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Efficient Smart Water Management Techniques to Enhance Crop Productivity for Maize

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Maize is identified as the "Queen of Cereals" owing to its high yield. Water scarcity is a major problem, where agriculture consumes significant freshwater. Smart Irrigation with Internet of Things technology can help farmers to maximize crop production with less water. The field experiment on sensor-based drip Irrigation and farmer practice was conducted in the research field to enhance growth, yield, and water efficiency. The experiment comprised eight treatments such as T1: IoT based Drip Irrigation at 60% depletion level, T2: IoT based Drip Irrigation at 80% depletion level, T3: Drip Irrigation at 60% PE, T4: Drip Irrigation at 80% PE, T5: Drip irrigation as Normal Practice, T6: Surface Irrigation at 60% IW/CPE ratio, T7: Surface Irrigation at 80% IW/ CPE ratio and T8: Flood irrigation as Farmer's Practice. The proposed systems-based Drip irrigation at a 60% depletion level can be recommended for hybrid maize to augment higher grain and straw yield. The highest water saving was recorded in IoT-based Drip Irrigation at a 60% depletion level(46.88%) followed by IoT-based Drip Irrigation at an 80% depletion level(40.63%).

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Keywords: Irrigation; sensor based irrigation; weather based monitoring; automatic irrigation system.

1. INTRODUCTION

"Maize is the prevailing crop cultivated both for food and economic purposes. Agriculture automation is an emerging technique in India. The world's population is rapidly increasing, and as the population grows, the demand for food also increases. The agricultural cropping system involves resourcefully using available water and land assets to meet the increased population requirement. In Irrigation management methods the required amount of water is applied to the field to satisfy the crop needs at various stages. Based on the soil moisture and crop evaporation conditions, IoT-based smart irrigation management detects irrigation schedule, the amount of water required, and the frequency of irrigation for the maize crop. In the agriculture industry, new technologies are required to satisfy the increasing food needs and requirements" [1–3]. "Advanced agricultural techniques generate data from various sensors, leading to a better understanding of the operational environment" [4–7]. "The SMART automates irrigation systems conserves water usage. This technique regulates irrigation based on soil and weather conditions; it allows farmers to meet their demands with a newly adopted technique that preserves the water for the irrigation process" [8-9]. To avoid water stress, farmers apply more water than the required water. Smart water management techniques are needed in agriculture to increase crop yield with reduced water requirements. The emerging Internet of Things (IoT) technology as the choice for smart water management applications. The IoT is a phenomenon that owes to the conjunction of several factors such as inexpensive devices, low-power wireless technologies, cloud data centers for storage and processing, unstructured data management, high-performance computing resources and computational intelligence algorithms to deal with Big data analytics. Water is the lifeblood of plants and humans. Water is a precious resource to be used wisely by the farmer. Measuring the water requirement of the plant is the best way of determining when and how much to irrigate. Farmers find too inconvenient and inefficient to complete the task manually.

Currently, to overcome the traditional methods, IoT-based smart irrigation is the best solution. In IoT-based methods, sensors have been installed on the soil to measure the soil moisture level in real-time. Wireless transmitters send the sensor value to a gateway, which forwards them to a cloud. Software provides information to the farmers with an irrigation recommendation that takes all the variables into account, including the particulars of the plantation, the type of crop, and the farm's water supply. Traditional irrigation methods have changed to IoT-based smart irrigation for agriculture, which is not yet fully automatized. Advanced IoT software platforms for automating part of the process and integrating different technologies such as IoT, big data analytics, and cloud computing for the deployment of applications for smart water management techniques are missing. The project is proposed to develop and assess an IoT-based smart water management platform for precision irrigation in agriculture. The main objective of the project is to reduce the water used in irrigation and to maximize yield. The main objective of the project is

- To evaluate the temporal soil moisture using sensor, actuator technologies and communication technologies.
- To develop and design software components for data acquisition, data storage, processing, and distribution.
- To assess the water-saving potential of IoT-based smart irrigation systems.
- To study the effect of IoT-based smart irrigation systems in maize.

2. METHODOLOGY

A field experiment "IoT Based Smart water management to enhance the crop productivity" in maize was carried out during the summer of 2023 on the farm of Agricultural College and Research Institute, Madurai,

2.1 Experimental Design and Treatment Details

The experiment was carried out in a randomized block design with 8 treatments with three replications. The maize hybrid COH(M) 8 crop variety with a spacing of 60 x 25 cm is used for the research work.

The treatment details are as follows:

T_1: IoT-based Drip Irrigation at 60% depletion level
T_2: IoT-based Drip Irrigation at 80% depletion level

T_3: Drip Irrigation at 60% PE
T_4: Drip Irrigation at 80% PE
T_5: Drip irrigation as Normal Practice
T_6: Surface Irrigation at 60% IW/CPE ratio
T_7: Surface Irrigation at 80% IW/ CPE ratio
T_8: Flood Irrigation as Farmer's Practice

2.2 Soil Characteristics

The experiment field soil is sandy clay loam in texture. The soil samples were collected randomly in five different places in the field at a depth of 0-15cm. The physicochemical properties of soil are pH -6.81, Nitrogen – 285, Phosphorus-15.2, Potassium - 418 in kg ha^{-1}

2.3 Crop Management

Preparation of the seedbed included plowing with a disk plow, cultivator, and rotavator. The formation of ridges and furrows enables the saving of irrigation water in maize. The spacing of maize is 60 x 25cm. Each treatment has 5 rows of maize. Each Lateral length is 26m long and the distance between the laterals is 120 cm.

2.4 Land Preparation and Manuring

Well-prepared ridges and furrows with deep ploughing is an ideal condition for crop sowing. Before sowing, blanket recommendation of maize 135: 62.5: 50 NPK Kg ha^{-1} was applied in the soil. Urea have applied in 3 splits, mainly at the sowing, knee-high, and tasseling stages. The entire dose of P & K_2O with 45 Kg of urea should be applied at the time of sowing. To prevent the spread of weeds, the Atrazine herbicide (500g /ha) was applied as three days after sowing. The Coragen insecticide was applied at a rate of 900ml per hectare to control maize pests.

2.5 Irrigation

Irrigation scheduling determines when and how much water is applied to the field. The quantity of water to be applied is estimated using a criterion to determine the irrigation requirement. Efficient irrigation scheduling applies irrigation water at the right time and right quantity to increase production. On the other hand, poor irrigation scheduling results in under-watering which affects water use efficiency.

In this experiment, four types of irrigation methods are applied.

- IoT Based Drip Irrigation
- Drip Irrigation based on PE Ratio
- Surface Irrigation based on the IW/CPE ratio
- Flood Irrigation

2.6 Sensor Based Irrigation

The irrigation timing in the smart farm was determined by soil moisture drainage from field capacity using a moisture sensor in the field. Two sensors have been installed in the field to measure the soil moisture value. The optimal sensor depth of the maize crop is 20cm. The sensors were connected to the controller through wires for better accuracy. The flow of water to the field is controlled by the soil moisture value received from the treatments (T1 and T2). The valves have automatically opened and closed based on prefixed soil moisture sensor observations for real-time operation. Accordingly, the plants were irrigated from planting to before corolla emergence, milking stage, moisture drainage, and from seed milking to physiological maturity the plants were based on 60% of field capacity moisture drainage (T1) and 80% of field capacity moisture drainage (T2).

The input parameter for minimum (60% of FC for T1 and 80% of FC for T2) and maximum (100% FC) threshold value of soil moisture needs to be set for automatic irrigation operation for T1 and T2. Users can set the value according to the crop-water requirement and management allows a deficit for a specific crop. As the soil moisture reaches or exceeds a pre-set threshold value, the motor driver module activates and opens the solenoid valve. Similarly, when the soil moisture came up to 100% of field capacity, the motor driver module activated and closed the solenoid valve.

2.7 Weather Based Monitoring

Weather-based monitoring involves real-time estimation of reference evapotranspiration ET using measured weather parameters and thus indicates the water lost by the plants and the soil environment. The quantity of water lost through evapotranspiration depends on humidity, wind speed, solar radiation, and air temperature. The temporal dynamics of evapotranspiration on daily timescales are appropriate for determining crop water use in Treatment T3 and T4.

A drip irrigation water delivery system is used for treatment T1 to T5, which gives the ability to deliver water directly to the root zone, in accurate amounts based on the plant's current needs. Drip irrigation is the only irrigation technique that has been able to avoid water stress without over-watering. In the sensor-based smart (T1 and T2), irrigation was based on Intelligent sensor-based control, Pan Evaporation value irrigation was applied in Drip irrigation (T3, T4, and T5) treatment. Irrigation was applied to the treatment (T6 and T7) using the IW/CPE ratio. The irrigation for T3 to T7 was applied as per data of the daily water sheet balance method. Flood irrigation was applied based on farmer practice every three days intervals.

2.8 Components of Automatic Irrigation System

2.8.1 Hardware components

The design and Implementation of the IoT-based smart intelligent system comprises a central controller, network operators and sensors. Implementation of this project in the field involved using the soil moisture sensor (Irrometer 200SS Watermark), Solenoid valves used for actuating the relay module and triggering the pump motor for automatic irrigation, and a water flow sensor used to measure the amount of water. The Block diagram of the IoT-based Smart Water Management system is mentioned in Fig. 1. The controller unit comprises voltage converter, motor drive module, Arduino nano microcontroller, power, and GSM Module. The control box designed as three option buttons, one for power off and on, a second for operation mode (Manual, Automatic, and Reset), third one for the status of water flow and sensor value display in the LCD Panel. The whole system was powered with a 230V 3-phase connection. The system was programmed to open and close the solenoid valve based on the sensor value (60% and 80% depletion value) for T1 and T2, PAN Evaporation value for T3 and T4, and IW/CPE ratio for treatment T6 and T7. Manual Operation for T5 and T8.

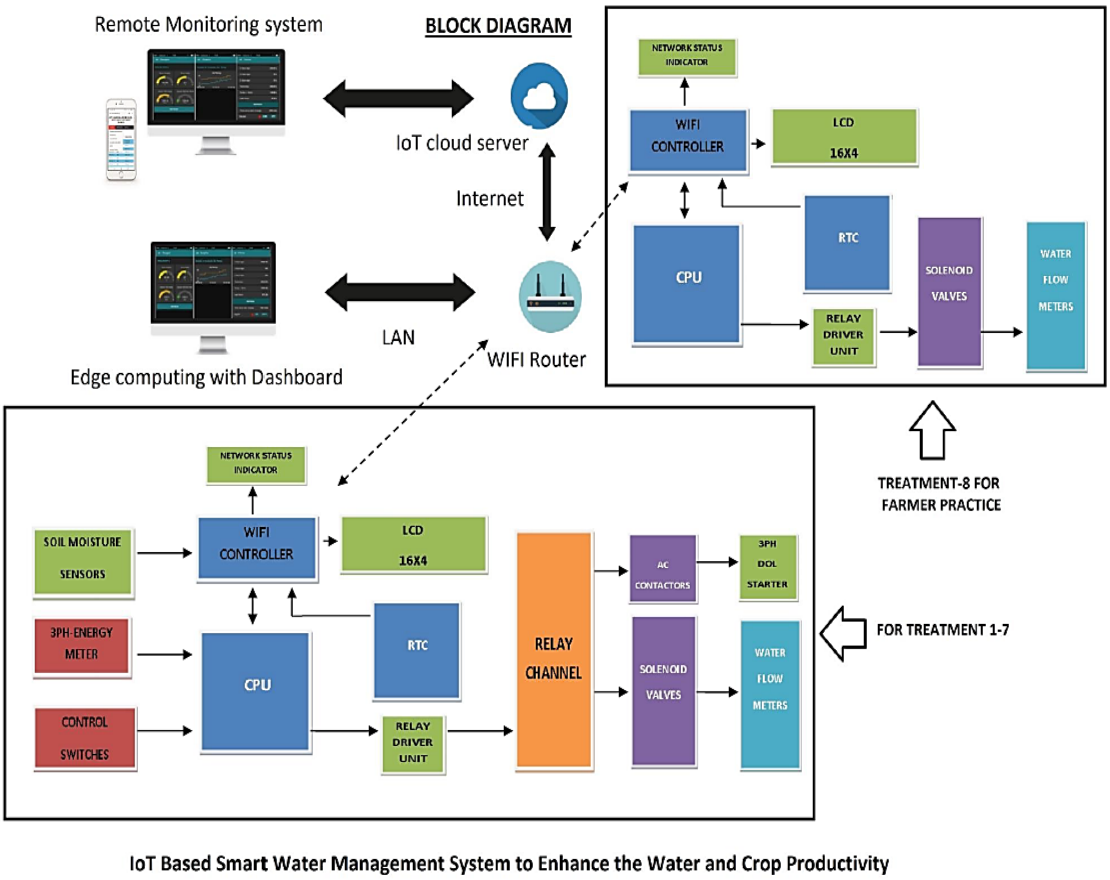

Fig. 1. IoT-based smart water management system

2.9 Software Component

The software used in the IoT-Agro unit was customized according to our research need, which consists of web and mobile-based interfaces. The users can access the device from anywhere. In the experiment field, soil moisture sensors were installed in the crop's root zone. Soil moisture varies in three dimensions, such as variability in soil wetting from irrigation/rainfall, drying of soil from evaporation, and root-zone water extraction for plant transpiration. Interaction of these dimensions was imperative for soil moisture sensor installation. The soil moisture is placed at the top of the active root system, relative to drippers and the bottom of the root system. The suitable position of the sensor position is 11cm between the drip line and 20cm beneath of surface of the soil.

3. RESULTS AND DISCUSSION

Growth analysis elucidated the impact of sensor-based irrigation in the different growing period and growth-attributing parameters. Plant height is a direct index to measure the growth and vigor of the plant. The data about the plant height of maize is influenced by irrigation methods and irrigation schedules. A perusal of data indicates that the plant height of maize has progressively increased with the advancement of crop age up to harvest, irrespective of the treatments. The plant height of maize was significantly influenced by irrigation methods and irrigation levels. Irrigation plays an imperative role in deciding the potential ability of maize to produce an economic yield. Characters like cob length, number of kernels per pod, and 100 kernel weight are dramatically affected by moisture stress.

In the present study, IoT sensor-based Drip Irrigation at 60% depletion level recorded lengthy cob (22.7cm) with higher girth (16.4 cm) and 110 kernel weight (27.8 g) compared to flood irrigation method which produced shorter cob with lower cob (17.0cm), cob girth(13.4 cm) and 110 kernel weight (23.8 g). The cob length, cob girth, and 100 kernel weight are represented in Fig. 2.

In the present study, among the Irrigation method, IoT sensor-based Drip Irrigation at 60% depletion level (T1) recorded the maximum grain yield (7050 kg ha^{-1}) and straw yield (11069 kg ha^{-1}) and the minimum grain yield (5069 kg ha^{-1}) and straw yield (7604 kg ha^{-1}) were recorded under surface irrigation method (T8). Treatment T1 was followed by IoT-based Drip Irrigation at 80% depletion level (T2) and Drip Irrigation at 80% PE (T4).

"The increase in the yield parameter was due to the availability of sufficient moisture in the soil, which also favoured photosynthetic production and translocation of photosynthates to the sink and improved 100-seed weight. Significantly, the lower grain yield in surface irrigation was associated with the non-availability of required moisture at critical times, creating stress near the crop-effective root zone". [10]

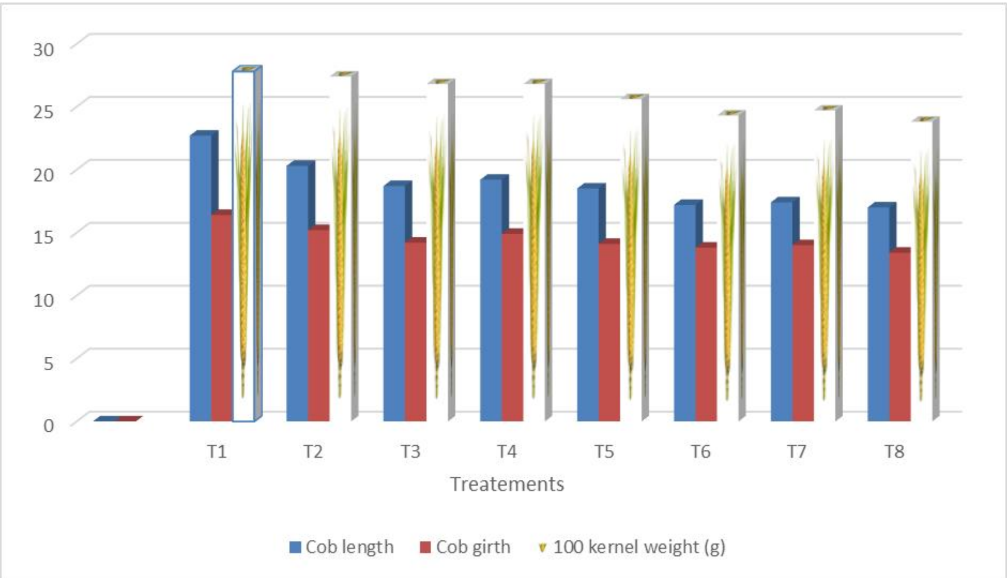

Fig. 2. Influence of irrigation methods and Yield attribute of hybrid maize

"Higher water use efficiency with sensor irrigation systems was due to reduced water loss and efficient water use by the plants, resulting in a higher yield. The favourable effect of sensor irrigation and drip irrigation helped in maintaining constant soil moisture potential. The lower water use efficiency of surface irrigation was attributed to more evaporation loss of soil moisture due to a more exposed wetting surface upon irrigation". [10]

The highest water saving was recorded in IoT based Drip Irrigation at a 60% depletion level (46.88%) followed by IoT based Drip Irrigation at an 80% depletion level (40.63%).

4. CONCLUSION

IoT-based Drip irrigation at a 60% depletion level can be recommended for hybrid maize to augment higher grain and straw yield, water use efficiency apart from saving on irrigation water (46.88). Farmers can use this Internet of thinking to schedule irrigation and monitor their fields from different locations. The application of artificial intelligence in agriculture will bring a new revolution in efficient irrigation and save used water. Smart irrigation technologies are changing the face of irrigation by increasing irrigation efficiency and increasing yields. Irrigation water used in agriculture is cut to a higher level so that excess water can be used in the field to grow other additional crops. Sensors help improve resource utilization.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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