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Research Article

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Performance evaluation of soil moisture sensor in black soil for effective water management

■ P. R. PATIL, K. NAGARAJAN, S. V. KOTTISWARAN AND K. ARULMOZHISELVAN

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MEMBERS OF RESEARCH FORUM:

Corresponding author :
P.R. PATIL, Department of Soil and Water Engineering, Tamil Nadu Agricultural University, COIMBATORE (T. N.) (INDIA)

Co-authors :
K. NAGARAJAN AND S. V. KOTTISWARAN, Department of Soil and Water Engineering, Tamil Nadu Agricultural University, COIMBATORE (T. N.) (INDIA)

K. ARULMOZHISELVAN, Department of Agricultural Chemistry and Soil Science, Tamil Nadu Agricultural University, COIMBATORE (T. N.) (INDIA)

Summary

A study was conducted to develop the sensor and evaluate the soil moisture by using soil moisture sensors and to establish the relationships between soil moisture content and electrical resistance value. Study involved the fabrication of the soil moisture probes, automation network and laboratory testing of automation system. The soil moisture sensor and automation system used for experiment were developed at Department of Soil and Water Engineering, Tamil Nadu Agricultural University, Coimbatore. System is tested and calibrated for automatic irrigation scheduling. Laboratory test programmes were conducted for the performance of the soil moisture sensor in salt solution and different soils and to develop the calibration curve. It was observed that a significant logarithmic relation between electrical conductivity and resistive value of sensor-1, sensor-2, sensor-3 and sensor-4 with an R^2 value of 0.95, 0.96, 0.96 and 0.96, respectively and with mean values of electrical resistance found R^2 value of 0.964. Because of the sensors were tested for wide range of electrical conductivities ranges 0.01 dSm^{-1} to 8.12 dSm^{-1}. Soil moisture sensor was evaluated with respect to the moisture content of the black soil and it was predicted that the electrical resistance in the range 197 Ohms to 260 Ohms at an average of 224 Ohms at average soil moisture content 58.51 per cent. And at the range of 410 Ohms to 511 Ohms at an average 468 Ohms at 32.41 per cent on 75 hours during the experiment. It was observed that average moisture content 58.51, 57.01, 55.08, 52.73, 50.63, 48.48, 46.16, 42.01, 39.68, 37.26, 34.73 and 32.41 per cent recorded at an average duration of 0, 3, 6, 18, 24, 27, 45, 48, 51, 69, 72 and 75 hours, respectively.

Key words : Soil moisture sensor, Black soil, Field capacity, Resistivity, Electrical conductivity

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Introduction

Irrigation is one of the fundamental problems of agriculture in developing countries. Typically in these developing countries farmers tend to use more water than required by manual techniques hence, wasting them. Soil moisture sensors are typically needed in such situations to indicate to the former when it is needed to irrigate the field and when not needed. The primary source of water in agriculture production in most parts of the world is rainfall. The three main factors that characterize rainfall are amount, frequency and intensity; the values of which vary spatially and temporally.In world, 40 per cent of area cultivated is under irrigation, gives food for 60 per cent of population. Due to tremendous increase in population, the per capita water availability came down from 5300 m^3 in 1960 to 2200 m^3. The per capita water availability will be reduced to 1500 m^3 by the year 2025 (Mahendran, 2004). Irrigation scheduling, in a technical sense, would mean the application of water to effective root zone of a crop at right time and in required quantities for the purpose of applying the moisture along with nutrient to meet the evapotranspiration and metabolic water requirement of a crop. Soil moisture deficit within the domain of the available water holding capacity of the effective root zone places vital role in scheduling irrigation. Soil moisture sensors may be used in applications such as crop production research, water budgeting in watersheds, precision agriculture, environmental monitoring and irrigation scheduling (Hanson and Peters, 2000).

Recently, technological advances have been made in soil water sensors for efficient and automatic operation of irrigation systems by which exact quantity of required water can be supplied to the crop.

The present work comprises of development of a soil moisture sensor. The soil moisture sensor has been developed using the basic property that the resistance of the soil between two points decreases with the increase of water content in it. We know that water is a good conductor of electricity in the presence of ions. So, greater the amount of with electrolytes in the soil, greater will be the conductivity of the soil. This means that the resistance of the soil decreases. However, it has to be ensured that chemical fertilizers are not administered into the soil within a radius of 1m from the sensor. This will ensure that the conductivity of the soil will not change at the point of measurement due to application of chemical fertilizers. The developed sensor has two probes that are inserted into the soil. The distance between the probes is kept fixed. A resistance is connected in series with the probe and current is passed through it.

Resource and Research Methods

Design and fabrication of drip automation system is done at Agriculture Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore and lab experiments based on soil moisture content were conducted at Precision Farming Development Centre (PFDC) of Tamil Nadu Agricultural University (TNAU), Coimbatore. This is located at 110 N latitude and longitude 770 E with an altitude of 398 m from mean sea level.The metrological data recorded in the Agro Climatic Research Centre, Tamil Nadu Agricultural University, Coimbatore showed that the mean annual rainfall is 674.2 mm. The mean maximum and minimum temperature are 37° C and 25° C, respectively. The mean monthly evaporation ranges from 3.5 to 7.6 mm. The climate is tropical with South West and North East monsoons. Coimbatore is under rain shadow condition and about 55 per cent of annual rainfall receives during north east monsoon and 30 per cent during south west monsoon. Soil samples were collected from the experimental plots and analyzed for the soil physical and chemical characters *viz.*, electrical conductivity, pH, field capacity, permanent wilting point, bulk density and volumetric water content, using standard procedure (Michael, 2003) the details are furnished in Table A.

Laboratory tests were conducted to evaluate the performance of soil moisture sensor in salt solutions with different concentration and black soil. The procedure adopted for calibration of the sensor are divided into two laboratory experiments namely calibration of soil moisture sensors with respect to different EC solution prepared from distilled water and sodium chloride and calibration of soil with respect to soil moisture content with irrigation.

Calibration method for moisture sensor in different concentration of salt solutions :

Distilled water and sodium chloride is use to prepare for different EC solution. For preparing different solution

Table A : Physical and chemical properties of soil

Sr. No.	Soil properties	Black soil
1.	Electrical conductivity (dS m^{-1})	1.05
2.	pH	7.85
3.	Texture (USDA texture classification chart)	Silt clay
4.	Volumetric water content (Gravimetric method)	4.90%
5.	Field capacity (Pressure plate apparatus)	39.14%
6.	Permanent wilting point (Pressure plate apparatus)	19.89%

of EC the known quantities of sodium chloride is added in 200 ml of distilled water and are presented in Table B.

Different EC solution were used to calibrate with soil moisture sensors to develop the calibration chart for different electrical conductivities in salt solution by dipping the moisture sensor in the different concentration of salt solutions as shown in Plate A.

Plate A : Soil moisture sensor with LM 393 driver and pins to connect Arduino board

Calibration method for soil moisture sensor in black soils :

Experiment were conducted to evaluate the performance of the soil moisture sensor in different soil types to develop calibration curves experiments were performed using a circular containers (Plastic pot) made up of polyvinylchloride (PVC) material, which is an electrical insulator having diameter of 0.35 m and 0.5 m height. The containers with drainage holes in the bases were filled with soil. Soil moisture sensors were located along the centerline of each plastic pot to minimize any interaction between the sensors or pot edge effects.Soil moisture sensor measures the resistance between the nickel parallel plate probes, which was a function of soil moisture content. The soil moisture content and corresponding soil electrical resistance were the monitored till constant moisture content was reached. Variation of moisture in soil caused variation in electrical resistances across the plates of the sensors. To evaluate the performance of the sensor, soil moisture content was measured from each pot thrice in a day at 10.00 am, 1.00 pm and other at 4.00 pm.

Procedure :

The soil filled in the plastic pot (tare) after taken reading of empty pot (W_0). Then poured the water upto edge of the pot and wait for drain all water. Generally for black soil it will take 3-4 day for draining all gravitational water. Weighing balance method used for measuring the moisture content of the soil. First moisture content reading of soil found by taken the sample from where soil moisture sensor was placed. Then by gravimetric method determined the moisture content of first soil moisture content reading. After that weighed the pot weight *i.e.* weight of wet soil + tare (W_1+W_0). Then every three hours weight of dry soil *i.e.* weight of dry soil + tare (W_2+W_0) was taken. The moisture content in dry weight basis was calculated using the following formula :

$$\textbf{Soil moisture content (\%)} = \frac{(W_1+W_0)-(W_2+W_0)}{(W_2+W_0)-(W_0)} \times 100$$

Connect the power by USB port or adapter below at side of the system. There is no polarity in the

Table B : Electrical conductivity at different salt concentration

Sr. No.	Quantity of NaCl added "g"	Concentration "ppm"	Electrical conductivity "dSm^{-1}
1.	0	0	0.01
2.	0.1	500	0.89
3.	0.2	1000	1.82
4.	0.3	1500	2.75
5.	0.4	2000	3.43
6.	0.5	2500	4.29
7.	0.6	3000	5.11
8.	0.7	3500	5.84
9.	0.8	4000	6.46
10.	0.9	4500	7.29
11.	1.0	5000	8.12

connections. Rear side of the system Sensor-1 (A0), Sensor-2 (A1), Sensor-3 (A2), Sensor-3 (A3). Connect the three wires from the sensor here as shown in Plate B.Totally four sensors are possible as shown in Plate C. The soil moisture sensor showed the reading typical resistance value in the air. The probe readout average resistance value 1023 Ω in air. The values were of used for soil moisture measurement and as a day-to-day monitoring of soil sensor stability.

Plate B : Performance of moisture sensor in salt solution

Research Findings and Discussion

The experiments were conducted to evaluate the moisture sensor in different concentration of salt solution and established the calibration curve between the soil moisture content and the resistance values for black soil with respect to soil moisture content under laboratory and open atmospheric condition.

Plate C : Performance of soil moisture sensor in black soil

Calibration of the soil moisture sensor :

Performance of soil moisture sensor in different concentration of salt solutions :

The sensors behaved different with different concentration of salt. Over the lower electrical conductivities, the data points followed the linear relation. But as the electrical conductivity increased, the relation become nonlinear and all the sensors followed the similar type of curves (Fig.1). And it was clearly observed that with increased electrical conductivity of solution, the resistive value of moisture sensor decreased. By dipping soil moisture sensor and EC probe to a container of water produces no electric current and it showed the resistive value as 1022 ohms with EC of 0.01 dSm^{-1} to 0.035 dS m^{-1} because pure water is an insulator. But a few grains of Table 1 salt added to the water changes things completely. Sodium ions and chloride ions are released

Table 1 : Performance of soil moisture sensor in salt solution with different concentration

Sr. No.	Concentration in ppm	EC dS/m	Electrical resistive value of soil (ohms) SMS 1	SMS 2	SMS 3	SMS 4	SMS mean
1.	0	0.01	1008	1021	1018	1022	1017.25
2.	500	0.89	367	427	414	423	407.75
3.	1000	1.82	320	380	369	377	361.5
4.	1500	2.75	304	364	357	361	346.5
5.	2000	3.43	295	355	348	352	337.5
6.	2500	4.29	289	349	342	346	331.5
7.	3000	5.11	280	339	332	335	321.5
8.	3500	5.84	271	331	323	324	312.25
9.	4000	6.46	262	319	315	316	303
10.	4500	7.29	254	311	307	305	294.25
11.	5000	8.12	245	305	298	294	285.5

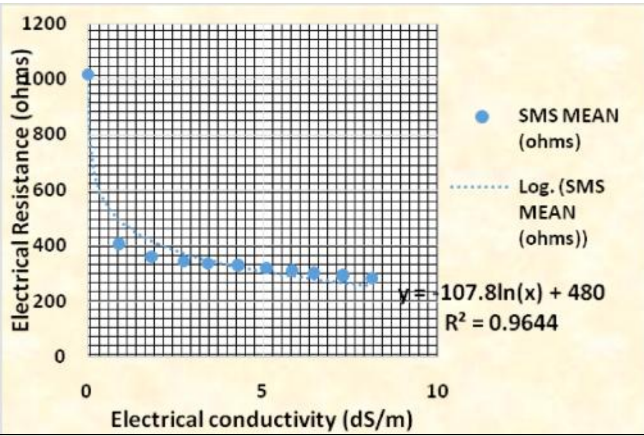

Fig. 1 : Relation between mean value electrical resistance and electrical conductivity of salt solution

from the salt, and the salt water solution becomes conductive. From the Table 1, it was observed that a significant logarithmic relation between electrical conductivity and resistive value of sensor-1, sensor-2, sensor-3 and sensor-4 with an R^2 value of 0.95, 0.96, 0.96 and 0.96, respectively and with mean values of electrical resistance it was R^2 value of 0.964. However, a very high concentration of salt, that is for higher electrical conductivities, the resistance value of the sensor became less sensitive to electrical conductivity. The resistance decreases non-linearly at diminished rate with increasing concentration of salt.

Sudduth *et al.*(2005) found that soil EC data obtained with each sensor exhibited similar qualitative trends at the field scale. As expected, field mean EC was highest for the field with finner-textured soils and both similarities and difference in EC data obtained with the Geonics EM38 and the Veris 3100. Difference were attributed to difference between the depth weighted response functions for the three data types, coupled with difference in the degree of soil profile layering between sites. Because the claypan soils of the Missouri fields exhibited the greatest by depth variation in clay content and CEC, two primary drivers of EC differences between EC data types were most pronounced on these field.

Evaluation and calibration of the sensor in black soils :

Soil moisture sensor was evaluated with respect to the moisture content of the black soil. And electrical resistance data by the sensors were obtained from experiment with respect to different soil moisture for black soil.

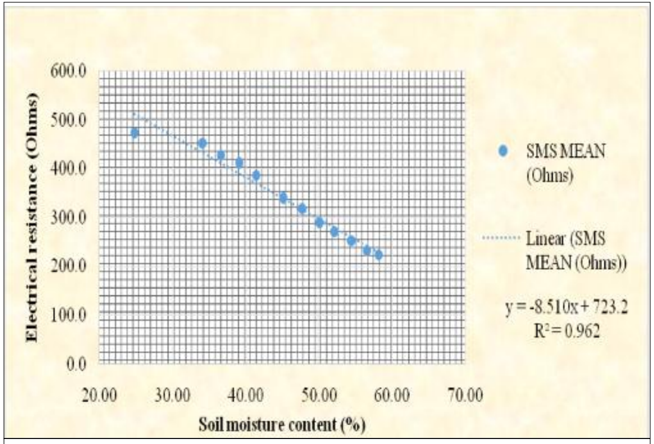

Fig. 2 : Relation between mean of all sensors electrical resistance and soil moisture content of black soil

Table 2 : Relation between mean of electrical resistance and soil moisture content with different duration in black soil

Sr. No.	Time interval hours	Moisture content (%)	Electric resistance (ohms)
1.	0	58.15	224.0
2.	3	56.55	232.5
3.	6	54.49	253.5
4.	18	52.20	271.8
5.	24	50.19	290.3
6.	27	47.77	319.3
7.	45	45.13	338.5
8.	48	41.42	386.8
9.	51	39.10	410.5
10.	69	36.61	427.3
11.	72	34.13	452.8
12.	75	24.77	471.8

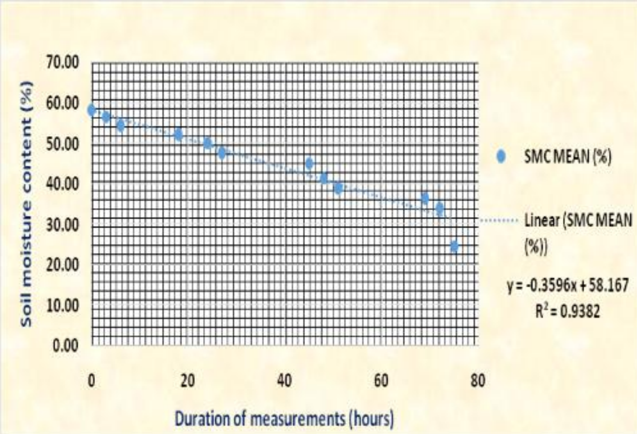

Fig. 3 : Relation between duration of measurement and soil moisture content of black soil

The calibration curves were plotted with respect to electrical resistance and soil moisture content from the twelve observation of four days. It was observed that the maximum electrical resistance was measured 498, 410, 511 and 468 ohms at soil moisture content 30.55, 38.25, 26.51 and 34.32 per cent, respectively and minimum electrical resistance was measured 223, 197, 260 and 216 ohms at soil moisture content 56.75, 64.25, 53.01 and 60.02 per cent, respectively because it was due to the soil moisture content. In this case soil moisture content very less, therefore, electric current will not flow.

From the calibration curve it was predicted that the electrical resistance in the range 197 Ohms to 260 Ohms at an average of 224 Ohms at average soil moisture content 58.51 per cent. And at the range of 410 Ohms to 511 Ohms at an average 468 Ohms at 32.41 per cent on 75 hours during the experiment. From Fig. 3, it was observed that average moisture content 58.51, 57.01, 55.08, 52.73, 50.63, 48.48, 46.16, 42.01, 39.68, 37.26, 34.73 and 32.41 per cent recorded at an average duration 0, 3, 6, 18, 24, 27, 45, 48, 51, 69, 72 and 75 hours, respectively.

From this calibration curve we can maintain the field capacity of black soil and apply optimum irrigation to the crop. The resistivity value of soil moisture sensor showed less value because of soil particle texture and EC value of soil which recorded 1.05 dSm^{-1}. It will effect to moving the electron freely in the soil profile, therefore, the resistance values shows in less. By this, calibration curve of soil moisture sensor we were starting and stopping the motor.

From the statistical regression analysis it was observed that R^2 value of 0.97, 0.97, 0.98 and 0.97 for sensor moisture sensor (SMS 1), SMS 2, SMS 3 and SMS 4, respectively under laboratory experiment. And these higher R^2 value showed a satisfactory results in performance of soil moisture sensor for black soil.

Conclusion:

In this study, it was clearly seen that as the moisture content decreased, the resistance value of sensor increased. But calibration of the sensor showed for different soil the resistance value with respect to moisture content will change. This might be due to the different soil texture and air gap between the soil and soil moisture content. The drip automation system based on soil moisture deficit was developed. Its work on the principle of electrical resistance offered by soil when electrical current is passes through it. The sensor were developed is evaluated in different concentration of salt solution and it shows the logarithmic relation between electrical conductivity and electrical resistance.The sensor were calibrated in black soil and it was shown the linear relation between electrical resistance and soil moisture content. By relay it was observed that the system was working precisely when the resistance value reaches set value for motor switch On and switch Off with respect to pre-set moisture content.The developed systems economical light weight and water proof.

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