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Performance evaluation of modified soil moisture sensor based automated drip irrigation system

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ABSTRACT

Indigenously developed soil moisture sensor based automated drip irrigation was modified, fabricated and demonstrated by the Department of Soil and Water Engineering, Swami Vivekanand College of Agricultural Engineering and Technology, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. The demonstration was carried out in the experimental plot of Krishi Vigyan Kendra, Raipur. The focus of the experiment was to modify and to install the developed soil moisture sensor system for the real–time monitoring of the moisture content of the soil after proper calibration of the sensor system, and to evaluate its performance while irrigating through sensor based automated drip irrigation system in the brinjal crop. The discharge through inline emitters has been monitored at specified locations at an interval of every 10 minutes while operating the system at a pressure range of 0.5 kg cm^{-2}, 0.7 kg cm^{-2}, 0.9 kg cm^{-2}, and 1.0 kg cm^{-2}. The purpose was to estimate the hydraulic performance of the drip irrigation system. Analyses show that the system performed well at an operating pressure of 1.0 kg cm^{-2} as maximum values of application efficiency, distribution efficiency, emission uniformity, and uniformity coefficient were obtained equal to 93.24%, 95.47%, 94.73%, and 94.18%, respectively. The soil moisture sensor system comprises of components including soil moisture sensors, 3.5 inches display, connecting cables, micro–controller, relay module, conductor and Miniature Circuit Breaker (MCB). The soil moisture sensor was calibrated in terms of volumetric moisture content (VMC) between 90–60% of the field capacity of the soil. The sensor based automated drip irrigation system automatically turned the pump "ON" whenever the moisture content in soil reduces below the pre–set moisture content that is 60% and it will irrigate the field till the moisture content reaches up to the pre–set upper moisture content limit that is 90% of the field capacity. The soil moisture sensor based automated displayed prominent effect on the yield and yield attributes observed such as the number of fruits per plant (15.42), maximum height of plant (121.1 cm), average length of fruit (14 cm), number of branch per plant (21), yield per plant (856 gm), average fruit weight (52.15 gm). The water use efficiency of brinjal under the soil moisture sensor based automated drip irrigation system was recorded as 81.71 kg ha–mm^{-1} against water use efficiency of 71.9 kg ha–mm^{-1} with the control treatment of normal drip irrigation system. The sensor–based automated drip system was found to be more water use efficient saving around 13.38% of water as compared to the control normal drip irrigation system with brinjal crop.

1. INTRODUCTION

Irrigation water is crucial for farm operations in the world, with irrigated lands contributing about 40% to food and fiber production (Mpanga and Idowu, 2021). Water and soil are the two most significant natural resources on which the agriculture is completely dependent and more precisely it is affected by the availability of water. It is a big challenge to maintain agricultural productivity while reducing pressure on these resources, large increases in water use efficiency will be required (Gleick, 2003, Rockström *et al.,* 2007), which can be brought about through the use of proven water efficient technologies only. Even good fertilizers and seeds will fail to accomplish their maximum potential if plants are not watered properly and adequately (Bhatnagar and Srivastava, 2003). Agriculture consumes around 69% of the total water withdrawn (Kumar *et al.,* 2005). The sustainability of the role of agriculture in nation's progress requires economic development derived from two main factors, increase the productivity per water unit and increase the cultivated area (Panigrahi and Panda, 2001; Farag *et al.,* 2017).

Availability of water for timely irrigation of crops is crucial that affects agricultural yield and therefore there is need to focus on ideal use of water through effectiveness (Panigrahi *et al.,* 1992; Sakthivelu *et al.,* 2016). From the various irrigation methods present today, drip irrigation system has the maximum water use efficiency as compared to other irrigation methods. As it is evident that irrigation water is limited and costly input to agriculture so it becomes necessary to maintain optimum soil moisture regime for better development and growth of crop hence giving the maximum yield. By knowing the moisture status of the soil irrigation water management practices can be efficiently used as soil moisture is an essential climate, environmental, and hydrological variable (Mittelbach *et al.,* 2012). Irrigation is mainly practiced based on the field conditions and the previous experiences of farmers, which may sometimes lead to over and under irrigation. Therefore, to irrigate the field at proper time the irrigation system can be automated with the help of sensors which can continuously monitor and measure the real time status of soil moisture content. Department of Soil and Water Engineering, Swami Vivekanand College of Agricultural Engineering and Technology and Research Station, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh has framed a low cost soil moisture sensor based automated system (Jeetraj, 2018), which was further modified making the system more user friendly for its better handling in the field and was successfully demonstrated during *rabi* 2019 with brinjal crop.

2. MATERIALS AND METHODS

The development and modification of low cost soil moisture sensor based automated drip irrigation system was done in the laboratory of Department of Soil and Water Engineering under All India Coordinated Research Project on Irrigation Water Management, Raipur centre. The field experiment was conducted at the farm of Krishi Vigyan Kendra (KVK), Indira Gandhi Krishi Vishwavidyalaya, Raipur which is located at 21º12'57.62"N and 81º42'05. 32"E having altitude of 292 m above the mean sea level.

Agro–Climatic Condition

Raipur comes within the sub–humid, dry agro–climatic zone (ACZ). It receives rainfall from South–West monsoon. It receives an average annual precipitation of 1150 mm, out of which about 80–85% is received in the third week of June to mid– September and the rest in the months from October to February. It is observed that May is the hottest and December is the coolest month of the year. From the past few decades, the rainfall pattern (particularly during June to September) is varying significantly from year to year. The minimum temperature ranges between 18 to 23.1ºC and the maximum in the range of 30 to 39.8ºC. The maximum daily rainfall of 35.8 mm was recorded during the experiment period. The maximum relative humidity during the experiment period was found to be 99%. The open pan evaporation observed reading from 1.0 to 11.6 mm, sunshine hour (0.0 to 11.4), maximum wind velocity (9.8 km h^{-1}) and minimum wind velocity (0.8 km h^{-1}) was recorded.

Experimental Details

There were total 28 rows of crops, out of which 20 rows of crop were irrigated with sensor–based automated drip irrigation system and remaining 8 rows of crop were irrigated manually under control condition. The soil moisture sensor–based drip irrigation system was set up in a 520 m^2 area. The soil moisture sensor was installed at different depths from the ground surface depending up on the expansion or extension of the root according to the growth stage or period of the crop. The wire lengths of the sensors probes were 5 m, 15 m, 15 m, 25 m and 35 m. Pump operated drip irrigation system was controlled by soil moisture sensors system. The installed drip irrigation system contains a 2000 liters capacity water tank which was connected with the electrical pump which was controlled by the sensor system. The drip irrigation system consists of laterals of 30 m length each and were placed at 75 cm apart and having inline emitters at 40 cm intervals. In the treatment, the irrigation level was sustained on each lateral with the help of lateral valves and water pressure was maintained at 1.0 kg cm^{-2}. The remaining experimental details are given in Table 1.

Soil Analysis

Based on the soil analysis of the experimental field it

Table: 1
Experimental details

Crop	:	Brinjal
Scientific name	:	*Solanum Melongena*
Variety	:	Navina
Experimental gross area	:	520 m^2
Experimental net area	:	325.3 m^2
Row to row spacing	:	75 cm
Plant to plant spacing	:	40 cm
No. of rows under controlled irrigation	:	8
No. of rows under sensor-based irrigation	:	20
Tank capacity	:	2000 l
Pump	:	1 hp
Length and width of field	:	26 × 20 m

was found that it has sandy clay texture of soil with field capacity bulk density as 31% and 1.31 gm cc^{-1}, respectively. A composite soil sample (aggregate from various location of the field) was taken out from 30 cm depth before planting during the study and analysed for particle field capacity, size distribution, bulk density, P, EC, K, O, C, N, and pH. Details of chemical and soil physical properties of the experiment site are shown in Table 2.

Modified Sensor System

Low–cost soil moisture sensor–based automated gravity–operated drip irrigation system was framed and developed in such a manner that it will deliver the irrigation water to the crops depending on the moisture depletion from the soil. Design of the automation unit was an essential step to conserve the exploitation of the precious irrigation water. The developed automated system was calibrated to provide three levels of moisture settings in the field. The system was made capable to work at 100–80% of ASM, 90–70% of ASM and finally 80–60% of ASM. The different level of soil moisture status reflects the irrigation water availability with the farmer. Farmer with good irrigation water availability can operated between 100–80% moisture content, with moderated irrigation water availability can operated between 90–70% moisture content and finally farmer with low irrigation water availability can operate at 80–60% moisture condition. The developed automated system was calibrated and tested along with soil moisture sensor at different levels of moisture content to ensure the rejuvenation of soil moisture by delivering accurate amount of water at the appropriate time by automatically switching 'ON' the drip irrigation system and automatically switches 'OFF' when the requirement is met out.

Table: 2
Soil properties of the experimental site

S.No. Particulars	Values	Method Used
A. Physical Properties		
1. Mechanical composition		
Sand (%)	42	Bouycous
Silt (%)	23	hydrometer
Clay (%)	33	Method
Textual Class	Sandy Clay	
2. Field capacity (%)	31%	Field Method
3. Bulk Density (g cm^{-3})	1.32	
B. Chemical Property		
1. pH	7.3	Glass electrode pH meter
2. Organic carbon (%)	0.7	Walkley and Black's rapid titration method
3. Available N (kg ha^{-1})	155	Alkaline permanganate method
4. Available P (kg ha^{-1})	22.7	Olsen's method
5. Available K (kg ha^{-1})	153	Flame photometric method
6. EC (ds m^{-1} at 25ºC)	0.23	Solubridge method

Components of Modified Sensor System

Soil moisture sensor sense the moisture content of the soil in the form of VMC of the soil. The soil moisture sensors employed in the experiment were calibrated and tested for automatic scheduling the irrigation based on soil moisture level. The automated system has a simple design and was simple to operate and the layout of the experimental field is shown in Fig. 1.

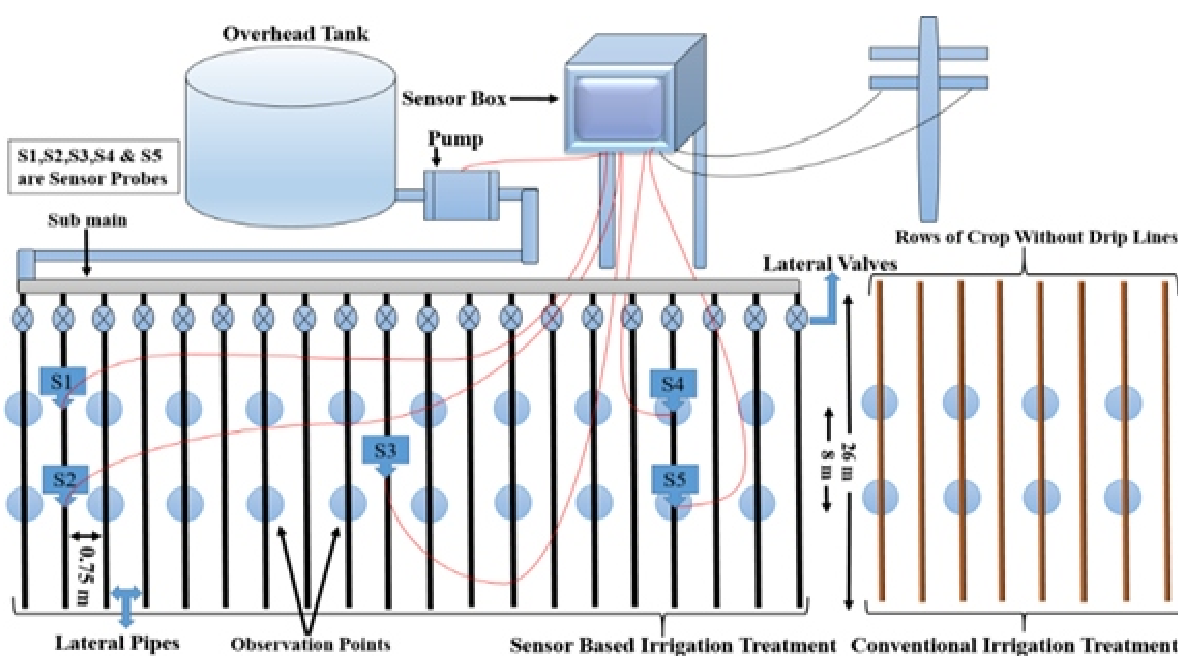

Fig. 1. Layout of the experimental field

Various components are used in sensor–based automated irrigation system such as Soil Moisture Sensor, 3.5 inch LCD (Liquid Crystal Display), sensor connecting cables, Micro–controller Atmega 328, Relay Module, Contactor and Miniature Circuit Breaker (MCB).

Soil Moisture Sensor

In this project, five numbers of soil sensors were used in the experiment. The sensors sense the electrical resistance based on the variation of moisture content in the soil and delivers the digital signal to the micro–controller (Fig. 2). The sensor works on the principle of electrical resistivity. Resistive soil moisture sensor works by using a relationship between electrical resistivity and water content to measure the moisture content of the soil. Soil moisture sensor contains two parts *i.e.* the main sensor and the control board. The sensor part consist of two conducting probes which measures volumetric moisture content (VMC) of soil and the second part of it is control board which is made up of LM393 IC, which is voltage comparator. It also contains other important components such as LEDs, connectors, resistors and potentiometer to adjust the sensitivity of the sensor. For connecting the soil moisture sensor to micro–controller board the analog output of the sensor was used. This provides value from 0–1023, while taking the analog value from the soil moisture sensor and was calibrated to the moisture content measured in percentage in the range of 0–100.

Arduino Micro–controller Board

Arduino an open–source or prototype platform (which means the hardware is reasonably priced and development software is free) based on a handy or an easy–to–use software and hardware, was used (Fig. 3). It contains a circuit board, that can be logically programmed (called a micro–controller) and readymade software which is known as Arduino IDE (Integrated Development Environment). IDE is used to write and upload the computer code to the physical Arduino board.

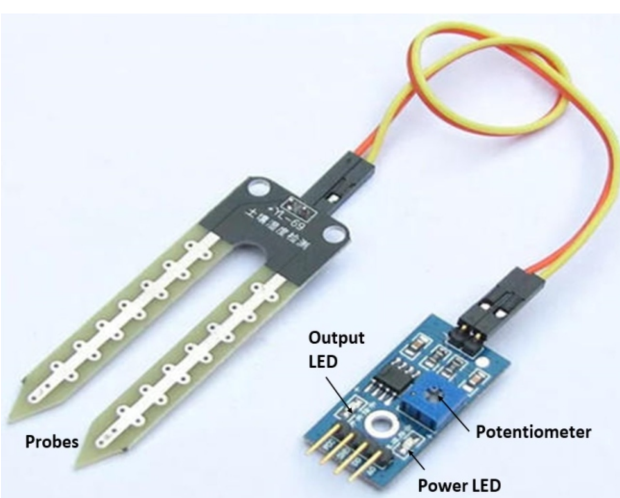

Fig. 2. Soil moisture sensor

LCD Unit

A 3.5 inch liquid crystal display unit was used for displaying the moisture content as detected by the sensors. The LCD displays the average moisture content as well as moisture content individually recorded by each of the sensors (Fig. 4). It also displays the pump running status as well.

Miniature Circuit Breaker (MCB)

A MCB is an electromagnetic device that supports a completely moulded insulating material. Its primary function is to switch the circuit. It is used to cut off a circuit during short circuits and overload. It automatically opens the circuit (to which it was connected) when the current passing along the circuit surpasses a set value. It can be manually turned ON or OFF like other switches as and when required.

Relay Module

The relay module is an electrically operated device (Fig. 5). It was used to control high voltage, a high current load such as motor, lamps, solenoid valves and AC load. It was designed to use with a micro–controller with the single channel (5 volts) module. It consists of three high voltage terminals NC, C, and NO which connect to the device that needs to be controlled in the system connected to electric pump. The other side has three low voltage pins *i.e.* Ground, Voltage Common Collector (VCC) and Signal terminal which was connected to the micro–controller board.

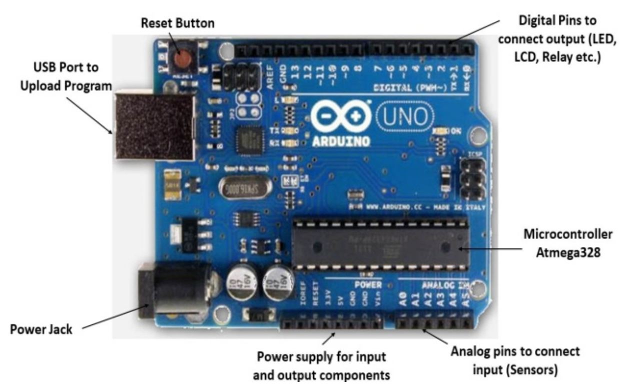

Fig. 3. Micro–controller board

Fig. 4. LCD unit

Fig. 5. Relay module

Hydraulic Evaluation of Drip Irrigation System

The hydraulic evaluation of the drip irrigation system was carried out which was based on a method as described by the Hahn and Landeek (1999). The drip irrigation system was tested for its manufacturing coefficient of variation, emission uniformity, emitter flow variation, uniformity coefficient and drip irrigation efficiency. The details of installed drip irrigation system is shown in Table 3.

Coefficient of Manufacturer's Variation

Coefficient of variation (CV) describes as a ratio of the standard deviation of flow to mean flow for a sample number of emitters. It is expressed by the following equation (Madramotto,1988):

$$Cv = \frac{S_q}{Q_{avg}} \times 100 \quad ...(1)$$

Where, S_q = Standard deviation of flow; Q_{avg} = The mean flow for a sampled no. of emitters of the identical type tested at a fixed pressure.

Emission Uniformity

Emission uniformity is used to measure the uniformity of emitters discharge from all the emitters or drippers of drip irrigation system and it is the single most essential parameter for evaluating system performance (Karmeli and Keller, 1975; Panigrahi, 2013).

$$EU_f = \frac{q_m}{q_a} \times 100 \quad ...(2)$$

Where, EU_f = Field test emission uniformity, percent; q_m = minimum discharge rate computed from the minimum pressure in the system; q_a = average design emitter discharge rate in the system, l h^{-1}.

Emitter Flow Variation

Emitter flow variation consists of finding the minimum and maximum pressure in the sub–units and measuring the emitter flow variation (Q_{var}) and it was calculated by the following equation (Wu and Gitlin, 1974).

$$EU_f = \frac{q_m}{q_a} \times 100 \quad ...(3)$$

Where, Q_{var} = emitter flow variation in percentage; Q_{min} = minimum emitter discharge rate in the system, lph; Q_{max} = design emitter discharge rate, lph.

Uniformity Coefficient

Statistical uniformity coefficient was calculated by the following equation (Bralts *et al*., 1981).

$$US = 100(1-V_q) = 100\,(1-S_q/q_a) \quad ...(4)$$

Where, V_q = Coefficient of variation; S_q = Standard deviation of flow; q_a = mean flow for a sample number of emitters of the same type tested at a fixed pressure lph.

Growth and Yield Parameters

In the experiment the treatment of soil moisture sensor based automated drip irrigation system was compared against the control treatment with normal drip irrigation system. The parameters measured to obtain growth and yield are plant height, number of fruits per plant, number of primary branches per plant, length of fruit, fruit yield and weight of fruit.

3. RESULTS AND DISCUSSION

Soil moisture sensor comprising two probes was inserted into the soil at different depths depending up on the growth of the root depth. The soil moisture sensor probe sends analog output which varies from 0.06 volts to 5 volts to the microprocessor unit, which reads the input analog data and converts into digital output in form of moisture content. Calibration of soil moisture sensor was done with the help of different soil moisture measured with soil moisture meter and gravimetric method. The core of the whole system is the micro–controller board. The micro–controller consist of various components like 13 digital pins, analog pins, USB port to upload program to the micro–controller, power jack to give power to micro–controller board, power pins to give power supply to input

Table: 3
Details of installed drip irrigation system

A. Control Head			
1.	Pump	–	1 HP
2.	Filter	–	Disc filter
B. Distribution Network			
1.	Type of mainline	–	PVC
2.	Size of mainline	–	67 mm
3.	Type of sub mainline	–	PVC
4.	Size of sub mainline	–	67 mm
5.	Type of lateral	–	LDPE
6.	Size of lateral	–	12 mm
7.	Spacing between laterals	–	75 cm
8.	Length of lateral	–	26 m
9.	Type of emitter	–	Inline
10.	Discharge of emitter	–	1.31 l h^{-1}
11.	Emitter spacing	–	40 cm
12.	Operating pressure	–	1 kg cm^{-2}

and output components reset button and a micro–controller unit which is Atmega 328 micro–controller. This LCD works as Human Machine Interface (HMI) and is being used to set or modified any logical programme in the mother-board. The ground terminal of relay was connected to the ground analog input pin of the micro–controller, the 5 volts VCC was connected to the 5V analog input terminal of micro–controller board. The high voltage terminal was connected to the pump. In between pump and relay module a MCB and a contractor was connected to safeguard the pump and system from short circuit or overload.

Hydraulic Performance of Drip Irrigation System

The evaluation of drip irrigation system hydraulic performance has been based on the coefficient of variation, horizontal and vertical movement of wetting front advance, Emission uniformity, Uniformity coefficient, Irrigation efficiency and discharge variation at different pressure for varying durations. The calculated and recorded results are discussed below:

Performance evaluation of drip system at different operating pressure: Table 4 shows the measured data regarding various performance parameters including discharge, coefficient of manufacture's variation (C_V), emission uniformity (EU_f), emitter flow variation (Q_{var}), uniformity coefficient (U_S), application efficiency (E_a), distribution efficiency (E_d) from the emitters of drip irrigation system operating under various pressures *i.e.* 0.5 kg cm^{-2}, 0.7 kg cm^{-2}, 0.9 kg cm^{-2} and 1.0 kg cm^{-2}. The results shows that the maximum values of performance parameters was achieved at 1.0 kg cm^{-2} with emitter discharge 1.31 lph, C_V = 0.04 (good), EU_f = 94.73 (excellent), Q_{var} = 5.14 (desirable), U_S= 94.18 (excellent), E_a = 93.24 and E_d = 95.47. So the operating pressure of 1.0 kg cm^{-2} was selected for estimating the wetting pattern of the drip system.

Behaviors of wetted soil width and depth at operating pressure 1.0 kg cm^{-2}: The behavior of wetted width and depth at operating pressure 1.0 kg cm^{-2} were measured and are given in Table 5. It was found that the horizontal wetting front advance with respect to time and space was almost uniform throughout the line source. It was also noted that small surface irregularities influenced the wetting front due to inertial forces. The vertical water front advance was recorded or measured just beneath from the emitter and at a distance of '0' to maximum distance that can covered by dripper throughout the lateral, and it was measured after the end of elapsed time *i.e.* 30, 60, 90 and 180 minutes.

Vegetative growth parameter: Various parameters were taken and measured to evaluate the vegetative growth of the brinjal crop which was influenced under two different treatments. The data regarding recorded observations for vegetative growth parameters under both the treatments are given in Table 6 which clearly displays the effect of adequate and timely application of irrigation caters for improvement in the yield and yield attributes. The average brinjal yield per plant from sensor based treatment was recorded as 0.81 kg whereas from control treatment average yield per plant of 0.71 kg was observed.

Table: 4
Hydraulic performance of drip irrigation system under different operating pressures

Operating pressure (kg cm^{-2})	0.5	0.7	0.9	1.0
Average discharge of drip (lph)	0.6	0.8	1.1	1.31
Coefficient of variation	0.1	0.07	0.05	0.04
Classification	Marginal	Average	Average	Good
Emission uniformity	85.47	87.31	91.56	94.73
Classification	Good	Good	Excellent	Excellent
Emission flow variation (%)	43.72	31.63	15.17	5.14
Classification	Not acceptable	Not acceptable	Acceptable	Desirable
Uniform coefficient (%)	87.23	89.85	92.31	94.18
Classification	Good	Good	Excellent	Excellent
Application efficiency (%)	67.04	78.32	84.57	93.24
Distribution efficiency (%)	86.23	90.14	94.75	95.47

Table: 5
Horizontal and vertical movement of water (cm) with respect to elapsed time at operating pressure 1.0 kg cm^{-2}

Elapsed Time							
30 min		60 min		90 min		120 min	
H.R (cm)	V.R.(cm)	H.R.(cm)	V.R.(cm)	H.R.(cm	V.R(cm)	H.R.(cm	V.R.(cm)
0	14.8	0	18.1	0	22.3	0	24.9
5.0	8.3	5.1	16.6	5.0	20.4	5.0	24.2
10.2	6.4	9.9	12.1	10.2	16.1	10.0	18.4
13.1	4.9	14.8	9.6	14.6	14.1	15.2	17.6
				19.2	11.6	20.0	13.3
						23.8	9.8

Table: 6
Measured Observations of vegetative growth parameters under two different treatments

Treatments		No. of fruits per plant	Yield of Fruit (kg per plant)	No. of branch per plant at harvest	Plant height at harvest (cm)	Avg. fruit weight (gm)	Avg. fruit length (cm)
Control Irrigation	R_1	14.58	0.713	13	98.2	9	49.58
	R_2	14.23	0.685	13	97.6	11	49.89
	R_3	15.14	0.721	14	98.4	10	47.03
	R_4	14.6	0.708	12	94.3	10	48.83
	R_5	15.42	0.754	13	95.1	11	48.81
	R_6	15.21	0.714	12	93.2	12	47.35
	R_7	14.53	0.689	11	91.8	9	48.17
	R_8	14.83	0.717	12	94.7	12	49.8
Sensor based Automated drip irrigation method	R_1	15.23	0.791	16	113.4	11	50.17
	R_2	15.45	0.813	17	115.1	13	50.21
	R_3	15.86	0.824	18	109.7	13	50.26
	R_4	15.31	0.804	15	112.3	12	51.4
	R_5	16.37	0.845	20	117.5	14	51.38
	R_6	15.51	0.816	17	113.2	13	50.45
	R_7	15.09	0.801	14	109.3	11	50.22
	R_8	15.42	0.81	17	118.8	12	51.43
	R_9	16.26	0.832	21	121.1	13	49.84
	R_{10}	15.48	0.803	16	114.4	11	51.22
	R_{11}	15.33	0.815	16	115.7	10	51.87
	R_{12}	16.81	0.856	20	119.2	13	49.13
	R_{13}	15.83	0.825	17	118.3	13	50.72
	R_{14}	15.74	0.809	17	117.8	12	50.53
	R_{15}	15.25	0.784	16	114.6	10	50.44
	R_{16}	14.98	0.751	15	116.3	12	52.15
	R_{17}	15.01	0.775	14	108.9	12	51.32
	R_{18}	15.32	0.781	15	112.7	12	50.09
	R_{19}	15.46	0.803	15	107.4	13	50.48
	R_{20}	15.5	0.811	16	107.8	11	50.21

Water use efficiency (WUE): Evaluated results reveals that the WUE of 81.71 kg $ha^{-1}mm^{-1}$ was obtained from sensor–based irrigation against the WUE of 71.9 kg ha^{-1} mm^{-1} from control treatment of drip irrigation system. The soil moisture sensor system when operates at the setting of 90–70% availability of soil moisture condition will save 13.6% of additional water from normal drip system.

Yield: The data pertaining yield of brinjal after harvesting was recorded by measuring the weight of fruits by mechanical and electrical weight balance. It was found that the yield of brinjal obtained under sensor–based treatment was 44.94 t ha^{-1} and yield obtained under controlled irrigation treatment was 42.04 t ha^{-1}. The results clearly indicates that the timely application of actual amount of required irrigation helps not only in water saving but have positive impact on the growth and yield of crop also.

4. CONCLUSIONS

The earlier developed system was too clumsy and big, it was decided to change the complete sensor system by reconfiguring all the parts to make it light, portable and user friendly (Fig. 6). The sensor system was further modified to cater the difference in the availability of irrigation water with the farmer also. The developed and modified soil moisture sensor system was found to working efficiently during the experiment and saved precious water as well as saves the labour work. The modified soil moisture sensor system was successfully calibrated for the drip irrigation system with three different levels of moisture range settings *viz*., 100–80%, 90–70% and 80–60% of available soil moisture content. Based on the study, the automated system fulfilled the irrigation water demand of the crop by automatically turns the irrigation pump "ON" when the moisture content falls below 70% of field capacity and switches the pump "OFF" when the moisture content of soil reaches 90% of field capacity. The modified soil moisture sensor system which was used for real–time monitoring of soil moisture content was successfully fabricated, calibrated and tested. Soil moisture sensor system delivers the best result as compared to that of controlled irrigation method. It recorded maximum water use efficiency of 81.71 kg $ha^{-1}mm^{-1}$, maximum plant height 98.4 cm and yield 42.040 t ha^{-1} was achieved under sensor–based drip irrigation treatment with water–saving of 13.38%. Sensor based automated drip irrigation system clearly shows better result on water saving alongwith increase in the crop yield.

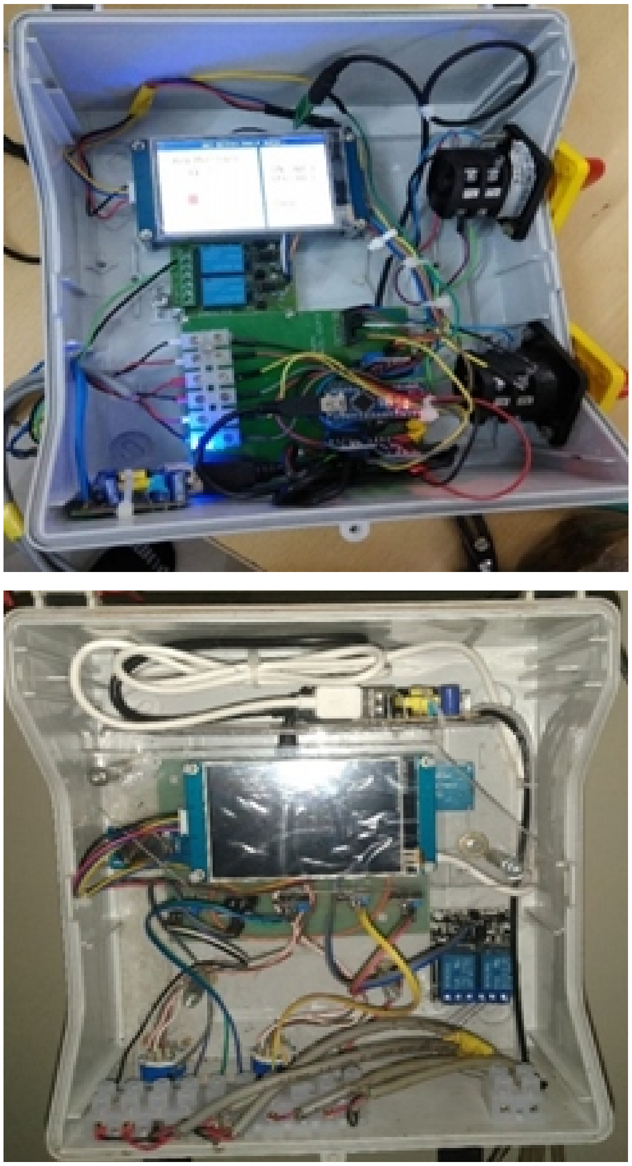

Fig. 6. Final assembled sensor system box

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