



Sensor network based irrigation system for real time irrigation scheduling in vegetable crops under different methods of irrigation

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ABSTRACT

Soil moisture sensor based irrigation scheduling is relatively a new concept in India. A soil moisture sensor based wireless irrigation system was designed, developed and tested during the years 2013-15 in vegetable crops, i. e. okra, tomato, brinjal, broccoli, potato, and knol-khol on the research farm of the Precision Farming Development Centre, Water Technology Centre, Indian Agricultural Research Institute, New Delhi, India. A network of sensors was integrated with a wireless system having modified tensiometer, level sensor, controller, GSM receiver, transmitter, solenoid valve, water meter, and pump for automated irrigation scheduling. The sensor network, global system for mobile communication (GSM) and short message service (SMS) carried the data from the sensors to the user through a mobile set. This system allows the user to effectively monitor and control water application in the field via sensors and/or through a mobile phone set by sending a command in the form of message and obtaining the moisture status in the field.

Key words: GSM, Irrigation, Mobile phone, SMS, Soil moisture sensor

There is a great need to modernize agricultural practices for better water productivity and resource conservation. Presently, farmers irrigate their lands at regular intervals through manual control. This process consumes more water and at times crops get damaged. The use of automatic micro-controller based irrigation system can resolve this problem as irrigation will take place only when there is an intense requirement for irrigation water. The use of automated irrigation system can provide water on a real time basis at the root zone based on the availability of soil water at the crop root zone which also leads to saving of water (Migliaccio *et al.* 2015, Ojha *et al.* 2015, Soulis *et al.* 2015, Cristi *et al.* 2016).

Efforts were made to develop sensor based irrigation scheduling by many researchers earlier but with limited success. Dursun *et al.* (2011) demonstrated that sensors used for soil moisture monitoring could be employed for irrigation scheduling, and by monitoring the soil moisture content, farmers could make timely decisions about when to start or stop water application, thus enabling them to optimize water use and produce good quality crop. Joshi *et al.* (1999) developed a soil moisture based automated

irrigation controller at IIT, Kharagpur. The irrigation controller uses a tensiometer connected with a U-tube manometer to sense the soil moisture potential. Luthra *et al.* (1996) designed and developed an automatic valve for auto irrigation system. In this system, soil water tension is sensed through a modified manometer, and the system controls the irrigation at the pre-decided soil water tension as programmed by a timer. Leib *et al.* (2002) described many instruments and methods, viz. tensiometers, resistance blocks, gravimetric methods, and granular matrix sensors to monitor and measure soil moisture which will continue to be widely applied in irrigation scheduling. Furthermore, scheduling of irrigation is important for maintaining environmental quality as it reduces both percolation of chemicals and nutrient loss, which occur under commonly practiced over-irrigation (Greenwood *et al.* 2010, Pinmanee *et al.* 2011, Lorite *et al.* 2014).

Sensor based wireless 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, particularly in developed countries. However, research in India is still in infancy. Research for developing a wireless irrigation system for adoption in open field conditions is lacking. The major constraint for adoption of this technology for addressing the spatial and temporal variability is the small holdings in India. The present study focuses on the development of a soil sensor based wireless irrigation system for monitoring soil moisture in different methods of irrigation. The soil sensor based wireless

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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. A soil moisture sensor based wireless irrigation system was designed, developed and tested during the years 2013-15 at the Precision Farming Development Centre of the Water Technology Centre, Indian Agricultural Research Institute, New Delhi in vegetable crops namely okra, tomato, brinjal, broccoli, potato, and knol-khol.

MATERIALS AND METHODS

The study was conducted at the Precision Farming Development Centre of the Water Technology Centre, Indian Agricultural Research Institute (IARI), New Delhi, India, which is located within 28°37'22" N and 28°39'00" N latitude and 77°8'45" E and 77°10'24" E longitude covering an area of about 475 ha at an average elevation of 230 m above mean sea level. The soil of the research farm is alluvial in origin and is sandy loam in texture.

The primary method for measuring the matric potential (capillary tension) in a soil involves the use of a tensiometer, which directly measures the matric potential. But the main limitation of the tensiometer based irrigation scheduling is that it requires the farmer to go to the field regularly to monitor the vacuum gauge readings. To overcome this problem, a soil sensor was developed by modifying the regular tensiometer. A level sensor, instead of a vacuum gauge, was installed to monitor the water column level on a real time basis, based on the soil moisture present in the root zone of the crop. The level sensor was a conductive type using water as the conducting medium. The level sensor had three probes inserted at the bottom, middle and top levels on different MAD (Management Allowable Deficit) value: 25%, 35% and 50%. These probes sent information in the form of electromagnetic signals to the level controller to actuate and de-actuate the irrigation pump through a timer and three different LED (light emitting diode) with different lights (pink, yellow, and red). These lights get illuminated on the basis of availability of moisture in the soil. The rate of rise and fall of water level depends on the soil moisture present in the root zone of the crop. The rise or fall of the water level sensed by the level sensor changed the capacitance sensed values to electromagnetic signals. These signals were received by a GSM receiver.

The GSM receiver was interfaced with the level controller to receive electromagnetic signals. The GSM receiver sent coded text SMS to the pre-programmed SIM number. As the level of water went up or down, it sent the SMS accordingly, operating on a 12V DC battery. It had been designed in such a way that the text SMS could be sent to five mobile phones simultaneously for monitoring and control. Each modified tensiometer had a sensor code number, e.g. 111, 110, 001; this code can be changed by the user. A holding circuit had been interfaced with the output of the controller. This was further latched with single pole single throw (SPST) as the timer operated, interface

occurred with double pole double throw (DPDT) relays that operated the pump and solenoid valve. It helped to operate both the units simultaneously. The pump and solenoid operated till the programmed time. After the running time period, the pump will get stopped and solenoid valve get closed immediately as there was only one pump to operate so as to latch all three relays with a Master Relay (SPST). The relay operated pump would run and continue to run until all the relays got off.

Remotely controlled water pumping stations switched ON the pump when the water level in the overhead water storage tank went low and switched it OFF as soon as the water level reached a pre-determined level. In the present study, three level sensors were fitted at the bottom, middle and upper levels of the water storage tank for maintaining optimum level of water storage. The developed water application system was using stored water. When the water level in the overhead tank touched the bottom sensor, it switched on the pump, which also prevented 'dry run' of the pump in case the water level in the water storage went below the suction level.

The layout of the experimental setup having a soil moisture sensor network, global system of mobile communication (GSM) and SMS (short message service) to carry the data from the sensors directly to alert the user through the mobile phone and to control the irrigation activity based on the level sensor. Remote control of the system allows the user to effectively monitor and control the water application in the field via a mobile phone set by sending a command in the form of message and obtaining the soil moisture status. The GSM based control system has the following steps: (i) the user sends a text message including a command to the receiver, (ii) the GSM receiver receives the message sent from the user's cell phone, (iii) the GSM receiver decodes the sent message and sends the command to the microcontroller, and (iv) the microcontroller issues the desired command to the motor and solenoid valves and the system switches ON and OFF wirelessly. The designed system was installed in the field for testing and evaluation, layout of experimental setup shown in Fig 1.

A field plot of 21 m × 21 m for each vegetable crops (Okra, tomato, potato, brinjal, broccoli, and knol khol) was used for conducting the field experiments to test the designed system. A buffer strip of 1.0 m was maintained for separating the plots from one another. The experiment was laid out in three plots having three methods of irrigation, viz. check basin, furrow and drip, respectively. The characteristic curve of the modified tensiometer having level sensors with three probes were developed and calibrated with frequency domain reflectometry (FDR). A total of 6 access tubes were installed up to a depth of 100 cm in the field to measure the soil moisture with the help of FDR.

Water requirement of the vegetable crops namely okra, tomato, brinjal, broccoli, potato, and knol-khol was calculated on the basis of reference crop evapo-

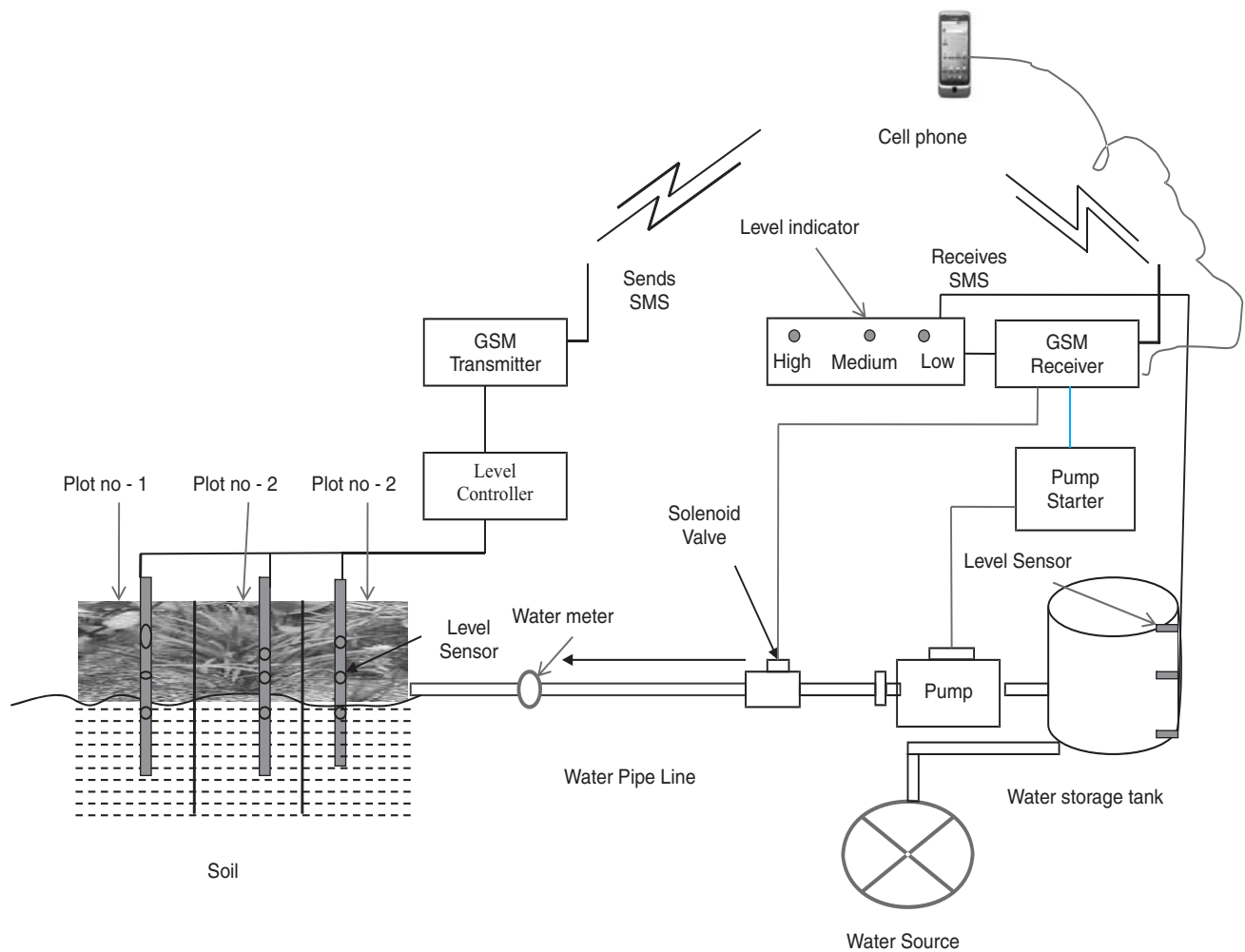


Fig 1 Layout of experimental setup

transpiration (ET_0) by using Penman-Monteith's semi-empirical formula (Smith 1992). The required weather data (min. and max. temperature, rainfall, sunshine hours, wind speed etc.) was collected from the automatic weather station, located near the experimental site. The actual evapotranspiration (ET_c) was estimated by multiplying reference evapotranspiration (ET_0) with crop coefficient (K_c) for different months based on crop growth stages ($ET_c = ET_0 \times K_c$). The total amount of irrigation water required by the crops under drip, furrow and check basin methods in their respective plots was estimated. The duration of irrigation was estimated by using the water requirement data of the crop for each method. In drip irrigation method,

the duration of irrigation was estimated based on dripper discharge, whereas in the case of furrow and check basin methods of irrigation, the duration was estimated by measuring the discharge through the pipe with the help of a water meter.

RESULTS AND DISCUSSION

Soil properties

The soil of the experimental area was a deep, well-drained sandy loam comprising 62.25% sand, 17% silt and 20.75% clay (Table 1). The bulk density of soil was determined as 1.56 g/cm³, the field capacity as 16.8 % and

Table 1 Physical properties of soil

Depth (cm)	Particle size distribution			Textural class	Hydraulic conductivity (cm/h)	Bulk Density (g/cm ³)	Field capacity (%)	Wilting point (%)
	Clay (%)	Silt (%)	Sand (%)					
0-15	16	12	72	Sandy loam	1.25	1.52	16.1	6.45
15-30	21	10	69	Sandy loam	1.33	1.61	18.2	8.87
30-45	24	20	56	Sandy loam	0.77	1.54	16.7	11.3
45-60	22	26	52	Sandy loam	1.12	1.57	16.2	11.5

Table 2 Chemical properties of soil

Depth (cm)	pH	EC (dS/m)	Organic carbon (%)	Available nutrients		
				N(kg/ha)	P(kg/ha)	K(kg/ha)
0-15	7.15	0.16	0.28	80.31	22	173
15-30	7.15	0.14	0.23	76.75	13	127
30-45	7.15	0.12	0.15	72.15	5.3	113
45-60	7.1	0.11	0.15	62.10	4.8	112

the saturated hydraulic conductivity as 1.12 cm/h. The pH and EC of the soil were 7.14 and 0.1325 dS/m, respectively (Table 2).

Soil moisture characteristic curve

Soil moisture retention characteristics of the experimental soils at various matric potentials were determined by using a Pressure Plate Apparatus (Richards 1949). Pressure chambers containing ceramic plates of 1.0, 5.0 and 15 bars were used.

Calibration of the developed soil moisture sensor

C-Probe (EnviroScan) system was used to calibrate the developed soil moisture sensor. Three developed soil moisture sensors were installed in the three different plots irrigated by different methods of water application. The measurement of soil moisture in the field was done using the developed soil moisture sensors and calibrated with frequency domain reflectometry with respect to variation of moisture in relation to the time.

It was found that the water level depletion in furrow and check basin methods of irrigation as compared to that in drip irrigation was initially less but it was more after 48 hr of irrigation. The average depth of water depletion in modified tensiometer in all three methods in okra, brinjal, potato was maximum 30-35 cm and in tomato, broccoli, knoll and khol was 35-40 cm at 25, 35, 50% management allowable deficit (MAD) of field capacity. Based on this consideration, the level of sensor was adjusted to probe in such a way that it would be actuated whenever the moisture content in the soil reached 25, 35, 50% of the field capacity. This relationship was developed on the basis of water level depletion in all three methods but moisture content varies with the method of irrigation used for water application.

The water level depletion in modified tensiometer in check basin method was initially less but it was more after 48 hr of irrigation as compared to that in drip and furrow methods. The average depth of water depletion in modified tensiometer in all three methods in okra, brinjal, potato was maximum 30-35 cm and in tomato 35-45 cm, broccoli 35-40 cm, knol- khol 30-40 cm at 25, 35, 50% management allowable deficit (MAD) of field capacity. This depth is useful for the level sensor to be installed inside modified tensiometer for good water scheduling in major crops. The frequency of irrigation was less in check basin as compared to that in furrow and drip. However, the volume of water

applied per irrigation in check basin was more and with time, significant amount of water moved beyond the root zone because of the dominant role of gravity forces.

The soil moisture sensor was successfully designed and integrated with the drip irrigation head work and telecommunication devices like GSM receiver, and transmitter to develop an automated irrigation system. The developed soil moisture sensor was tested successfully in vegetable crops namely okra, tomato, potato, brinjal, broccoli, and knol khol irrigated through check basin, furrow and drip methods at 20 and 30 cm depths at a preset position of the level sensors during the field test. The automated irrigation system carries the data from the sensor and makes the data base information available directly to alert the users through their mobile phones to control the water level in the field. Remotely, the system allows the user to effectively monitor and control the water application in the field via mobile phone by sending a command in the form of message and obtaining the application status. The design is resource-efficient by consuming low power. However, more testing of the system would be necessary to quantify the water and labour savings on large scale. The use of efficient and reliable technologies involving sensor network, GSM, mobile phone, and SMS can certainly help the farmers to obtain better yields from their crops and on a large scale.

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