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Gypsum block soil moisture sensor for real time monitoring using Global System for Mobile (GSM) Module using MPLAB software for horticulture crops

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ABSTRACT

The judicious application of irrigation water is one way to reduce water consumption and improving water use efficiency. The best management practices are needed to be adopted to maintain proper soil moisture content around the crop root zone. The real time monitoring of soil moisture content can be achieved using sensing devices, communicating and controlling devices. Such a system could be wired or even wireless. At present, several types of sensors are used for continuous monitoring of real time soil moisture content data. The present study was carried out to evaluate the performance of automatic drip irrigation system by selecting gypsum block as soil moisture sensor for real time monitoring using Global System for Mobile (GSM) Module. Gravimetric method was used as a standard for comparing the readings obtained by developed gypsum block soil moisture sensors. These sensors can measure the soil moisture tension varying from 10 kPa to 200 kPa, which corresponds to the entire range required in irrigation scheduling. The soil moisture content values ranged from 5, 12 and 15 % for layers 0-15, 15-30, 30-45 and 45-60 cm respectively, at constant Soil Matric Potential 15 kPa. Statistical analyses of sensors were evaluated for different crops namely Tomato, Brinjal and Onion. The volumetric soil water content for different depths was approximately equal to18 cm³/cm³ at tension of 15 kPa. While for watermark the tensions values 20-34 kPa were higher than that of tensiometers. Most sensors performed rationally well between 30 and 45 cm depths, therefore, these sensors are successfully able to produce accurate trend variations in SMC values over a period of time. Gypsum block sensor remains a good tool for automatic irrigation scheduling with limited drawbacks. The developed gypsum block sensor is cheaper as compared to other soil moisture sensor like tensiometer, frequency domain reflectometer (FDR), Neutron probe and time domain reflectometer (TDR).

Keywords: *Gypsum block, Global System for Mobile (GSM), Wireless Soil Moisture Sensor Network WSMN, Drip irrigation.*

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INTRODUCTION

Soil moisture content is considered one of the most important and critical properties of the soil for irrigation scheduling, environmental management and crop production. The real time monitoring of soil moisture content can be achieved using sensing devices, communicating and controlling devices. Such a system could be wired or even wireless. The Wireless Soil Moisture Sensor Network WSMSN is serves as back bone in modern precision agriculture and it is used for real time automating irrigation in field for delivering precise and accurate amount of water for crop at each stage of its growing period (Kuncham *et al.,* 2014). At present, several types of sensors are used for continuous monitoring of real time soil moisture content data (Incrocci *et al.,* 2011). These sensors are classified into the following categories based on their functional requirements such as tensiometer, resistance blocks, frequency domain reflectometer (FDR), time domain reflectometer (TDR), neutron probe technology, remote sensing etc. (Pavithra *et al.,* 2014). The performance of sensor systems in terms of accuracy and sensitivity in measuring soil moisture content for automated irrigation is critical (Chaitanya *et al.,* 2013). Available irrigation automation sensors besides being expansive have other limitations too; like difficult installation and operation etc. (Vellidis *et al.,* 2008, Suresh *et al.,* 2014). To overcome the problems in available irrigation automation systems, the present study was carried out to evaluate the performance ofautomatic drip irrigation system by selecting gypsum block as soil moisture sensor for real time monitoring using Global System for Mobile *(*GSM) Module.

Agriculture sector is considered as a vital sector throughout the world and most of the agricultural land is depend on rainfall. In agriculture, the availability of sunlight, water and nutrients throughout the vegetation period is crucial for crop development, yield and quality (Nolz et. al. 2013). Areas where water is a limiting factor, nonscientific management of irrigation water can cause both economical losses and environmental hazards. Lack of water to the plants causes stress whereas over irrigation causes water logging, yield reduction, poor soil aeration, increases diseases and unproductive losses of energy (Nolz et.al. 2013). Good agricultural practices must include both the knowledge of water usage by crop and techniques that permit an efficient irrigation management (Hutchinson et.al. 2002). Water saving in agriculture sector through efficient application of irrigation water is one way to reduce water consumption and improving water use efficiency.

The best management practices are needed to be adopted to maintain proper soil moisture content around the crop root zone (Vazquez et. al. 2010). Soil moisture content is considered one of the most important and critical properties of the soil for crop production, irrigation scheduling, and environmental management which can be maintain through proper irrigation scheduling techniques to the crop. Irrigation scheduling is achieved by measuring soil moisture content in the field and also by calculating crop water requirement (Rahim et. al. 2013). The real time monitoring of soil moisture content can be achieved through modern technologies which assist computing, communication, sensing devices, power sources and controllers within devices, called Wireless Soil Moisture Sensor Network (WSMSN). The performance of sensor systems related to soil water content with automation is important, which can be available to user in low cost and environmental friendly (Cardenas et. al. 2012). However, in India, very few researchers made effort towards this. Again available sensors have their own limitations, lot of installation and management costs, due to this effect the grower are not using the sensors.

MATERIALS AND METHODS

A.Description of the study site

The present study was conducted in Precision Forming Development Centre (PFDC) farm having the locations of 28°37′22″ to 28°39′05″ N Latitude and 77°08′45″ to 77°10′24″ E Longitude in New Delhi at an average elevation of 230 m above mean sea level (m.s.l.). The climate of study area is characterized as semi-arid tropical with hot dry summer and cold winter. It falls in the Agro-eco region-IV. The mean annual temperature is 25°C. The Maximum and minimum temperature in the month of May-June reaches up to 45°C and an average annual rainfall about650 mm to 750 mm.

B. Fabrication and placing of the sensor

Different components of a sensor were purchased for fabricating a real time soil moisture sensing system namely; the gypsum block. The sensor was calibrated, installed in the field and then tested under three specified crops namely Tomato, Brinjal and Onion (Shock, 1998). The sensor outputs were recorded for different water availability situation in the soil and relationships between the output of the sensor and the soil moisture content were generated. This is a resistive sensor that works when an external device applies a voltage across the electrodes. The medium between the electrodes (soil) acts as a resistor. As the moisture in the medium varies, the voltage carried across the electrodes varies. This voltage can be used to determine the status of soil moisture. The stainless steel electrodes were embedded in the gypsum block and placed in the soil which indirectly measured the soil moisture tension based on resistance.

These sensors can measure the soil moisture tension varying from 10 kPa to 200 kPa, which corresponds to the entire range required in irrigation scheduling. It is suitable for all types of soils. Hence, gypsum blocks of appropriate sizes were designed in the Irrigation laboratory of WTC, ICAR-IARI, New Delhi, standards suggested by Bouyoucos (1949). For fabrication of gypsum block sensors a mould containing 15 cubicles of size 5 cm X 4 cm X 2.5 cm in a wooden boxes type frame was fabricated using ply board of 10 mm thickness. Two 22-mesh stainless steel screen electrodes of 1.25 cm × 0.5 cm size were connected to 0.1 cm diameter thick single core with P.V.C. coated wire and electrodes were taken out with help of single ply aluminum wires (Fig. 1).

C. Calibration of gypsum blocks

The developed sensor was calibrated in pressure plate apparatus under different suctions (0.1, 0.3, 0.5, 1, 2, 3, 5, 7, 10, 12, 15 bars) and a relationship between the electrical resistance (ohms) and soil moisture tension (atmosphere) was developed (Kallestad et. al., 2006).

Programme for developed circuit

The developed circuit and flow chart were prepared according to the standard MP LAB software tool was used to write program in the assembly language for the conditions to be fed in the microcontroller unit PIC 16F87XA (Fig. 2). The written program was then compiled to the machine readable hexadecimal format which the microcontroller can read (Rashid *et al.,* 2013). The written program converted to the hexadecimal format was then burnt microcontroller unit using a universal programmer.

Start of the programme

```
void main()
{
int i;
TRISC = 0xC0;
TRISD = 0x00;
TRISB = 0x00;
PORTB = 0x00;
PORTC = 0x00;
Lcd4_Init();
UART_Init();
lcd4_delayms(1000);
unsigned  x,y,c=0x100,z;
//unsigned  x,y,c=0x100,z;
float tmpr,p,f;
float f;
sensor1();
sensor2();
sensor3();
sensor4()
sensor5();
if(smc1>=18&&smc2>=18&&smc3>=18&&smc4>=18)
{
send SMS ();
MOTOR=ON;
}
else if(smc1<=15&&smc2<=15&&smc3<=15&&smc4<=15)
{
MOTOR=OFF;
Send SMS1 ();
}
sms=0;x=0;y=0;
lcd4_delayms (2000);
//__delay_ms(35);
//bin_bcd(p);  */
}
}
```

End of the programme.

D. Soil analyses and data collection

Soil samples were taken from different locations of the field to determine the physical and chemical properties. Experimental soil was sandy loam soil. Soil samples were collected from different depths up to 60 cm using tube auger and were analyzed to determine its physical properties (Table 1). Soil moisture sensors namely granular matrix sensor (5 nos.), gypsum block sensor (5 nos.), access tubes for FDR (5 nos.) and tensiometer (5 nos.), were installed in each plot up to 60 cm soil depth(Fig. 2). The sensor installation process and operational procedures were performed according to the manufacturer's recommendations and instructions.

Soil moisture characteristic curve

Soil moisture characteristics curve of the experimental soil at various metric potentials were determined by Richard's Pressure Plate Apparatus (Richard 1947). The pressure chamber containing ceramic plates of 1,5,10, and 15 bars was used. The soil moisture characteristic curves for sandy loam soil is shown in Fig 3.

After that soil moisture suction of developed sensor was calibrated in pressure plate apparatus for different suctions and a relationship between the electrical resistance (ohms) and soil moisture tension (atmosphere) is developed (Kallestad *et. al*. (2006). To converts the resistance readings of Gypsum block sensor to soil matric potential developed following equation developed by Shock *et. al*. (1998), Allen *et. al*. 2000, Girisha *et. al.* 2012) was used. The gypsum blocks give reliable reading at a tension of 0.40 atm. and above (up to 160 atm.)

For R smaller than 1 kΩ

$$P = -20[R(1 + 0.018(T - 240) - 0.55]$$

For R between 1 kΩ and 8 kΩ

$$P = \frac{-3.213R - 4.093}{1 - 0.009733R - 0.01205T}$$

For R larger than 8 kΩ

$$P=-2.246-5.239R\,(1+0.018(T-24))-0.0675R^2\,(1+0.018(T-24))^2$$

Where,

P =soil water potential in kPa (centibars),

R =measured resistance in kΩ

T =soil temperature in °C

Statistical Analysis

In this work three statistical parameters were adopted to assess the performance of each sensor against the Gravimetric Method (GM). The Mean Difference (MD) describes the average difference between sensor measurements and the corresponding GM measurements (Table 2), is expressed as:

$$\text{MD}=\frac{\sum_{i=1}^{n}(Msi-Mgi)}{n}$$

Where,

M_{si}=the i^{th} measurement obtained by a sensor.

M_{gi}=the i^{th} measurement obtained with GM.

n =the number of samples.

The Relative Root Mean Square Error (RRMSE) is calculated as the total difference between the sensor and the GM measurements of soil moisture content as a percentage of the mean GM measurement value, is given as:

$$RRMSE = \sqrt{[\sum_{i=1}^{n}(MSi - Mgi)2]} \times (\frac{100}{Mg})$$

Where,

M_{gi}=the corresponding mean of gravimetric measurement, calculated as:

$$Mg = \frac{1}{n}\sum_{i=1}^{n} Mgi$$

The Coefficient of Determination R^2 was used for calculating the degree of similarity between the sensors and GM measurements. If the values of MD and RRMSE close to zero indicate a better performed of sensors. Other Statistical analysis method such as paired *t*-test was used to observe mean of difference between calibrated sensors.

Performance and testing of automated pump system operated by mobile

The automatic GSM based control system was used to effectively monitor and control the water application in field. The desired soil moisture conditions were programmed in the microcontroller unit, and microcontroller unit gives an output pulse to the two parallel connected relay units. The relay unit then activated and started giving output pulses. On receiving the output pulses from the relay unit through wireless connection, the GSM water pumping stations switch ON the pump when the moisture content in the soil is dry which can be sensed by at least four gypsum block sensor out of five sensors which were installed in filed.

RESULTS AND DISCUSSION

The soil moisture curve was used to develop relationships to obtain the soil moisture retention at corresponding depths. The soil moisture content values ranged from 5, 12 and 15 % for layers 0-15, 15-30, 30-45 and 45-60 cm respectively, at constant Soil Matric Potential 15 kPa. Statistical analyses of sensors were evaluated for different crops namely Tomato, Brinjal and Onion. The calibration equations for all the sensors at each depth were obtained using a linear equation (Jose *et al.,* 2014). The volumetric soil moisture content was determined from the samples regressed against the gypsum block sensors readings were presented in figure 4 (a-d) and the statistical date were presented in table 2.

Performance evaluation of the sensing system for the selected crop

In this section the procedure adopted for the performance evaluation of the developed wireless sensor with the automated irrigation system under three crops namely; tomato, brinjal and onion have been discussed (Noor *et al.,* 2013). The Gypsum blocks were inserted in PVC pipes of 6 cm diameter and fixed to be used as probes with wires hanging out for repeated measurements. The probe was soaked in water before installation in the field. For testing, it was wetted in irrigation water for 30 minutes in the morning, dried till evening, wetted overnight and installed wet for improving sensor response and accuracy in the next morning in the tomato, onion and brinjal crops. The tensiometers and gypsum blocks were less responsive to the soil drying between irrigations in comparison to the gravimetric method. This setup was based on soil sample analysis conducted at the depth of 0 to 60 cm in the both fields. All the sensors were installed in this depth and were similar to the depth of root zone of crops. From the experiment conducted on onion, tomato and brijal crops, the calibration equations for all sensors and treatments were developed using a linear regression equations.

The curves for all sensors were following similar trend, but different moisture tension values were obtained. The soil moisture tension values ranged from 10-100 kPa. The volumetric soil water content for different depths was approximately equal to18 cm^3/cm^3 at tension of 15 kPa. While for watermark the tensions values 20-34 kPa were higher than that of tensiometers. The tensiometers showed reading in the range of 8 to 20 % of the volumetric water content but they did not provide measurements lower than 8 kPa which was corresponds to approximately 19 % of volumetric water content. It was observed that the tensiometer readings remained at 45 kPa when the volumetric water content varies from 10-15 % the gypsum block sensor performed well in the 8-20 % range of the volumetric water content. The gypsum block sensor did not give measurements lower than 32 kPa at the 18% of volumetric water content. From the above data tensiometer was found to be consistent only in the range of 30-60 kPa. But gypsum block sensor was found to be performed better up to 90 kPa.

The statistical analyses were carried out to discrepancies between soil moisture contents estimated by the Gravimetric and sensors readings. The mean difference (MD) and the Relative Root Mean Square Error (RRMSE) were used to evaluate the degree of coincidence. An MD value equal to zero denotes no difference between these measurements. A smaller RRMSE indicates better performance. The correlations for gypsum block sensor were (R^2=0.95, 0.93, 0.91 and 0.96 at depth of 0–15, 15–30, 30–45 and 45-60 cm respectively for field one and R2=0.90, 0.95, 0.93, and 0.92 established in all the layers for second field at same depths respectively.

The similar results were obtained for tensiometer also (R^2=0.92, 0.94, 0.90 and 0.94) for comparing gypsum block sensor (Table 2). The paired t-Test results were calculated to check level of significance between gypsum block sensors which were installed in fields. Most sensors performed rationally well between 30 and 45 cm depths, therefore, these sensors are successfully able to produce accurate trend variations in SMC values over a period of time.

A real time Wireless Sensor Network (WSN) using GSM module with microcontroller unit and developed gypsum block sensors were installed in both fields to monitoring precise irrigation scheduling. The system will switch ON the motor when threshold values (less than 15%) reaches in field which can be sensed by four sensors out of five sensors. After collecting all information from sensor the microcontroller gets activated and sends a message to user mobile in the form of motor on through transmitter and receiver via use of GSM and SMS technology. On other hand, once the moisture content reaches to field capacity as sensed by at least four gypsum block sensor out of five sensors, the microcontroller get activated which then send signal to motor as result the motor and solenoid value get OFF. Through the receiver and transmitter a message is revived by the user in the form of motor off. The WSN system will sense soil moisture content and allow user to reliably collect data from field. With the help of theses system the sensors detect the land where water moisture level is low and irrigated for particular place where water is needed. So that water can be saved and water logging problem can be minimized using this method. Use of mobile phone in this operation saves time, low cost, water losses and is user friendly. The WSN technology also successfully applies on agro ecology fields by investigating environmental situations. The complete real time and past environment information is expected to help the agro ecological specialists achieve efficient management and utilization of agro ecological resources.

CONCLUSION

This research work opens up new vistas in real time automated irrigation management and can revolutionize on-farm water management on Indian farms with very high efficiency. An automated WSN system was designed, fabricated, calibrated, installed in the field and tested for real time irrigation scheduling of three crops using gypsum block soil moisture sensor. The system was highly successful in maintaining the soil moisture content in the crop root zone at field capacity throughout the growing season.

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Fig. 1. Different components used for fabrication and developing the gypsum block soil moisture sensing system

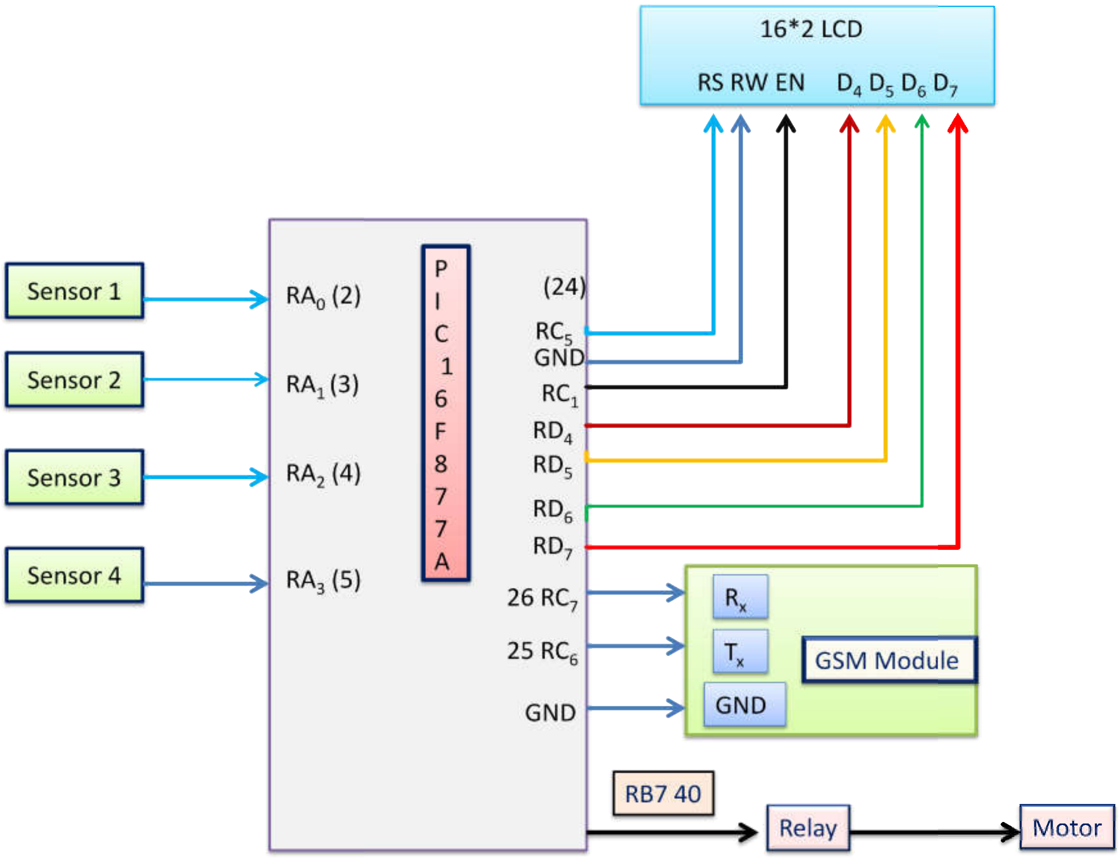

Fig. 2. Circuit schematic for hardware model showing various subsystems

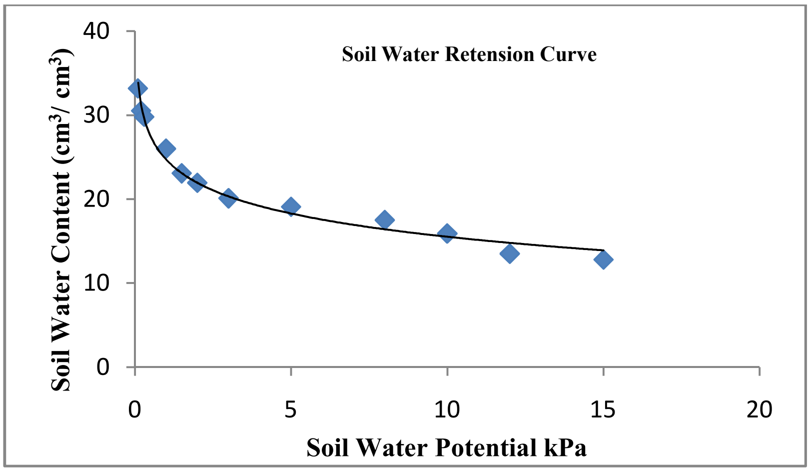

Fig. 3. Soil Moisture Retention Curve.

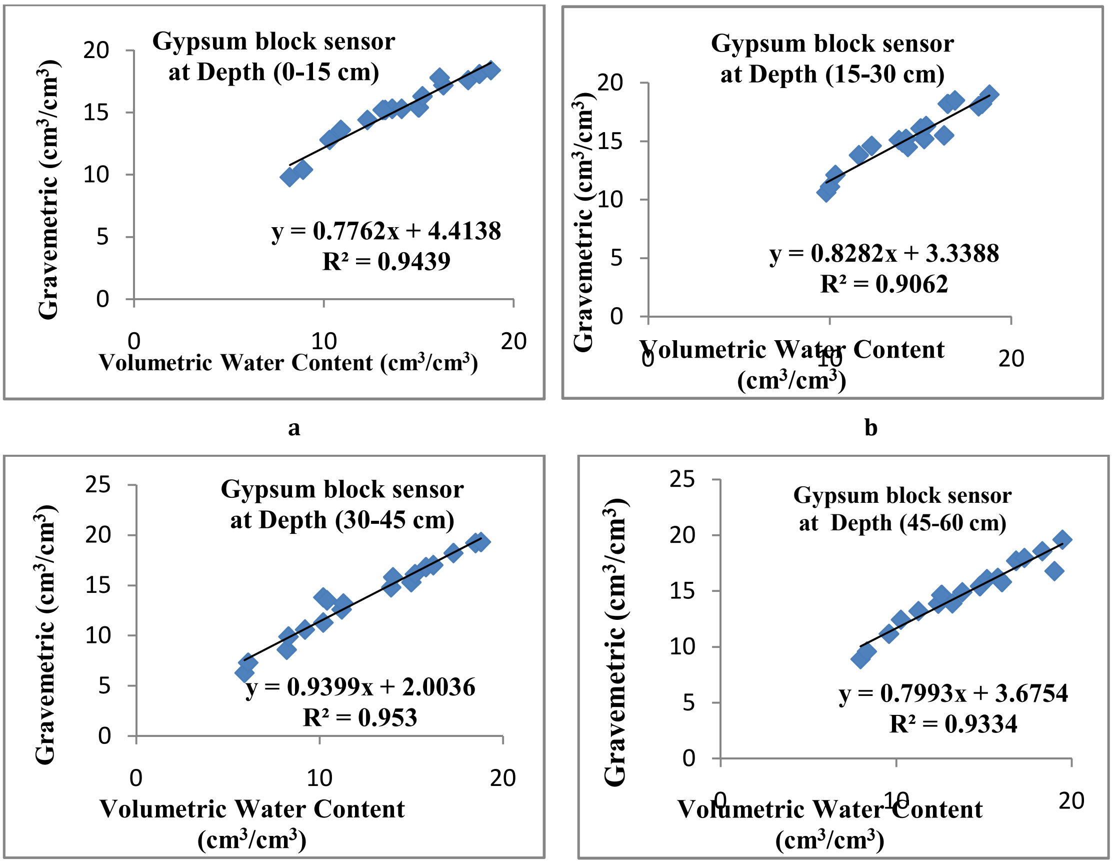

Fig. 4. Regression relations between gravimetric measurements and volumetric water

Table 1. Soil properties of different soil layers

Soil Layer depth (cm)	Particle size distribution (%) Sand	Silt	Clay	Soil texture class	BD (g/cc)	FC % ($m^3\ m^{-3}$) on gravimetric	PWP % ($m^3\ m^{-3}$)
0-15	67.5	12.5	20	Sandy Loam	1.32	30.5	9.8
15-30	66.1	13.1	20.8	Sandy Loam	1.38	30.1	9.3
30-45	65.9	12.8	21.3	Sandy Loam	1.47	29.8	12.8
45-60	64.9	13.3	21.8	Sandy Loam	1.48	30.1	16.8

Table 2. Statistical summary of the sensors performance at different soil depths

Sensor (field one)	Depth, cm	No. of Observations	RRMSE	Intercept	Slope	Relative Basis %	R^2
Gypsum Block	0-15	8	8.149	4.4138	0.7762	-4.014	0.9439
	15-30	8	8.590	3.3388	0.8282	-5.587	0.9062
	30-45	8	10.758	2.0036	0.9399	-8.987	0.953
	45-60	8	5.581	3.6754	0.7993	-10.587	0.9334
Tensiometer	0-15	8	5.690	0.8719	0.9367	-0.9781	0.956
	15-30	8	13.890	1.8391	0.9113	-7.589	0.931
	30-45	8	7.586	0.7197	1.0508	-6.781	0.9123
	45-60	8	6.871	0.9304	0.9776	-11.580	0.9639

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