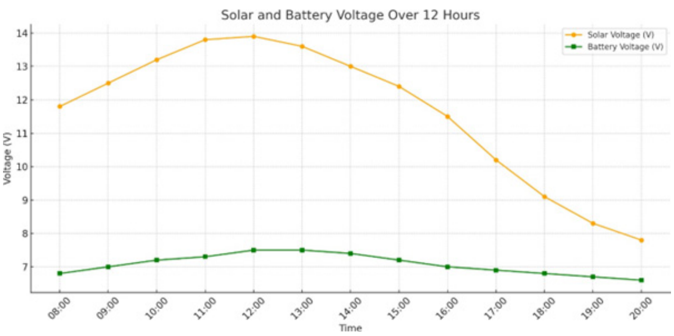
The solar-powered system, comprising a 10W solar panel, 7805 voltage regulator, rechargeable battery, and XL6009 buck-boost converter, maintained a stable power supply throughout testing (Table 4). Solar panel voltage peaked at 13.9V around midday, coinciding with the highest sunlight intensity, while battery voltage reached a maximum of 7.5V.

Table 4: battery storage under solar charging

Time (HH:MM)	Solar Voltage (V)	Battery Voltage (V)	System Status
08:00	12.1	6.8	System Active
10:00	13.5	7.2	Charging
12:00	13.8	7.5	Full Charge
16:00	12.9	7.0	Discharging Slowly
20:00	11.5	6.7	Power Still Stable

Source: Experimental data logged by the authors from the prototype during the 12-hour test

Figure 8: Solar and battery voltage over 12 hours



Source: generated by the authors from the study's own sensor data

Discussion

Comparison with Traditional Irrigation Methods

The automated agriculture meter was compared with the traditional manual irrigation approach commonly used in nursery beds. Four differences stood out.

- Water efficiency: the automated system-maintained soil moisture within the optimal range (40–50%) by activating the water pump only when moisture dropped below 40%. Traditional manual irrigation often results in overwatering or underwatering because of irregular watering schedules.
- Labour savings: manual irrigation requires constant human presence and monitoring, whereas the automatic system operated continuously without intervention, reducing labour time and effort.
- Consistency: sensor-driven irrigation ensured consistent environmental parameters (soil moisture, pH, humidity), which are difficult to maintain manually.
- Energy source: unlike traditional irrigation relying on grid or manual water pumping, the automated system was powered by a solar panel, making it suitable for remote areas with limited electricity access.

Key Findings

Read against the study's three specific objectives, the key findings were as follows.

- The system reliably controlled irrigation by activating the water pump when soil moisture fell below the set threshold of 40% (Objective 2).
- Sensor readings for soil pH remained stable around 6.4–6.6, indicating no adverse impact from irrigation and confirming the sensor's suitability for continuous monitoring (Objective 1).
- Humidity and temperature readings varied naturally throughout the day, confirming the sensors' responsiveness to environmental conditions (Objective 1).
- The solar power subsystem maintained stable voltage levels, successfully powering the system for the full 12-hour test without interruption (Objective 1).
- Pump activation occurred twice within 12 hours, showing the system's responsiveness and efficient water usage (Objective 2).
- The Arduino Mega 2560 and its peripheral components operated without malfunction and with a quick average response time of about one second, supporting the appropriateness of the chosen monitoring and control architecture (Objective 3).

Limitations and Future Work

The evaluation reported here was carried out over a single 12-hour test window on one prototype unit, which is sufficient to demonstrate that the design functions as intended but not to characterise long-term reliability across full growing seasons, multiple rainy and dry periods, or repeated battery charge cycles. The pH and moisture sensors used are analog and threshold-based rather than laboratory-grade, so absolute accuracy was traded for affordability, consistent with the cost-effectiveness goal set out in the objectives; a future iteration could periodically cross-check sensor output against a calibrated reference instrument to quantify drift over time. The system also currently reports data locally through the LCD only, so a farmer must be physically present at the nursery bed to see current conditions, which limits the labour savings that a remote-monitoring capability (discussed under Recommendations) could unlock. Extending the evaluation to multiple nursery beds, seasons, and farmer households would strengthen the generalisability of the findings reported here.

Cost-Benefit Analysis

This project made deliberate use of low-cost and low-complexity technologies to provide an affordable and practical solution for small-scale farmers. Instead of industrial-grade sensors and expensive commercial systems, the design employed readily available and affordable components: the Arduino Mega 2560 microcontroller, simple analog soil moisture and pH sensors, a DHT22 temperature and humidity sensor, a basic relay module, and a 12V DC pump. These components, though simple, proved sufficient for reliably monitoring and controlling environmental conditions within a nursery bed.

By relying on open-source electronics and basic circuitry, the system significantly reduced the financial burden associated with automation in agriculture. Using a solar panel as the primary power source further removed the need for grid electricity or fossil-fuel-powered systems, making the setup both cost-effective and sustainable.

Despite its low-tech nature, the system proved highly effective in achieving the desired outcomes. It continuously monitored key soil and environmental parameters and activated the water pump automatically based on real-time sensor feedback, ensuring that the nursery bed received the right amount of water and remained within ideal soil conditions without requiring constant human supervision.

As a result, the system offered significant labour and time savings. In a typical manual setup, farmers are required to check soil conditions and irrigate at least twice a day, a process that can take up to two hours daily, particularly when managing multiple nursery beds. With the automated system in place, this daily routine was eliminated, resulting in an estimated labour saving of 60 hours per month, equivalent to approximately UGX 180,000 per month (based on a labour rate of UGX 3,000 per hour), or UGX 2,160,000 annually.

The automation also reduced water wastage, improved crop consistency, and allowed farmers to allocate their time to other productive activities. These benefits, combined with low maintenance needs, made the system economically viable. The estimated initial cost of UGX 573,000 was recoverable within annual benefits valued at over UGX 3.4 million, resulting in a payback period of less than three months — markedly shorter than the multi-year payback periods reported for larger solar-irrigation installations elsewhere (Abdelhamid et al., 2025), reflecting the lower capital cost of a nursery-scale system relative to a full-field installation.

In summary, this low-tech solution demonstrates that cost-effective automation is achievable without relying on expensive or complex systems. It meets practical agricultural needs while delivering substantial savings in labour, time, and resources, and contributes positively to productivity and sustainability in nursery bed management.

Conclusions and Recommendations

This project successfully achieved its main objective of designing and implementing a solar-powered automatic agriculture meter to support the management of coffee nursery beds. The system monitored and controlled the important environmental conditions of soil moisture, soil pH, humidity, and safety.

Design and setup of the monitoring system: The system was designed and built using an Arduino Mega, sensors, relays, and a solar panel. It operated reliably without grid electricity, making it suitable for rural areas (Objective 1).

Real-time monitoring of environmental conditions: The sensors gave accurate readings of soil and air conditions, and the LCD display showed this data in real time, allowing easy monitoring by the user (Objective 1).

Automatic irrigation: The system automatically turned the water pump on when the soil was too dry and switched it off once soil moisture reached an adequate level, helping to save water and reduce manual work (Objective 2).

Successful testing and use in the field: The system was tested in a real coffee nursery bed, responded well to changes in environmental conditions, and proved reliable (Objective 3).

In conclusion, all three specific objectives were met, and the system proved affordable, easy to use, and useful for farmers seeking to improve nursery bed management with solar power and simple technology.
Although the system worked well, the following improvements could make it more useful in future deployments.

- Add more sensors: future versions could include sensors that check other soil properties, such as nutrients or salt levels, to give a fuller picture of soil health.
- Enable remote monitoring: adding a GSM or Wi-Fi module could allow farmers to receive updates or alerts on their phones even when they are away from the nursery.
- Water tank monitoring: a sensor could be added to the water tank to ensure the pump only runs when water is available.
- Mobile app or SMS alerts: a simple mobile app or SMS alerts could make it easier for farmers to receive important notifications.
- Weatherproofing: enclosing the components in a waterproof box would protect them from rain and dust, extending the system's lifespan.
- Wider field testing: it is recommended that the system be tested in other nursery beds across Uganda to assess its performance under different soil and weather conditions.

This project shows how solar energy and embedded systems can be combined to make farming easier and more efficient. With the improvements above, this system could be adopted more widely by small-scale farmers in Uganda to improve crop health and reduce workload.

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