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Optimizing Water Use for Okra Cultivation: A Soil Moisture Sensor-Based Approach

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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

Indian agriculture relies on monsoons, a water source notorious for its unreliability. To ensure sustainable production and productivity, the judicious and timely utilization of available water becomes imperative, emphasizing the need to maximize soil moisture while minimizing water losses. Drip irrigation stands out as a widely adopted and highly regarded water-conserving technology. The potential of an automated drip system becomes evident as it holds the promise of blessing farmers with higher yields despite the constraints of limited irrigation water. The necessity for a soil moisture-based drip irrigation system becomes apparent, tailored to the specific moisture and soil types of individual farms. A low-cost soil moisture sensor-based automated drip irrigation

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system emerges as the research objective, aiming to enhance efficiency and resource management. Gravity, coupled with drip irrigation, emerges as the most suitable method. The system operates in a closed-loop fashion, continuously monitoring and adjusting based on soil moisture content and the crop's water requirements. In the agricultural landscape of Chhattisgarh, where the total cultivable land spans 4.8 million hectares, with 0.51 million hectares dedicated to cultivating okra crops, the Crop Water Requirement (CWR) for okra varies from 30 cm to 55 cm, influenced by factors such as variety and crop seasons. The research yields insightful results, showcasing maximum water use efficiency in the sensor-based treatment at 46.76 kg/ha/mm, while the control irrigation exhibits a minimum efficiency of 26.66 kg/ha/mm.

Keywords: Sensor; soil moisture; okra; automation; drip irrigation.

1. INTRODUCTION

Freshwater is a vital resource for both ecosystem health and human survival, and it is the natural resource that is the most extracted at the global level. Excessive freshwater consumption can be responsible for a scarcity in the circulation rate, which occurs when the freshwater demand exceeds its availability [1].

Agricultural production plays a key role in guaranteeing food security, but consumes a large amount of freshwater resources [2]. Globally, agricultural irrigation accounts for ~70% of the total freshwater withdrawal and 80–90% of human water consumption [3]. Owing to population growth, richer diets and biofuel use increase, food demands are projected to increase substantially in the coming decades [4].

The potential solution lies in the availability of sufficient water resources. With ample water, the intensity of cultivation could increase by 300% or more. Vast areas of waste or fallow lands could be brought under cultivation, addressing the pressing issue of food shortages for the growing global population. Jackson (1982) reported that the ideal irrigation scheduling technique should use the plant as the indicator of the plant stress, since the plant response both the aerial and soil environments [5].

To address the challenges of achieving higher productivity and resource-use efficiency, a sensor-based irrigation system has been introduced. This system adapts to temporal and in-season variability, aggregating data on soil and plant conditions. In collaboration with decision support advisories and control systems, it enables real-time irrigation based on the specific needs of the crops.

A sensor-based irrigation system has been demonstrated to address the challenges of higher productivity with greater resource-use efficiency by applying water as per the temporal and in-season variability. The soil moisture sensor-based irrigation system facilitates aggregation of data on soil and plant conditions and in conjunction with decision support advisories and control systems, applies real-time irrigation based on crop need.

2. MATERIALS AND METHODS

The experiment took place in the experimental plot of the Department of Soil and Water Engineering at SV College of Agricultural Engineering and Technology & Research Station, Faculty of Agricultural Engineering, IGKV Raipur (C.G.). The experiment's layout is depicted in Fig. 1. It was conducted during the summer season of 2018, aiming to assess the impact of a Sensor-based Drip Irrigation System (Sensor-based treatment) on crop yield attributing characters. The sensor was strategically placed at depths of 5 cm, 10 cm, and 20 cm during the initial, vegetative, and maturity stages of crop growth, respectively. The probe's wire lengths were set at 18 m, 15m, 12 m, 10 m, and 4 m. The gravity-fed drip irrigation system operated under the control of the sensor system. This system included a 750-liter overhead tank connected to an electrical pump, both managed by the sensor system. The drip irrigation setup featured 20 m-long drip tubing, positioned at a 50 cm distance with inline emitters at 30 cm intervals. Throughout the treatment, irrigation levels in each lateral were regulated using lateral valves, and the water pressure was monitored at 0.25 kg cm^{-2}.

The climate of Chhattisgarh is tropical. It is hot and humid because of its proximity to the Tropic of Cancer and its dependence on the monsoons for rains. The maximum temperature during the experiment varied between 30.6^{o}C to 45.5^{o}C from 5 February 2018 to 10 May 2018 whereas, the minimum temperature varied between 13.6°C to 31°C. The maximum rainfall during the period of the experiment was 10 mm. The average maximum relative humidity for different months varied from 11% to 91 % while monthly average minimum relative humidity varied between 5 to 55 %. The average values of open pan evaporation ranged from 2.3 to 4.6 mm, whereas average sunshine values varied from 3.5 to 11.2 hours, maximum wind velocity during crop period was 9.8 km h^{-1} and the minimum was recorded 1.2 km h^{-1} [6].

2.1 TDR (Time Domain Reflectometry)

TDR technology delivers very accurate determination of soil moisture content. Data can be read from a handheld unit, logged or sent via a telemetry network to a PC for analysis. TDR sensors that measured the variation of soil water content for estimation using water balance consisted of two parallel rods attached at the probe head (300 mm long × 3.2 mm diameter) with 32 mm spacing. Voltage impulses are generated and reflected within the head and output is calculated based on reflections per second (frequency), which depends upon the dielectric permittivity of the medium surrounding the probe.

2.2 Gravimetric Method

To measure soil moisture content by the gravimetric method, a subsample of a fresh, sieved composite sample or a fresh soil core is weighed, oven dried until there is no further mass loss, and then reweighted. The moisture content is expressed as mass of water per mass of dry soil.

2.3 Soil Moisture Based Sensor System

2.3.1 Displays

Single display 0.56" RED LED display was used to show output of sensor system. An LED display was a flat panel display, which uses an array of light-emitting diodes as pixels for a video display.

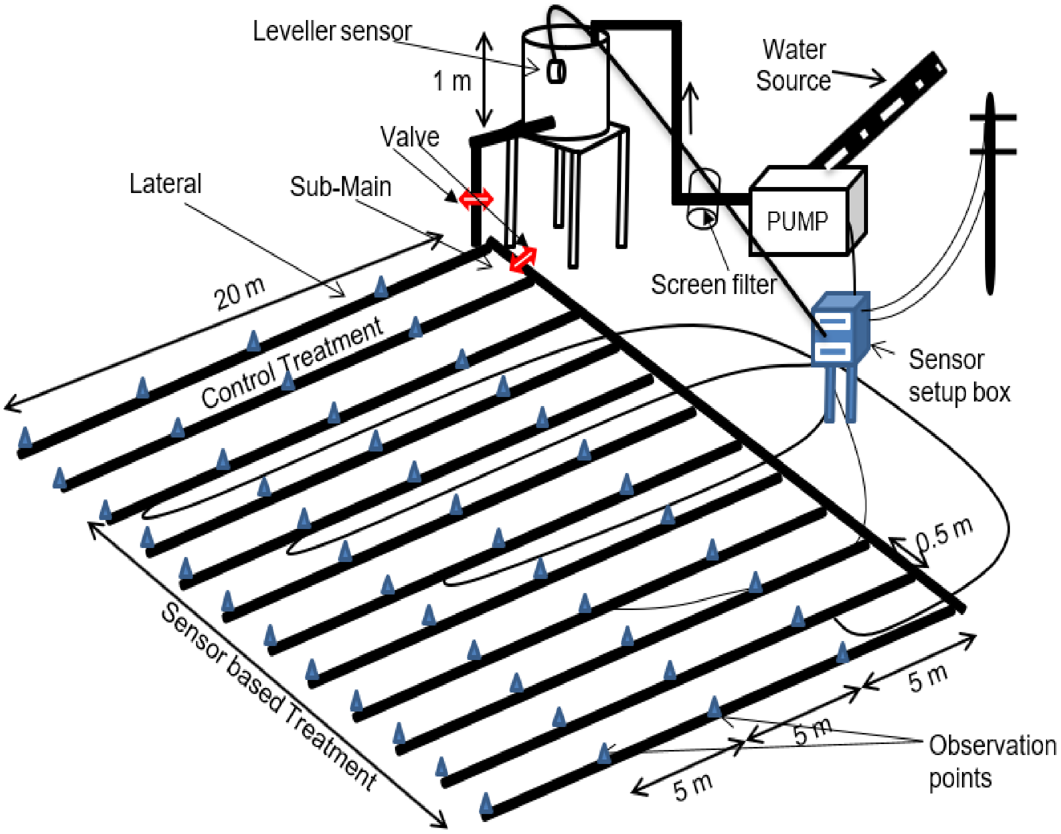

Fig. 1. Layout of Experiment Field

2.3.2 Miniature circuit breakers – MCBs

Miniature circuit breakers protect installations against overload and short-circuit, warranting reliability and safety for operations. For this project I used two different tripping mechanisms, the delayed thermal tripping mechanism for overload protection and the magnetic tripping mechanism for short circuit protection.

2.3.3 Motor starter

The MS132-32 manual motor starter. This device was used to manually switch ON and OFF motors and to protect them reliably and without the need for a fuse from short-circuits, overload and phase failures.

2.3.4 Control panels

The CP620 HMI control panels offer a wide range of features and functionalities for maximum operability. ABB Control Panels are distinguished by their robustness and easy usability, providing all the relevant information from production plants and machines at a single touch.

2.3.5 Relay

The MG6 relay was used for applications where several independent circuits may be energized or de-energized upon the operation of a single primary relay contact or where the capacity of the primary relay contact is inadequate for the energy required.

2.4 Soil Physiochemical Parameters

Field Capacity refers to the quantity of soil moisture or water content retained in the soil after excess water has drained away, and the rate of downward movement has slowed. This is measured by determining the water content after saturating a soil profile, covering it to prevent evaporation, and monitoring moisture changes over time [7]. The oven-drying method is employed to ascertain moisture content. After 5 to 6 days, when the moisture content stabilizes, a graph is plotted to visualize the resultant moisture content. The resulting graph typically depicts a straight line, representing the field capacity of the soil (as illustrated in Fig. 2 and 3).

Core cutter method was used to determine the bulk density. Bulk density is used to convert gravimetric moisture content to volumetric moisture content (VMC). VMC (%) is the product of bulk density and gravimetric moisture content (% wet basis).

2.5 Calibration of Soil Moisture Sensors

Firstly, a 100-gm sample of dry soil was taken, and 20 gm of water (an amount equal to field capacity) was added to it. After allowing it to stand for one hour, the moisture content of the sample was measured using Alfa-mart and TDR-sensor. Subsequently, the moisture content was measured using the gravimetric method. The measured moisture content was 27% (VMC), which is equal to the field capacity of the soil. Our sensor system was calibrated using CoDeSys software. The probe was inserted into the same prepared sample. During this time, the moisture content was set between 0% to 100% using the scaling on the system software. The same process was repeated with 10 different soil samples, validating the sensor system with the help of these readings.

Table 1. Experimental details

Crop		Okra
Scientific name	:	*Abelmoschus esculentus L.*
Variety	:	Samrat
Experiment Gross area	:	100 m^2
Experiment Net area	:	60 m^2
Row to row spacing	:	50 cm
Plant to plant spacing	:	30 cm
Tank capacity	:	750 l
Tullu pump	:	0.5 hp (0.7lps)
Delivery head	:	4.05m

Measurement of soil moisture content is crucial for scheduling irrigation and conducting water balance analysis. Therefore, three different sensors were tested to identify one that could be used consistently. Sensor calibration was performed using ten 100 gm of samples. Before installing the sensors, some water was added to the soil samples. TDR and our Soil moisture sensor were installed in the containers at an angle of about 90^o and at three different depths (5 cm, 10 cm, 20 cm) from the soil surface.

2.6 Validation of the Sensor System

The validation of the sensor system was conducted by implementing it in the cultivation of okra crops. Sensor data validation is a crucial step carried out during the data acquisition and data processing phases of the multi-soil moisture sensor system. This process involves validating the external conditions of the data and ensuring its suitability for a specific purpose, aiming to achieve accurate and reliable results. This validation sequence may be applied not only in data acquisition but also in data processing to enhance the confidence level of the systems. Ten random samples were selected to check the validity of the sensor system. Additionally, the sensor's response was compared to individual soil moisture sensors for precise validation of the system, as illustrated in Table 3.

2.7 Experimental Crop

The crop chosen for the experiment was okra (*Abelmoschus esculentum* L.), specifically the Samrat variety. The plant and row spacing were 50 cm and 30 cm, respectively. The total gross area was 120 m^2, with a net shown area of 72 m^2. Out of the 72 m^2, 12 m^2 was designated for conventional drip irrigation (control), and the remaining 60 m^2 was allocated for the sensor-based drip irrigation system.

2.8 Irrigation Water Requirement

The okra crop's water needs were determined based on soil moisture content. A gravity-fed drip irrigation system, utilizing a 750-liter overhead tank with a height of 3.05m, was employed. A 0.5 HP pump filled the tank, serving 10 lateral lines spaced at 50 cm and 30 cm for plants and rows, respectively. The sensor system activates the pump when the field's moisture content is low, turning it off once the required water volume is in the tank to achieve the desired moisture level. A floating switch in the tank stops the pump upon reaching the set volume, determined by the gravitational drip system's water requirements.

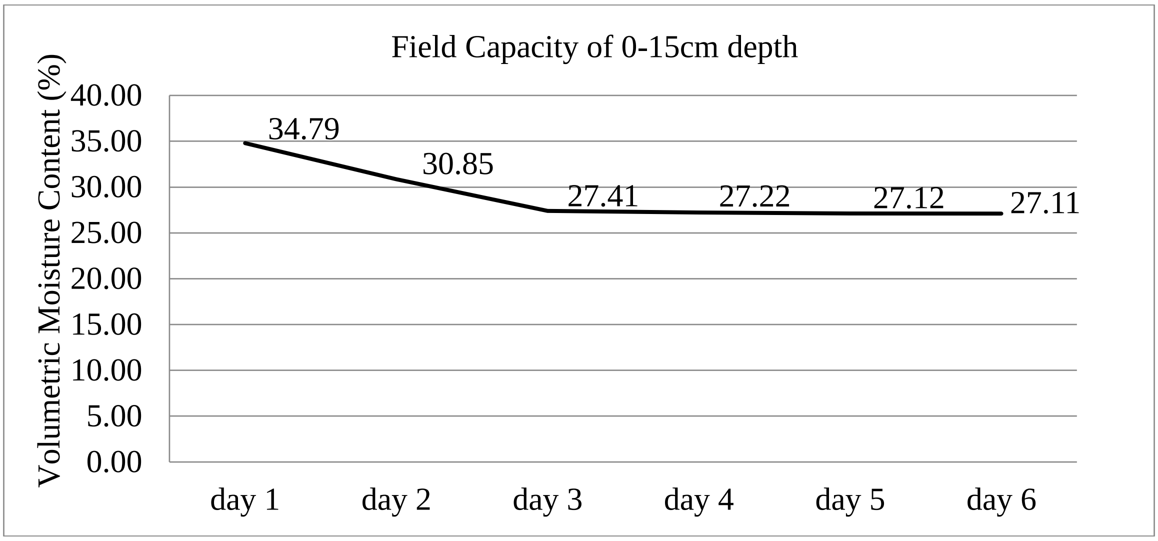

Fig 2. field capacity of 0-15 cm depth

Table 2. Soil properties

Particulars		Values	Method used
A.	Physical properties		
1.	Mechanical composition		
	Sand (%)	19.05	International Pipette method (Black,1995)
	Silt (%)	56.42	
	Clay (%)	44.75	
	Texture class	Clay loam	
2.	Field capacity	27%	
3.	Permanent wilting point(cm m^{-1})	10.74	Pressure plate apparatus method
4.	Bulk density (g cm^{-3})	1.34	Soil core method
B.	Chemical properties		
1.	pH	6.5	Glass electrode pH meter (Piper,1967)
2.	EC (ds/m at 25ºC)	0.08	Solubridge method (Black, 1965)

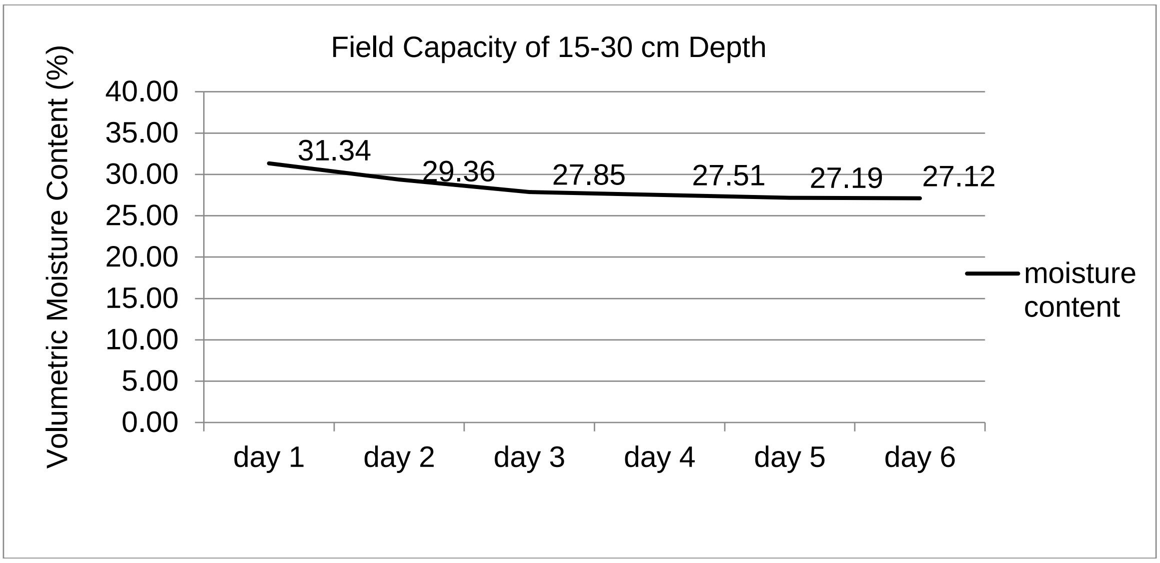

Fig. 3. field capacity of 15-30 cm depth

The water needs of the okra (*Abelmoschus esculentum* L.) crop were determined based on soil moisture content. Employing a gravity-fed drip irrigation system, a 750-liter overhead tank at a height of 3.05 m was used, filled by a 0.5 HP pump. This treatment included 10 lateral lines spaced at 50 cm for plants and 30 cm for rows. The sensor system activates the pump when the field's moisture content is low and turns it off once the required water volume is reached in the tank, achieving the desired moisture level. A floating switch in the overhead tank stops the pump when the set volume is achieved in the gravitational drip system, with the switch height set based on the required irrigation water volume [8].

The formula used for calculating the required volume of irrigation water as follows:

2.8.1 Volume of Irrigation water

$$u = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} \times A_i \times D_i \quad \ldots\ldots\ldots \quad (1)$$

In which,

u = water use from the root zone for one irrigation cycle (mm)
n = number of soil layer sampled in the root zone depth D
M_{1i} = Soil moisture percentage at the time of first sampling in the i^{th} layer
M_{2i} = Soil moisture percentage at the time of second sampling in the i^{th} layer
A_i = Apparent specific gravity of the i^{th} layer of the soil
D_i = Depth of the i^{th} layer of the soil (mm)
Irrigation water requirement

$$I_R = \frac{u \times \pi r^2}{1000} \times \text{No. of Plants} \times 1000 \quad (2)$$

Where,

I_R = Irrigation water requirement (l)
r = wetted surface area (m^2)
u= Water use from the root zone for one irrigation cycle (mm)

3. RESULTS AND DISCUSSION

3.1 Calibration & Validation of Sensor System

3.1.1 Soil moisture sensor

Soil moisture sensor with two probes was inserted into the soil at different soil depth level. As per moisture content sensor probe sends analog output variation from 0.06 volts to 5 volts to the PLC (Programmable Logic Controller) unit which in terms read the analog data and converts into digital output in form of moisture content. The complete setup is shown in Fig 5. The arrangement of the parameter data (input and output) is performed with Control Builder Plus software. The parameter data directly influences the functionality of modules. For non-standard applications, it is necessary to adapt the parameters to a system configuration.

3.1.2 Calibration of soil moisture sensor

With the assistance of various soil moisture calibrations, the soil moisture sensor was calibrated, and the results were compared, as shown in Fig. 4. The water requirement for the okra crop using the moisture sensor was calculated based on the field capacity of the soil, apparent specific gravity of the soil, and the root-zone depth of the crop. Equation 1 in the article (Volume of Irrigation Water) explains this calculation. The field capacity was determined to be 27% on a V.M.C. basis. M_{1i} (Soil moisture percentage at the time of the first sampling in the i^{th} layer) and M_{2i} (Soil moisture percentage at the time of the second sampling in the i^{th} layer) were taken as 80% and 50% of this value, respectively. From the experiment, the apparent specific gravity value was found to be 1.34. Using Equation 1, the calculated water requirement was 1.60 cm in terms of depth and 6.109×10-4 m^3 in terms of volume. This represented the water requirement for one plant per irrigation, amounting to 0.41 m^3 for the entire field (670 plants) per irrigation. This information was utilized to set up a leveller sensor inside the overhead tank. When this volume of water is reached in the tank, the sensor turns off the pump to prevent further filling.

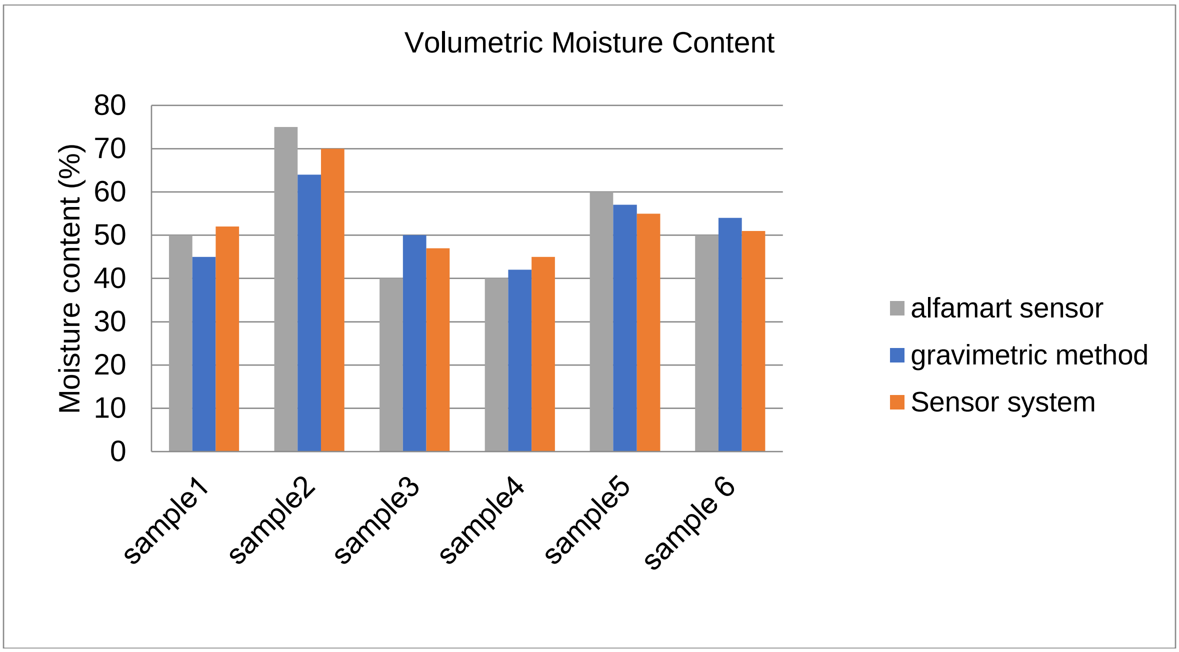

Fig. 4. Response of different moisture sensors after calibration

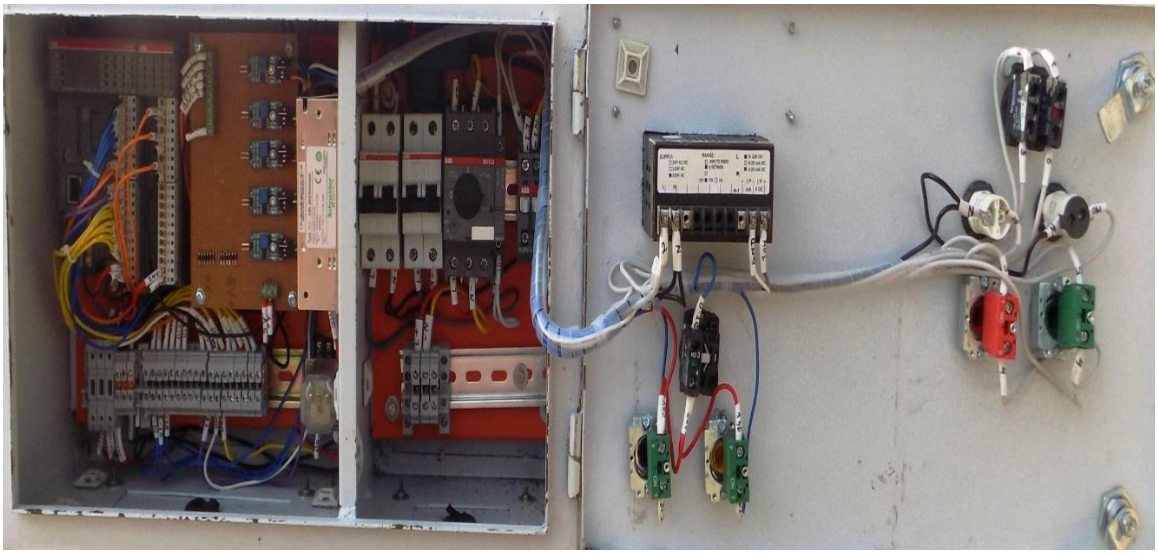

Fig. 5. Complete setup of sensor system

Table 3. After calibration reply of sensor system

S.NO	Gravimetric method		Alfa-mart sensor (%)	TDR (%)	Sensor system (%)
	Wt. basis %	VMC %			
1	20	27	25	26.50	100
2	14	18.75	19	18.40	69
3	16	21.44	21	21.10	79
4	9	12.06	12	12	45
5	13	17.42	17	16.90	65
6	16	21.44	22	21	79
7	11	14.74	15	14.50	55
8	5	6.7	7	6.50	25
9	14	18.76	18	18.20	69
10	11	14.74	15	14.30	55

Table 4 Water use efficiency under different treatments

Treatments		Yield kg per hectare	Depth of water cm	Water use efficiency (kg ha^{-1} mm^{-1})
Control irrigation	L_1	13425.3	48.5	27.68
	L_2	12933.2	48.5	26.66
Sensor based treatment	L_3	12467.4	31.16	40.01
	L_4	13471.7	31.16	43.23
	L_5	13894.4	31.16	44.59
	L_6	12749.5	31.16	40.92
	L_7	14571.5	31.16	46.76
	L_8	13698.8	31.16	43.96
	L_9	13654.4	31.16	43.82
	L_{10}	13963.1	31.16	44.81
	L_{11}	13674.4	31.16	43.88
	L_{12}	12618.3	31.16	40.50

3.1.3 Growth parameters and water use efficiency

The water applied (including rainfall) for the cultivation of the okra crop is detailed in Table 4. Daily irrigation was administered for both control irrigation and sensor-based drip irrigation, adjusted according to moisture content. Field water use efficiency under varying irrigation levels is outlined in Table 4. Calculating the total water volume, Control irrigation utilized 4850 m^3, and sensor-based drip irrigation utilized 3116.0 m^3 for okra production in a one-hectare area. The maximum water use efficiency was observed in the Sensor-based treatment at 46.76 kg ha^{-1} mm^{-1}, while the minimum water use efficiency was noted in Control irrigation at 26.66 kg ha^{-1} mm^{-1}.

4. CONCLUSIONS

The positive impact of drip irrigation and the utilization of a Sensor system in water conservation, leading to increased crop productivity, is widely acknowledged. This technology not only enhances farm economics but also ensures the realization of the full potential of crop productivity during droughts in the rainy season. It facilitates the cultivation of post-monsoon crops under limited water resources. The combined influence of drip irrigation and the Sensor system on the yield and water-use efficiency of okra production needs to be explored. The experiment aimed to integrate and establish a low-cost sensor system for monitoring soil moisture content, along with the calibration and validation of the sensor system in conjunction with a low-cost gravity-operated drip irrigation system. Laboratory tests identified the soil texture as clay loam, with a field capacity of 27% and a bulk density of 1.34 g cc^{-1}.

Alfa-mart sensor, TDR, and gravimetric method were employed to measure soil moisture content. The soil moisture sensor system underwent calibration within the VMC range of 80-50%, representing the field capacity of the soil, using the gravimetric method. A two-probe soil moisture sensor was inserted into the soil at different depths. The sensor probe transmits analog output varying from 0.06 volts to 5 volts to the PLC (Programmable Logic Controller) unit. The PLC reads the analog data and converts it into digital output, indicating moisture content. The complete setup is illustrated in Fig. 5.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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