



Development, Field Testing and Economic Evaluation of Automatic Irrigation System

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Water plays a key role in agriculture and economic development of a country. Worldwide, about 70 % of water is used in agriculture sector, followed by 20 % in industrial sector, and just 10 % for domestic use (Michael and Ojha, 2018). Agriculture being the largest consumer of water, a slight improvement in the efficiency of water application would lead to considerable savings in the water used in this sector. At present, irrigation systems over a large proportion of the irrigated areas in India are manually operated for regulating the quantity of water, wherein farmers irrigate the land as per their own assessments of soil and crop conditions leading to water loss in terms of runoff and deep percolation, thereby reducing the system efficiency. The traditional methods of irrigation scheduling and water distribution can be improved using advanced technologies of irrigation management (Kansara *et al.*, 2015). Automatic irrigation system (AIS) is one such advanced technology for efficient use of water resources for improved crop yields. The

ABSTRACT

Sensor-based automated irrigation scheduling reduces the water losses, and applies precise quantities of water as per the crop water requirements, thereby improving the water use efficiency of irrigation systems. An automatic irrigation system (AIS) comprising of controller (raspberry pi), dual probe conductance-based soil moisture sensors and liquid crystal display it should read as liquid crystal display (LCD) LCD screen was developed to automate sprinkler irrigation system. The controller of the system was programmed using python programming language to control the solenoid valve and the motor on the basis of field-sensed soil moisture data. Field capacity and 50 % depletion of available soil moisture content were set as the upper and lower limits of soil moisture for switching the motor to 'OFF' or 'ON' condition, respectively. The developed system was compared with manual sprinkler irrigation for cabbage as indicator crop. Over the crop growing season, the moisture content under AIS was in the range of 0-10 % of soil moisture, indicating better accuracy of the AIS in sensing the water content in the crop root zone. The total cost of the AIS for 1 ha area was ₹ 16,058/-. The benefit-cost ratio of AIS was higher (2.59) as against manual irrigation (2.16), for cabbage.

soil moisture sensor-based AIS can reduce the irrigation water use by 50 % (Boutraa *et al.*, 2011). However, adoption of the AIS was limited mainly because of its high initial cost (Abdurrahman *et al.*, 2015).

There are various types of automatic irrigation systems, and can be classified as time based system, volume based system, open loop system, closed loop system and real time feedback system. Closed loop and real time feedback systems are most advanced forms of AIS. In closed loop system, irrigation decisions are made and actions are carried out based on data from sensors. These systems require data pertaining to parameters such as soil moisture, temperature, radiation, wind-speed, system pressure, pump flow etc. In real time feedback system, the irrigation is based on actual dynamic demand of the plant itself, plant root zone effectively reflecting all environmental factors acting upon the plant. Various sensors viz., soil moistures, relative humidity sensors, rain sensors, temperature sensors etc. control the

irrigation scheduling. These sensors provide feedback to the controller to control its operation.

Recent studies (Sanjukumar and Krishnaiah, 2013; Nallani and Hency, 2015; Chaware *et al.*, 2015) have demonstrated the benefits of sensor-based automated irrigation systems in terms of precise application of irrigation water and improvements in water use efficiency. Soil moisture sensors placed in the root zone of the crop sends signal to the controller, which operates the irrigation system to deliver desired quantity of water as per the preset soil moisture level. When the soil moisture reaches a preset level, controller turns off the relays and solenoid valves (Prathyusha and Suman, 2012). Keeping in view the ease of operation and other advantages offered, this type of improved systems can be potential alternative to manually controlled irrigation systems. The prerequisite is that these systems needs to be configured to match the crop water requirements, and should operate in synchronization with the soil moisture status of the root zone (Abdurrahman *et al.*, 2015).

Researchers have used Artificial Neural Network (ANN) based controllers for irrigation scheduling. These systems are data intensive, as they require daily weather parameters like temperature, air humidity, wind speed and radiation as inputs. Further, these systems failed to precisely ON/OFF the motor as per the crop water demands (Umair and Usman, 2010). Accuracy of the AIS can be improved by using more precise sensors, developing the Peripheral Interface Microcontroller (PIC) and replacing it with motherboard, and adding a switch to control water flow into the storage tank (Massadeh, 2014).

Both the adoptability and suitability of AIS is limited mainly by the type of crops to be grown, data availability, technical expertise required, complexity of operation, non-availability of components, failure to adjust with power failure and accidental storms, high initial investment and maintenance (Abdurrahman *et al.*, 2015). Therefore, a real-time sensor-based low-cost technology integrated with micro-irrigation system, and applying water as per crop needs was considered useful (Nallani and Hency, 2015). Automatic drip systems from Jain Irrigation Systems Ltd and NetBeat™ from Netafim India Ltd. are commercially available automated irrigation systems used in India. These systems are presently being adopted by the farmers of Maharashtra and Karnataka for banana cultivation. However, the cost of these AIS is high and can vary in the range of ₹ 1 - 4 lakh per ha depending on the

level of automation, durability of its components and ease of operation. Though auto-irrigation systems offer long term benefits in saving water, labour, energy, and fertilizer and also increase in agricultural produce, but higher initial investments generally preclude large scale adoption of these systems among the Indian farmers.

Keeping in view the high initial cost of automated irrigation system and water losses associated with manually operated irrigation systems, this study aimed at developing an efficient and low-cost automated irrigation system (AIS) using the output from conductance-based soil moisture sensors for efficient use of water resources in agriculture and tested its performance for cabbage crop cultivated in the Western Ghat region of India.

MATERIALS AND METHODS

Design Considerations

The automatic irrigation system designed in this study was aimed to apply water automatically based on the soil moisture content monitored continuously using the soil moisture sensors. The major design considerations in the development of AIS include selection of sensor material, standardizing the principle of sensor operation (e.g. capacitance or conductance based), using appropriate converters for converting the sensor signal into digital form, development of suitable signal processing unit, placing mechanisms for storing the collected data and selection of relays for activating and deactivating the motor. Other design considerations included optimization of number of sensors for a unit area and the depth of sensor placement as per the root zone depth of a crop. The different components of the AIS thus consisted of a controller, soil moisture sensors, solenoid valve and a motor.

Development of AIS

Raspberry Pi, a credit card-sized single-board computer was used as a controller, details of which are provided in Table 1. The controller of the system was used to automatically operate the irrigation system based on soil moisture data that was programmed using Python language of Raspberry Pi (Aarthi and Shaikh, 2015). Four conductance-based copper plated soil moisture sensors were used to sense the soil moisture. Four number of sensors were deemed to be sufficient to sense the soil moisture from one ha area. The soil moisture sensor was Robocraze make 5 V DC having the dimension of 60 x 30 mm (Nagarajapandian *et al.*, 2015). Gao *et al.* (2018) had reported that conductance-

based copper-plated sensors were more reliable in assessing the soil moisture content of a variety of soils. Further, the discrepancy in the gravimetric and sensor-based readings can be minimized by using nickel plated sensors, which are more expensive (Chow *et. al.*, 2009). An analog-to-digital converter (ADC) was used to convert analog signal from soil moisture sensor to digital form (Table 1). These digital signals were transmitted to the controller to take control action (Sanjukumar and Krishnaiah, 2013). Characters to be displayed were converted into corresponding American Standard Code for Information Interchange (ASCII) code, and then sent to liquid crystal display (LCD) module for display. The LCD was of 5x7 pixel matrix black text on green background single row for easy bread boarding and wiring pins were documented on the back of the LCD to assist in wiring it up (Shiraz and Yogesha, 2014). Solenoid valve and motor were controlled by a solid-state relay (SSR) so as to irrigate the field when there is depletion in the moisture content to a preset level (Jadhav and Hambarde, 2015). The detailed specifications of the components used in the AIS are presented in Table 1.

Soil moisture sensors, raspberry pi, solid state relay (SSR) and LCD worked on 5 Volt DC supply. An electric supply of 5V 2 ampere was used to power the raspberry pi controller. Soil moisture sensors, SSR and LCD were powered through raspberry pi’s 5 V output pin. A membrane keypad was connected as input to the raspberry pi, and hence used 3.3 V power provided by the GPIO (general-purpose input/output)

pin of raspberry pi. The analog readings sensed by the soil moisture sensors were recorded in terms of voltage by the controller. Analog-to-digital convertor converted these readings in digital form. These digital readings were stored in the controller, and necessary action was taken as per the designed programme in python language. The controller sent the signal to the solid state relay to ON/OFF the solenoid valve and the motor depending upon the soil moisture status.

The developed AIS was capable of controlling four plots of 1 ha in one operation cycle. The flow chart (Fig. 1) explains the steps in automation of the irrigation system.

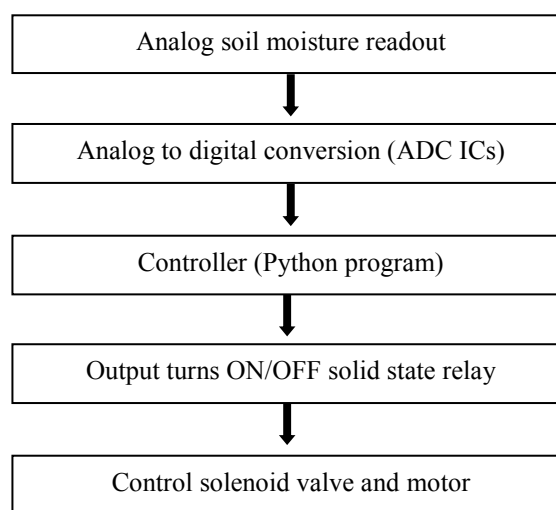


Fig. 1: Steps for automation of irrigation system

Table 1. Specifications of components used in AIS

Sl. No.	Part	Specification
1.	Controller	Raspberry Pi 4, Storage - 2GB , Model- B 4B SBC IOT, Board - Broadcom 1.5GHZ A72 Processor with 2 GB DDR4 4K, Video - Dual Micro HDMI, Gigabit Network
2.	Analog to digital convertor	Robocraze, 16 Bit with Module RC-A-569
3.	Storage	Sandisk U1A1, 98 Mbps, 16 GB, Ultra Micro SDHC, Class 10
4.	Printed Circuit Board (PCB)	100 x 75 mm deigned for AIS using the process of itching
5.	Solid state relay	Xcluma, BE-001485, SSR-25DA 25A, DC 3-32V to AC 24-380V, SSR 25DA
6.	Solid state relay	Omron, G3MB-202P, DC-AC PCB SSR, In -5V DC, Out -240V AC, 2A
7.	Transformer	Generic, TRANS550 12-0-12, Transformer 1/5 AMP
8.	Membrane Switch Control Panel	Sun Robotics, EK-DIT-088-01, 1x4 MATRIX, Array membrane 4 key flexible PCB keypad
9.	LCD screen	Robotbanao, LCD, 16x2 alphanumeric display (Jhd162a), 5x7 pixel matrix, 0C-GSTV-ZRAF Model
10.	Soil moisture sensor	Robocraze, DC 5V, conductance based, copper plated, RC-A-4079

Sensor calibration

The sensor was calibrated against the observed values of soil moisture. The sensor output voltage (mV) was compared against the percentage moisture content obtained by gravimetric method. The calibration procedure was repeated for 10 times to check the accuracy and precision of the sensor.

Sensor readings were obtained for soil samples having soil moisture content of 0 %, 5 %, 10 %, 15 %, 20 %, 25 %, and 30 per cent. The relationship between sensor output and soil moisture content is presented in Fig. 2. The sensor output increased with increasing soil moisture content, although the rate of increase was low at moisture contents higher than 15 per cent. The percentage increase in the output of sensor voltage for each unit rise in soil moisture within the respective moisture intervals (0-5 %, 5-10 %, 10-15 %, 15-20 %, 20-25 %, and 25-30 %) were estimated using simple interpolation technique. A non-linear polynomial equation of third degree was fitted to the calibration data in order to obtain the interpolated values.

Calibrated values of sensor voltages corresponding to field capacity, and 50 % depletion of available soil moisture content (AWC) were used to program the controller of the AIS to activate the solid-state relays.

Experimental Details

The experiment was conducted during 2015-17 at the Department of Irrigation and Drainage Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth (Dr.

BSKKV), Dapoli. The experimental site was situated at 17°45'12" N latitude and 73°10'48" E longitudes and altitude of 250 m. The location comes under coastal belt of Konkan region of Maharashtra state.

The experiment was conducted in two plots of 14.35 m x 17.10 m size each, equipped with micro-sprinkler irrigation systems having sprinklers of 26 l.h⁻¹ discharge capacity, 3.4 m diameter of throw and blue colour. The micro-sprinklers were manufactured by M/S Jain Irrigation System Limited. The lateral-to-lateral and sprinkler-to-sprinkler spacing was kept 1.5 m. There were 110 sprinklers per plot. The source of irrigation water was open well, and water was pumped using a 0.7 kW open well submersible pump (Kirloskar KOSi-135; 210 volt; 2800 rpm; discharge range: 0.3 to 2.2 litres per second; head: 18-32 meter). The soil was sandy loam with sand 73.17 %, silt 15.2 % and clay 11.63 %, respectively.

Cabbage crop of variety *Sukirti* was planted at a spacing of 0.30 m x 0.45 m in both plots on 29th January, 2017. Well decomposed farm yard manure was applied uniformly in both the plots. Manually operated sprinkler system was implemented in plot-I, while plot-II had the automatic irrigation system. Four soil moisture sensors were installed at four random locations in the plot-II to sense the soil moisture in the crop root zone.

Considering the depth of soil and active root zone of the crop, two sensors (Sensor 2 and sensor 4) were placed

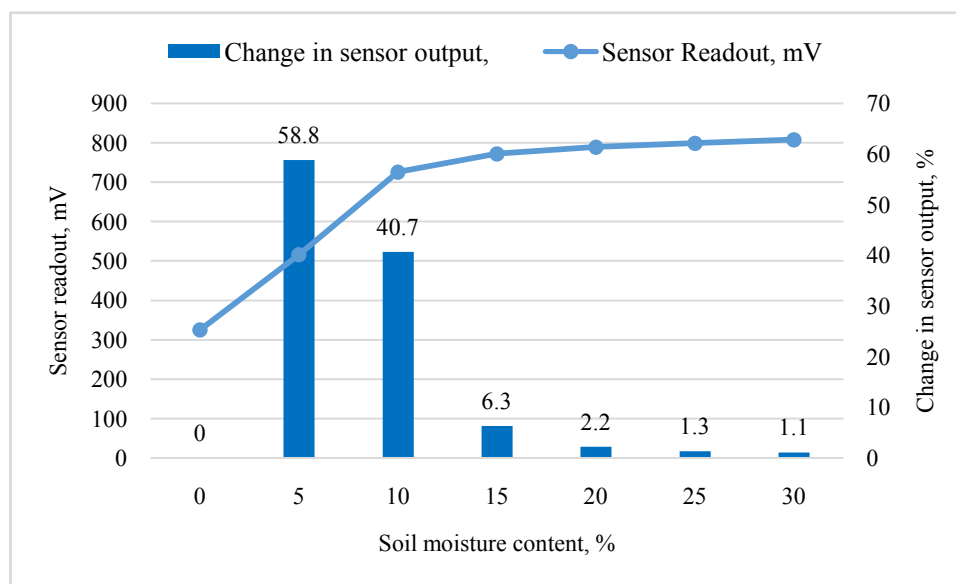


Fig. 2: Relationship between sensor output and soil moisture content

at a depth of 50 mm, and the remaining two sensors (Sensor 1 and sensor 3) were placed at a depth of 100 mm below soil surface (Fig. 3). The sensor arrangement permitted to maintain the optimal level of moisture content in the root zone of the crop (Nallani and Hency, 2015). Each of these sensors were programmed to provide the moisture content in the field at intervals of 30 seconds, which were continuously displayed on the LCD screen. If any of the two sensors showed 50 % depletion of available water, then the solid state relay opened the solenoid valve and the motor started automatically. Also, when any of the two sensors read moisture content near to field capacity, the motor would be automatically put OFF by the solenoid valve.

Irrigation scheduling

For manually operated irrigation system in plot-I, irrigation scheduling was done using daily climatic data pertaining to maximum and minimum temperature, maximum and minimum relative humidity, wind speed, and sunshine hours obtained from meteorological observatory of the Department of Agronomy, Dr. BSKKV, Dapoli. Reference evapotranspiration (ET_o) was estimated using FAO 56 Penman Monteith Method (Allen *et al.*, 2006). The daily ET_o values were multiplied with crop coefficient (K_c) to get the daily crop evapotranspiration (ET_c). The K_c values for 'initial', 'mid' and 'end' stages of crop growth were taken as 0.7, 1.05 and 0.95, respectively.

Field testing of system

Testing of the system was continued during 120 days from the first day of transplanting to the harvesting of

the crop. Calibrated sensors sensed the soil moisture levels at different soil depths within the root zone, and the signals were recorded by the controller. Controller was set to ON and OFF the motor and solenoid valves as per the preset levels of soil moisture.

During each run cycle, the soil water lost by the processes of transpiration and evaporation was refilled to the level of field capacity. The automation procedure is presented in flow chart (Fig. 4). All readings of soil moisture were recorded and stored in a micro SD card. The LCD screen of the AIS displayed the ON or OFF status of the valve and motor along with moisture content recorded from the field.

Economic Analysis

Cost of automation system

Total cost of controller included the cost of components as raspberry pi, analog-to-digital convertor, soil moisture sensors, LCD screen, solenoid valves, printed circuit board, solid state relays, plugs, sockets and wires, etc. Considering the uniformity of the soil in experimental plots, 4 sensors were assumed to be sufficient for 1 ha land.

Cost of crop production

The cost of crop production included the seasonal fixed cost and total operating cost. The total operating cost included variable cost on hired human labour, seed, fertilizers, chemicals, water charges, supervision charges, interest on working and fixed capital, depreciation and maintenance cost of sprinkler irrigation system. Cost of sprinkler irrigation system was estimated considering all of its main components and accessories



Fig. 3: Sensors installed in experimental plot

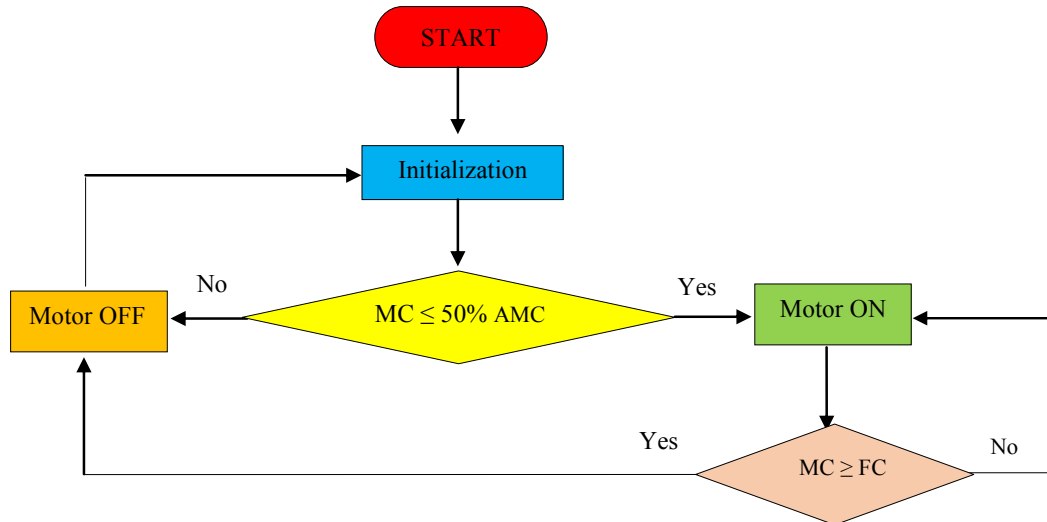


Fig. 4: Process flow chart of automatic irrigation system

with 3 % of systems cost as cost of installation.

Book keeping method was followed to record all the labour, input and machinery cost in plots throughout the cropping season. In the economic analysis, life of the developed AIS was considered as 5 years.

Economic returns and B:C ratio

Gross monetary returns per hectare were worked out by considering the curd yield and prevailing market prices for cabbage. The net income was estimated by subtracting the cost of production from gross monetary returns.

Benefit-cost ratio was worked out by dividing the gross monetary returns to the cost of production. Rental value was considered as the fair market value of property while rented out in a lease. It was considered as 1/6th of the gross monetary returns. Interest on working capital was current liabilities subtracted from current assets. It was taken as 3 % of the total variable cost. Payback period was computed as the ratio of initial investment to the cash inflows.

RESULTS AND DISCUSSION

Description of Developed AIS

The assembled unit of the AIS had the switch for motor and solenoid valve and a switch to power the controller (Fig. 5). The controller had USB slots to download the soil moisture data stored in the SD card. VGA slot was provided to connect the monitor, and check for any errors in the program. LCD screen with membrane keys was used to calibrate and set the field

capacity and wilting ranges for the type of soil in the experimental plots.

Soil Moisture Dynamics in Experimental Plot

Soil moisture dynamics at two depths (50 mm and 10 mm) for four representative days in the middle of the cropping season is presented in Table 2.

At 50 mm soil depth, the sensor-based soil moisture varied from the gravimetric measurement method by 0.1 % to 9.9 %, with average variation of 5.9 per cent. At 100 mm soil depth, the variation of sensor-based soil moisture with that with gravimetric method was 2.5 % to 9.6 %, with an average variation of 5.5 per cent. Overall, it was observed that the per cent variation in measured soil moisture content was less than 10 per cent. Gao *et al.* (2018) also reported that AIS works with an average variation of 5 % when tested for loam soil.

Irrigation Water Use and Water Saving

Temporal variation of soil moisture (average of data of 4 sensors) in the root zone of the crop (Fig. 6) showed that soil moisture in the root zone was confined between field capacity (26 %) and 50 % of the AWC (19 %), implying operation of motor as per the pre-set soil moisture limits. On many occasions, it appeared that the system was started before reaching the 50 % depletion in AWC, or was shutoff before reaching the field capacity. Sensor signals were processed at intervals of 30 s, and the controller was set to trigger the irrigation event even if two of the sensors sensed soil moisture below 50 % of AWC. This was the reason for the motor

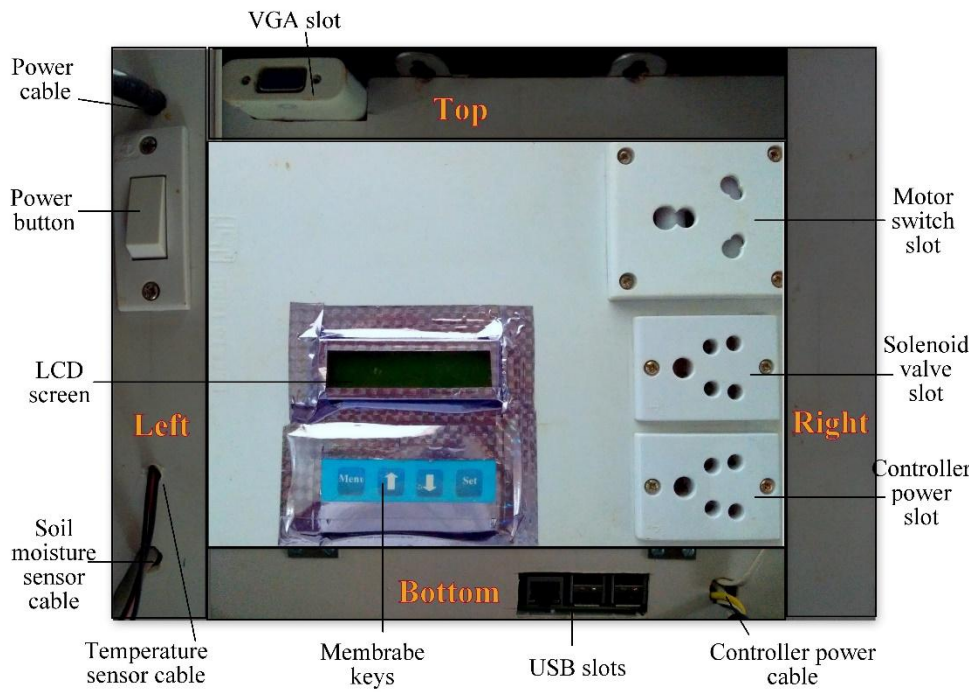


Fig. 5: Developed automatic irrigation system

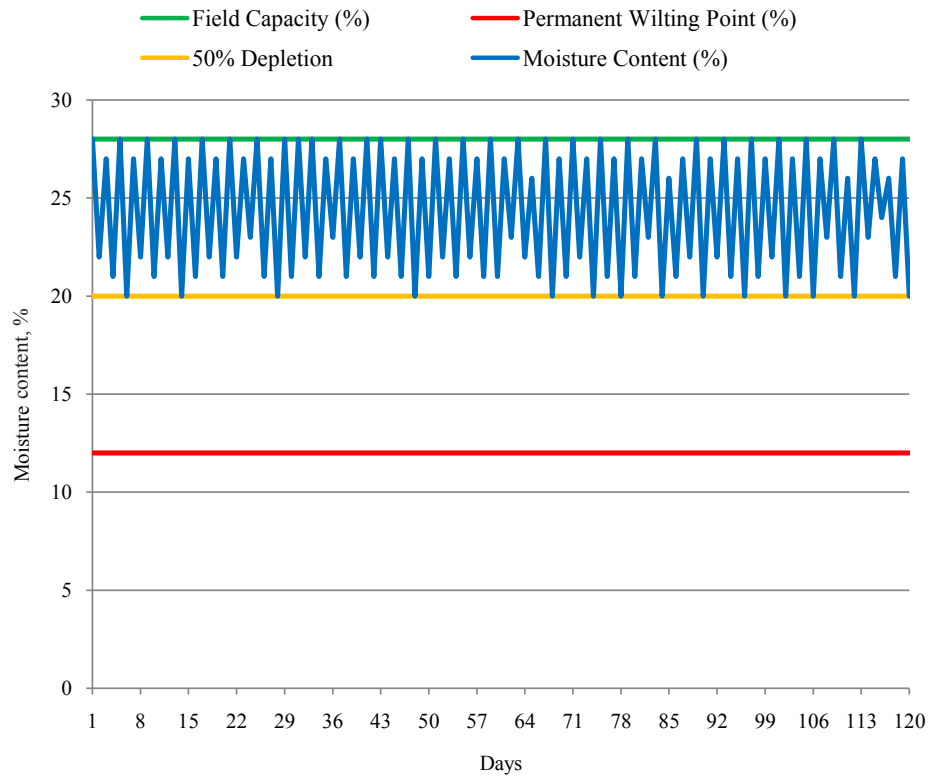


Fig. 6: Daily moisture content variation in the plot using AIS

Table 2. Comparison of gravimetric and sensor-based soil moisture at different soil depths

Time	Moisture content at 50 mm depth, %					Moisture content at 100 mm depth, %				
	Sensor 1	Sensor 3	Sensor Average	Gravimetric moisture	% variation	Sensor 2	Sensor 4	Sensor Average	Gravimetric moisture	% variation
06/02/2017										
8:00 am	28	28	28.0	30.77	9.0	25	25	25	27.27	8.3
10:00 am	28	27	27.5	29.41	6.5	25	24	24.5	27.10	9.6
12:00 pm	26	27	26.5	28.57	7.3	22	24	23	25.00	8.0
02:00 pm	25	26	25.5	27.27	6.5	22	23	22.5	23.08	2.5
04:00 pm	24	25	24.5	26.85	8.8	21	22	21.5	23.53	8.6
06:00 pm	24	25	24.5	26.61	7.9	21	22	21.5	22.22	3.2
07/02/2017										
8:00 am	24	25	24.5	25.00	2.0	21	22	21.5	23.53	8.6
10:00 am	24	24	24.0	25.00	4.0	21	21	21	22.22	5.5
12:00 pm	23	24	23.5	25.00	6.0	21	21	21	22.22	5.5
02:00 pm	23	24	23.5	23.53	0.1	21	21	21	22.22	5.5
04:00 pm	27	28	27.5	30.00	8.3	22	23	22.5	23.53	4.4
06:00 pm	26	27	26.5	29.41	9.9	22	23	22.5	23.08	2.5
08/02/2017										
08:00 am	22	22	22.0	23.53	6.5	20	21	20.5	22.22	7.7
10:00 am	26	28	27.0	29.41	8.2	22	24	23	25.00	8.0
12:00 pm	27	28	27.5	28.57	3.8	22	23	22.5	23.53	4.4
02:00 pm	26	27	26.5	27.27	2.8	22	23	22.5	23.53	4.4
04:00 pm	25	26	25.5	26.67	4.4	21	22	21.5	23.53	8.6
06:00 pm	24	25	24.5	25.00	2.0	20	21	20.5	22.22	4.7
09/02/2017										
08:00 am	26	26	26.0	28.57	9.0	23	22	22.5	23.53	4.4
10:00 am	26	25	25.5	27.27	6.5	23	22	22.5	23.53	4.4
12:00 pm	26	25	25.5	27.27	6.5	23	22	22.5	23.08	2.5
02:00 pm	24	25	24.5	26.67	8.1	22	21	21.5	22.22	3.2
04:00 pm	24	24	24.0	25.00	4.0	21	21	21	22.22	5.5
06:00 pm	24	24	24.0	25.00	4.0	21	20	20.5	21.05	2.6

to have been activated / deactivated before the actual prescribed limits of field capacity and 50 % of AWC.

Irrigations were scheduled as per FAO-56 approach, and applied 304.3 mm of water in the plot with manually operated system, while the seasonal water use in AIS was 283.74 mm. Thus, AIS-based system applied 6.7 % less water as compared to manually operated sprinkler irrigation system.

Economic Evaluation

Fabrication cost (2017) of the AIS suitable for an area of 1 ha was ₹ 16,058/- (Table 3). It was observed during

field operations that the developed AIS worked on real-time basis, and was user-friendly. The system did not require frequent calibrations in the events of power cut-offs. It was programmed in such a manner that the controller would take the stored readings from the sensor and start the process, implying that the system could perform under adverse situations and regions with erratic power supply. The low manufacturing cost of the developed AIS made it affordable for Indian farmers who typically have small (< 2 ha) farm holdings, and are unable to make high investments in sophisticated automated irrigation systems.

Table 3. Cost of developed automatic irrigation system

Sl. No.	Description	Quantity, No.	Unit cost, ₹	Cost, ₹
1.	Raspberry Pi 4 2GB	1	4000	4000
2.	Analog to digital convertor	1	400	400
3.	5 Volt 2 Amp power adaptor for Raspberry Pi	1	986	986
4.	Class 10 – 16 GB micro SD card	1	450	450
5.	100 x 75 mm Printed circuit board (PCB)	1	200	200
6.	Solid state relay 25	1	890	890
7.	Solid state relay 2 Amp	1	1600	1600
8.	24V 1A Transformer	1	510	510
9.	Membrane Switch Control Panel Slim	1	355	355
10.	DS 18B20 Temperature sensor	1	200	200
11.	16 x 2 LCD screen	1	250	250
12.	Soil moisture sensor	4	90	360
13.	Solenoid valve	4	620	2480
14.	Other connection accessories			3377
	Total			16058

Table 4. Comparison of cost-benefit ratio for manual and automatic irrigation systems

Sl. No.	Particulars	System cost	
		Manual	Automatic
1.	Seasonal fixed cost, ₹ . ha ⁻¹	59213	60498
2.	Total variable cost, ₹ . ha ⁻¹	152659	131059
3.	Interest on working capital, ₹ . ha ⁻¹ (3 % of total variable cost)	4580	3932
4.	Rental value, ₹ .ha ⁻¹ (1/6 of gross monetary return)	121450	148850
5.	Total operating cost per season, ₹ . ha ⁻¹	278689	283841
6.	Cost of cabbage production, ₹ . ha ⁻¹	337902	344339
7.	Yield, t.ha ⁻¹	48.58	59.54
8.	Selling price of cabbage, ₹ . kg ⁻¹	15.0	15.0
9.	Gross monetary returns, ₹ . ha ⁻¹	728700	893100
10.	Net income, ₹ . ha ⁻¹	390798	548761
11.	B : C ratio	2.16	2.59

Assessments on cost of cultivation showed that cabbage crop cultivated using manually operated sprinkler irrigation system incurred 3,37,902 ₹ .ha⁻¹, while that cultivate under AIS incurred 3,44,339 ₹ .ha⁻¹, which was only 1.9 % higher than the manual system. Cabbage yield increased from 48.58 t.ha⁻¹ under manual system to 59.54 t.ha⁻¹ under AIS due to optimum application of water. This manifested in increase in net income from 3,90,798 ₹ .ha⁻¹ under manual system to 5,48,761 ₹ .ha⁻¹ under AIS. The benefit-cost ratio for manual and automatic sprinkler systems was 2.16 and 2.59, respectively (Table 4). Higher net income and benefit-cost ratio justified the use of the developed AIS for small and marginal farms.

CONCLUSIONS

An AIS using conductance-based copper sensors was capable of assessing the soil moisture condition of the root zone on real-time basis. The variations in soil moisture measured by controller and gravimetric measurement at 50 mm and 100 mm soil depths were less than 10 %, implying better reliability of the AIS system. Precision in matching water supplies with crop water demands by the AIS reduced the seasonal water use by 6.8 %, and increased crop yields by 22.5 per cent. Besides monetary gains and water saving, the ease of operation and low initial cost justified the applicability of the irrigation system.

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