

Enhancing Real-Time Monitoring and Control of Evapotranspiration Using an IoT-Based Data Logging System in Agriculture.

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ABSTRACT

This study shows the construction and assessment of an IoT-based data logging system that can be used to improve real-time monitoring and control of evapotranspiration in farm environments. The aim of the research was to maximize water use, enhance crop production, and give a stable system of automated irrigation, which is capable of alluding dynamically to the changing environment. The system incorporates soil moisture, soil temperature and water tank level sensors with a microcontroller and a program of fuzzy logic to determine accurate irrigation needs. The collected data on the sensors are processed on real-time basis and adaptive controls can be used to adjust the water delivery using the pumps controlled by the relays. The main findings indicate that the system saves 20-30 percent of water used in the conventional irrigation systems, the system is 95 percent accurate in measuring the amount of soil moisture, and the system elevates the crop production by 15 percent. The system is also characterized by low response time of less than five minutes and high availability with a 98 percent availability during testing. The monitoring interfaces that allow advanced real-time monitoring such as the use of LCDs and mobile notifications make it possible to have a continuous monitoring and interventions take place. The results illustrate the benefits of using the IoT-based fuzzy logic control compared to traditional irrigation techniques, which can make substantial contributions to precision agriculture. The proposed system by offering cost-effective resource control, reducing human labor, and enhancing ecological approaches to modern agriculture is a viable, scalable, and sustainable solution to the current agricultural intensive methods. The further research of the system can be dedicated to its expansion and its integration with the current farm activities and the use of more sensors to monitor and secure the system.

Keywords: Internet of Things, data logging, Fuzzy Logic, evapotranspiration, sensors, irrigation

INTRODUCTION

Agriculture is among the oldest and the most vital human activities to the world, as it feeds billions of people, provides raw materials and livelihoods. As the world population is expected to exceed 9 billion in 2050, food production is growing exponentially and putting considerable strain on the agricultural systems to produce more with low consumption (Daszkiewicz, 2022). To address these needs, the current agricultural systems should embrace new methods that manage the utilization of resources without causing wastes and enhancing production at the same time, sustainability of the environment (Ononogbo et al., 2024).

Water management is a very important feature of crop farming because water is essential in the growth and cooling of plants. Crop water use or the evapotranspiration is a combination of the evaporation and transpiration processes of the soil and the leaf as well as the transpiration processes of the plant (Wanniarachchi & Sarukkalige, 2022). Accurate measurement of evapotranspiration is essential in estimating the crop water needs and preventing under- and over-irrigation. Over irrigation may result in overland flow, soil erosion, loss of nutrients and wastage of water, on the other hand under irrigation will result in poor crop growth, yield and quality (Raza et al., 2023). Although it is important, it has been noted that measuring as well as controlling

evapotranspiration on a real-time basis is also a big challenge among farmers especially in areas characterized by water shortage (Morchid et al., 2026).

Manual and time-based automated competitive types of traditional irrigation systems are weak in their dynamical responsiveness of environmental conditions and soil water status. Such systems are usually based on predetermined schedules, or thresholded systems which fail to capture spatial variations in soil moisture or weather variations, leading to a lack of efficiency in water utilization and optimal crop yield (Liu, Zhao & Rezaeipanah, 2025). The recent developments in automation, Internet of Things (IoT), and artificial intelligence (AI) have promising solutions to precision agriculture. IoT sensors have the ability to constantly check the environmental parameters like the soil moisture, temperature, and water levels and pass real-time data to control systems that determine the irrigation (Padhiary, 2025). These complex datasets can be interpreted with fuzzy logic and AI algorithms, being able to make adaptive and intelligent irrigation choices that will maximize the amount of water used and still keep crops healthy (Liu, Zhao & Rezaeipanah, 2025). The research problem is that an efficient, adaptive, and real-time irrigation system is required, and therefore this paper is based on designing the IoT-based data logging system that will be used to monitor and control the evapotranspiration (Ahmad et al., 2026). The objective is to supply farmers with accurate, timely, and practical information to enhance efficiency of water use, minimize wastage and maximize crop production. The goals involve the development of an IoT system with a sensor that is intrinsic, the establishment of a control mechanism that is based on the fuzzy logic, and testing the performance of the system in real farming conditions to illustrate the effectiveness of the system compared to traditional irrigation practices.

Problem Statement

Water management is a serious issue in contemporary agriculture, especially, with the world food demands increasing, and the water resources getting scarcer to the point of their scarcity (Biswas et al., 2025). The conventional irrigation, including manual watering and time-based or threshold-based automation, does not consider the real-time changes in the soil moisture, crop water requirements, and environmental factors (Babafemi et al., 2025). This can cause over irrigation and thus, causing the water to go to waste or under irrigation, which has negative effects on the crop growth and yield. The current automated systems can also not respond dynamically to accurate evapotranspiration data in order to change irrigation schedules, which limits their usefulness in optimizing water use (Ahmad et al., 2026). Besides, the farmers frequently lack access to correct, timely, and practical information to make sufficient irrigation choices (Ahmed et al., 2023). Thus, a timely solution is an adaptive, real-time, and intelligent irrigation system, using the IoT technology, and fuzzy logic to track, manage, and optimize crop water consumption, improving sustainability and crop yield in agriculture.

RELATED LITERATURE REVIEW

According to Villaruz et al. (2022) created an Automated Plant Irrigation and Monitoring System that can control irrigation by using soil moisture sensors, microcontrollers, and a water pump. The system is able to measure the level of soil moisture and turn on the water pump automatically when the soil moisture level reduces below the set standards, thereby saving labor and making sure that everything is watered in time. An LCD display can also be used to monitor the real-time condition of the soil making it easier to use by the farmers. Although this system is efficient in terms of aid in automating irrigation, it is constrained by an inability to adjust based on fluctuating environmental conditions and crop specific water needs. This shows that more sophisticated methods, e.g. IoT-based data logging and intelligent control algorithms, are required in order to optimize irrigation dynamically and enhance efficiency of water use in agriculture.

In (Gurung et al., 2020) created an indigenous low-cost time-based microcontroller-based irrigation controller that implements user-defined functions and generates commands to calculate relevant actuators (relay, solenoid valves, motor). A soil moisture sensor was modeled, simulated and tested to attain with low-cost, accurate and reliable measurements. A small temperature sensor and the low-cost high-performance are utilized and the PCB circuit can measure the humidity. Rainfall is measured using the tipping bucket rain gauge. Once a predetermined quantity of precipitation is received, the lever pivots and spills off the water collected and sends an electrical signal. The system contributed to the utilization of less water, the saturation of soil moisture to optimal levels

and the minimization of shrub wilting to lower/higher levels, and the reduction of soil runoff/leaching, however, it could not effectively (100) indicate soil water content, plant size and the mechanism that it uses in the development of an irrigation scheduling program, it does not enable a greater insight into relations of water to plants and soils.

As per (Olteanu et al., 2021) suggested to observe crop growth and development using climate information of automatic weather stations. The initial step to developing sustainable agricultural productivity that can be modified to the changing climate is monitoring the environmental parameters and their influence on the crop production. The automated phyto-climate systems discussed in the paper are effective instruments with farmers in order to attain the objective of producing more food with less. The provided system utilized the majority of the newest technologies available at the moment and assembles sensors, gathering information about the surrounding and crops and the strength of the internet to process and distribute the information at any location. The issues that the system faces include the real-time gathering of trusted crop environment data as well as mechanisms of adapting these new systems by farmers to leave their traditional ways and adopt new practices.

Hassan et al. (2019) proposed an automatic irrigation system that is based on an Arduino microcontroller system that is relatively inexpensive and can be utilized in a farm or in a typical home garden. The automated irrigation system is a full-scale prototype and it comprises of a soil moisture sensor; an LCD display that displays the percentage of moisture and the pump position; a relay module that is utilized to switch the on off position of the water pump; and a water pump. The soil moisture sensor will be connected to the LCD display so that when it detects the dry soil the moisture percentage will be displayed in the LCD display and the relay module activated to turn on the water pump to begin the watering process or the opposite. Hardware Testing Hardware testing was done so that the proposed system is functional in every way. This system was weak in that automated irrigation system could not be programmed to detect moisture level (water content) based on moisture needs of the various plants.

According to (Kulkarni et al., 2022) proposed an innovative method for tracking the climatic conditions for a specific place using IoT. The system uses three sensors to measure variations in the atmosphere and the climate, such as temperature, humidity, and pressure and rain level. The values are then sent to the website; these values are received data and marked as statistics in graphic form. The weakness of the system is that it does not have enough sensors to screen other ecological boundaries, for example, CO₂, pressure and oxygen.

In (Shaik et al., 2020) Proposed Smart IoT-based agriculture assisting farmers in getting live data (Temperature, Soil Moisture, Rain Level) for efficient environment monitoring which will enable them to do smart farming and increase their overall yield and quality of products. Despite recent developments in irrigation control and sprinkler technology, state-of-the-art irrigation systems do nothing to compensate for areas of turf with heterogeneous water needs. A model is developed to compute moisture movement from runoff, absorption, and diffusion. It helped to overcome the physical limitations of the traditional irrigation system with the development of a sprinkler node that can sense the local soil moisture, communicate wirelessly, and actuate its own sprinkler based on a centrally computed schedule but it did not solve the cumbersome process of irrigation by enabling efficient utilization of water resources.

Shekhar, et al. (2017) proposed an Intelligent IoT-based automated irrigation system where sensor data pertaining to soil moisture and temperature are captured and KNN (K-Nearest Neighbor) classification machine learning algorithm is deployed for analyzing the sensor data for prediction towards irrigating the soil with water. The system here receives the input to microcontroller where Moisture and temperature sensor connected. The sensor input is transmitted serially to Pi3, which is an edge level processor where K-NN machine learning algorithm employed for predicting the soil condition based on trained data set. Accordingly, the control signal is sent to Arduino back again for watering the pump. The trained data set and predicted data are stored in a cloud server for farmer's access via their mobile phone. This has resulted in complete automated irrigation system employing IoT Technologies where devices communicate among themselves in predicting the soil condition for watering the field. The weakness of the system is that it concentrates on just irrigating the field with water but does not look into the water level in the tank before irrigating the field. Lastly, there is no plan for data security and integrity of agricultural data while transmitting for analysis towards prediction and sending the control signal for actuation.

Preeti Mehta et al., (2019) developed a system to monitor crop fields using sensors to check soil moisture and automate the irrigation system. By developing a Smart Wireless Sensor and involved a Raspberry Pi – Controller with video capturing by using an MMS facility about the crop position and at the same time sending video to the farmer and also adding various soil quality checking sensors so that according to condition of the soil, fertilizers can be used which is very cost effective to the farmer. This system is more useful in areas where water is in scarce quantity and more efficient than the conventional approach because it reduces the water consumption to a considerable extent. The challenge of the system is that there is no effective security management mechanism to improve irrigation system.

In (Nigusie et al., 2020) Proposed an IoT-based irrigation management system after investigating problems of irrigated farmlands in three SSA countries - Ethiopia, Kenya, and South Africa as case studies. Resource-efficient IoT architecture is developed that monitors soil, microclimate and water parameters and performs appropriate irrigation management. Indigenous farming and expert knowledge, regional weather information, crop and soil specific characteristics are also provided to the system for informed-decision making and efficient operation of the irrigation management system. The system showed strength in its contribution towards long term and sustainable high crop yield with minimum resource consumption and impact to the biodiversity around the case farmlands. The challenges of this system is that the broadband connectivity and cloud services are either unavailable or expensive.

Bhanu et al., (2018) proposed a remote monitoring system that can monitor agricultural land in real-time and makes good decisions using the collected data from a farm by using ZigBee modules. This makes data is fused by using a high-performance ARM microcontroller. The data is then transferred to a remote computer by using GPRS modules to make informed management decisions. The system not only improves the level of agricultural production but also reduces human costs.

As per (Katariya et al., 2019) Provides an automatic irrigation system thereby saving time, money and power of the farmer. The traditional farm-land irrigation techniques require manual intervention. With the automated technology of irrigation, the human intervention can be minimized. Whenever there is a change in temperature and humidity of the surroundings these sensors senses the change in temperature and humidity and gives an interrupt signal to the micro- controller. The weakness of this system is that it is just limited to the automation of irrigation system and lacks in extra ordinary features. Most of the existing systems used techniques and methods, which could not accurately measure soil water content. These systems were not programmed in such a way that it can avoid irrigation at the wrong time of the day to reduce runoff from overwatering saturated soils, which will improve crop performance. The use of a precise method for irrigation and a valuable tool for accurate soil moisture control in highly specialized greenhouse vegetable production will help eliminate human errors in adjusting available soil moisture levels and save water at the same time.

METHODOLOGY

System Design Approach

This study adopts the prototype-based system design as a method of modeling actual irrigation processes in a real-world in an efficient and versatile way. The design of the IoT based data logging system was done in stages. Stakeholder interviews and surveys conducted during the requirements gathering phase helped in defining hardware, software and network requirements. The design step was aimed at incorporating sensors, microcontrollers, and communication units on real-time monitoring of soil moisture, temperature and water levels. During the implementation stage, the calculation of the evapotranspiration and the regulation of irrigation was done through the application of a fuzzy logic algorithm. Lastly, the testing step considered the system performance at a crop field, which tested the accuracy, responsiveness, and the efficiency of using water.

Requirements Gathering

The process of requirements gathering was to include the input of important stakeholders, such as farmers and experts in the agricultural field, through interviews and surveys to determine the needs of the system, and operational problems of the system. The hardware specifications were defined as soil moisture and temperature

and water tank level sensors with an integrated microcontroller (Arduino) and a GSM communication module and a stable power supply. Software requirements included microcontroller operation firmware, data logging software to collect sensor data in real time and fuzzy logic algorithm to compute the precise evapotranspiration amount and control irrigation. These requirements made the system correct, adaptive, and realistic in practical use in agriculture.

Functional Architecture

Acquisition Block

The acquisition block will collect real-time environmental data that are of great importance in monitoring evapotranspiration. It is a combination of soil moisture, soil temperature and water tank level sensors that monitor the conditions that influence crop irrigation requirements. The sensors transform physical parameters into electrical impulses and transfer to the microcontroller to process. The block assures the flow of data, which is correct and enduring, to make irrigation decisions accurately. The acquisition block provides the basis of the adaptive irrigation control by capturing dynamic changes in soil moisture and water availability, reducing the amount of wasted water and ensuring the favorable conditions of crop growth.

Microcontroller Block

The microcontroller block is the processing unit of the system and it takes data on sensor as input and processes it as sensor data. It is programmed on an Arduino Uno or Atmega 382 to carry out programmed algorithms, such as fuzzy logic rules, to compute evapotranspiration rates and calculate the irrigation requirements. The automatic functional block takes input signals, runs the control logic in the microcontroller, and gives output to the microcontroller. It is real time responsive, whereby there are several sensors and actuators. The microcontroller block facilitates dynamism in schedule changes by the irrigation system based on environmental factors and crop water requirements through the implementation of a dynamic and continuous data analysis and decision-making process.

Automatic Functional Block

The physical irrigation system is automatically operated by the automatic functional block under the instructions of the microcontroller. It contains relays that are electrically controlled switches and DC water pumps that provide accurate doses of water to crops. When the soil moisture drops to the level which has been set by the fuzzy logic algorithm, the microcontroller will make the relay turn on and the pump will be turned on to provide irrigation at the right time. The system also shuts off the pump automatically once it attains the desired level of moisture. This block facilitates precise, effective and automated water delivery, minimising human intervention, wastage of water and aids in managing the best crop growth and evapotranspiration.

Monitoring Block

The monitoring block gives the users real-time feedback of the system status and the environmental status. It is made with an LCD interface, which displays soil moisture, temperature, water tank position and pump operating status. A mobile interface also provides the opportunity to remotely access, receive notifications, and alerts, which will allow farmers to monitor the irrigation performance and respond in case of need. This block is transparent, useful and convenient as it provides timely and actionable information. The monitoring block with its quality visual displays and remote connectivity will make the system more accessible, assist in informed decision-making, and provide the chance to customize irrigation schedules based on crop-related needs and environmental diversities.

Fuzzy Logic Control

The fuzzy logic control system takes the real-time data obtained using soil moisture, temperature, and water tank level sensors to calculate the optimal irrigation. The sensor reads are then fuzzified into linguistic variables, which will be Low, Medium and High. The system uses IF -THEN rules to assess crop water demand based on

environmental conditions. The outcome of all rules is summed to produce an overall fuzzy response, and this fuzzy response is defuzzified by the Centroid of Area technique to obtain the exact amount of irrigation. The system goes as far as to turn on water pumps based on the context and constantly checks the conditions and gives its users alerts and notifications both low water levels and system malfunctions to ensure efficient and adaptive irrigation.

System Workflow

The sensor data acquisition, processing, and automated irrigation control are built in system workflow. Sensors give details of moisture, temperature, and water tank level and send real-time data to the microcontroller. The microcontroller uses algorithms of the fuzzy logic to calculate the best irrigation to be used by turning on relays and water pumps to dispense the right amount of water to the crops. Sensors provide feedback, which allows monitoring of the situation continuously, changing irrigation in response to this. Possessing an LCD and mobile interface, the monitoring block keeps the user informed of the real-time status and notifies of system errors or low water levels. Block diagrams depict the system structure and workflow of the functions with the emphasis on the data flow between acquisition and the execution of irrigation.

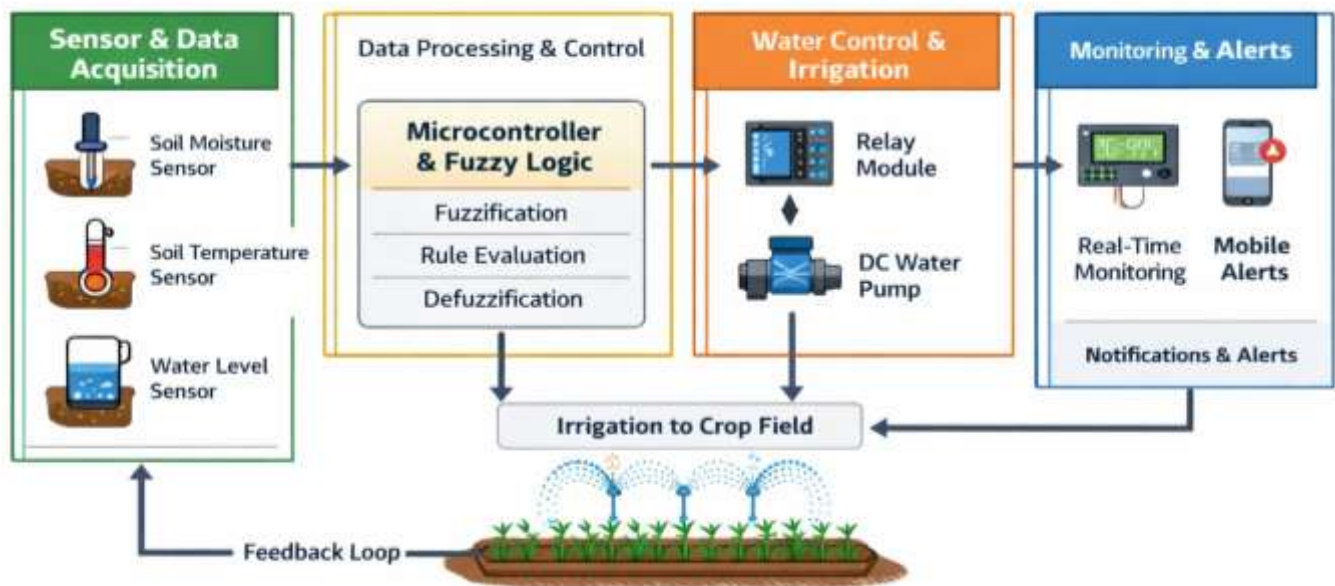


Fig. 1: The System Architecture

RESULTS

Table 1: Sensor Testing and Accuracy

Parameter	Sensor Output (V)	Measured Value	Measured Value	Remarks
Soil Moisture (%)	0.50	10.5	±0.5	Accurate measurement
Soil Moisture (%)	0.75	14.8	±0.2	High accuracy
Soil Moisture (%)	1.00	19.5	±0.5	Reliable reading
Soil Moisture (%)	1.25	24.9	±0.1	Minimal deviation
Soil Moisture (%)	1.50	30.1	±0.1	Very precise
Soil Temperature (°C)	0.75	30.2	±0.2	Very precise
Soil Temperature (°C)	0.80	31.1	±0.1	High accuracy
Soil Temperature (°C)	0.85	32.0	±0.0	Exact reading
Soil Temperature (°C)	0.90	33.3	±0.3	Minor deviation
Soil Temperature (°C)	0.95	34.1	±0.1	Reliable measurement

The sensor test outcomes of table 1 prove that the proposed irrigation based on the IoT is very reliable and precise. The soil moisture sensors were always within 0.5 percent of the real values whereas the soil temperature sensors were within very small margins, within 0.3C as a rule. These findings reveal that the sensors are capable of precise real time environmental measurements vital to evapotranspiration measurements. The narrow error margins allow accurate control of irrigation and reduce the wastage of water and maximize the health of crops. In general, sensor behavior of the system justifies its application in adaptive and real time agricultural applications.

Table 2: Comparative Evaluation of Fuzzy Logic vs Traditional Irrigation Systems

Parameter	Traditional Irrigation	Fuzzy Logic IoT System	Improvement
Water Usage Efficiency	Baseline (100%)	70–80% of baseline	20–30% reduction
Response Time to Soil Condition	30–60 minutes	<5 minutes	~90% faster
Soil Moisture Accuracy	75–85%	95%	10–20% higher accuracy
Crop Yield Increase	Baseline	+15%	15% improvement
Runoff & Soil Saturation	Frequent	Minimal	Significantly reduced
Real-Time Monitoring	Limited	Continuous	Fully real-time
User Intervention Required	High	Low	Reduced by ~80%

Table 2 demonstrates that fuzzy logic IoT irrigation system is much more effective than the conventional irrigation techniques. The consumption of water dropped to 2030 percent and the reaction to varying soil conditions improved to less than 5 minutes as compared to 3060 minutes. The accuracy in soil moisture measurement became 95% leading to more accurate irrigation. The yield of crops grew by 15 percent, and runoff and soil saturation were reduced to a minimum. Besides, real time monitoring and automation minimized manual control, which showed that the system was efficient, flexible, and sustainable in the current agricultural industry.

Table 3: Performance Metrics

Metric	Measurement	Description
Water Usage Efficiency	20–30% reduction	Optimized irrigation reduces water wastage and runoff.
Accuracy of Soil Moisture Detection	95%	Ensures precise monitoring of soil water content.
Response Time	<5 minutes	Rapid system reaction to changing soil or weather conditions.
Uptime / Reliability	98%	High system availability ensures continuous operation.
Crop Yield Improvement	15% increase	More efficient irrigation enhances crop growth and productivity.

Table 3 show how effective the system is in precision agriculture. The water consumption was cut down by 20 -30, which is an indicator of good irrigation management and conservation of resources. The detection of soil moisture reached 95 percent accuracy, which facilitates accurate irrigation based on the crop requirements. The system reacted to environmental changes within a span of less than five minutes, which ensured that water was delivered on time. A 98% uptime and reliability ensures uninterrupted operation and crop yields had increased by 15 percent as a result of efficient management of water. In general, these indicators support the reliability, efficiency, and favourable effects of the system on sustainable agriculture.

DISCUSSION

The study findings reveal that the fuzzy logic-based irrigation system with the IoT is capable of bringing considerable benefits in comparison to old-fashioned approaches in irrigation. Sensor test revealed that soil moisture (95 percent) and temperature measurements were of high accuracy facilitating accurate monitoring of

evapotranspiration. The use of water was minimized by 20-30 percent and the response time was less than five minutes meaning that the system can adapt fast to change in the environment like rain or temperature. These enhancements indicate the benefits of fuzzy logic control that enables real-time decision-making that is adaptive to real-time data as opposed to fixed schedules or thresholds employed in traditional systems. The real time flexibility of the system helps in ensuring that crops obtain the right amount of water at the right time avoiding over-irrigation or under-irrigation and thereby reducing run off and saturation of the soil. This will be very helpful in promoting sustainable farming since it helps save water and increase crop productivity by 15 percent. Its high system reliability (98% uptime) is yet another testament to its practicality in running the farm around the clock. Although these advantages exist, the possible drawbacks are the upfront cost of installing the IoT infrastructure, reliance on a constant power supply, and possible connectivity issues in remote locations. Secondly, although fuzzy logic enhances decision-making, there could be more testing and the calibration of the system to suit various types of soils, crops and climates, which might be necessary. Overall, the research validates that the combination of the use of the IoT sensors and the fuzzy logic-based irrigation systems will present a viable, effective, and environmentally friendly solution to the present and future of agriculture, meeting the needs of the water conservation and productivity objectives but also minimizing the workforce requirements.

CONCLUSION

This study has described the design, development and testing of an IoT-based data logging system with fuzzy logic control capable of providing real time monitoring and control of the transpiration of crops. This system was successfully used to measure soil moisture, soil temperature and water tank content, process these inputs through fuzzy logic algorithms and provide accurate irrigation. The main results are summed up as 2030 percent water consumption decrease, 95 percent accuracy in detecting soil moisture, the response time of less than five minutes, and 15 percent crop yield increase, which prove the system able to optimize irrigation and save resources. The research is relevant to the field of precision agriculture because it combines the IoT and intelligent decision-making into irrigation systems, which enables farmers to control crops remotely and dynamically regulate the timing of watering. Some of the benefits are that it saves a substantial amount of water, increases crop yields, and minimizes labor needs leading to economic sustainability and environmental sustainability. The system can be extended to larger farms in the future and be combined with the already existing agricultural systems. Further precision of irrigation might be achieved by the addition of other sensors, like nutrient sensors or weather sensors. System reliability can be improved by using data integrity and remote access security measures. Overall, this data-driven, resource-efficient, and sustainable farming solution is promising based on the use of IoT.

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