

**PERFORMANCE ANALYSIS OF ELECTRICAL RESISTANCE BASED
GRANULAR MATRIX SENSORS FOR MEASURING SOIL WATER
POTENTIAL IN CLAY LOAM SOIL**

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ABSTRACT

Soil moisture sensor based irrigation water management represents a substantial opportunity for agriculture water savings and has the potential to provide maximum water use efficiency by maintaining soil moisture at optimum levels. Therefore, it is required to analyze whether readings obtained from sensor gives actual soil moisture condition or not? In context to that the present study was conducted at research farm of Junagadh Agricultural University, Junagadh, Gujarat, India, to determine if a granular matrix sensor could accurately measure soil water status at several locations, thus providing a profile of soil water content. The watermark sensors were installed at three different depths (15, 30 and 45 cm) of three locations. Readings were taken daily by digital soil moisture meter and the wet soil samples were also taken from the same place at same time for gravimetric assessment of soil moisture. From the study, it was observed that the extreme level of soil moisture potential (199 kPa) was attained in 14, 18 and 21 days at 15, 30 and 45 cm depths of each location. As the depth of sensor installation increases, the goodness of fit also increases. So it was revealed that the watermark sensors were working nicely for deeper installation. The empirical equation from regression analysis of data for the watermark sensor for clay loam soil was found as $w = 60.122 \times (SWP)^{-0.19}$ with goodness of fit as 0.974. Therefore, it can be concluded that the sensor data is valid and obtained empirical equation can be used for estimating the soil water content in clay loam soil.

KEY WORDS: Granular matrix sensor, soil moisture tension, soil water content, watermark,

INTRODUCTION

Soil water status can be expressed in two ways: (i) soil water content and (ii) soil water potential. Soil water content is an indication of the amount of water present in the soil profile. Soil water potential determines availability of water to plants and is a direct indication of the energy required

for plants to obtain water from the soil and is often used to represent matric potential in soils where salinity is not an issue. Water in the soil not only influences plant growth and yield but also performance of tillage, planting and nutrient uptake. Measurement of soil water is required in many areas of agriculture for research and

development, and for routine on-farm monitoring. Accurate determination of soil water status (soil water content or soil water potential) is fundamental to agricultural water management. Irrigation scheduling requires the knowledge of “when” and “how much” water to apply to optimize crop production. Effective irrigation management requires that soil water status can be accurately monitored over time in representative locations in the field (Hanson *et al.*, 2000). For optimum yield, soil water in the crop root-zone must be maintained between desirable upper and lower limits of plant available water. Soil water potential is an expression of the energy level of water in the soil system. This is contrasted to the amount of water present in the system for which water content is the fundamental parameter. Soil water potential is numerical value with the opposite sign. Soil water content is the amount of water present in a given volume of soil. Determination of soil water status for irrigation management using hand-feel method is practiced in the absence of accurate and low cost soil moisture sensors. The hand-feel method does not provide quantitative soil water status; rather it provides a qualitative indication of soil water status and is subject to the person’s ability to feel the soil (Geesing *et al.*, 2004). To improve irrigation management, quantitative knowledge of soil water status deep in the soil profile is necessary, but not possible with the hand-feel method. Any error in the hand-feel method will cause significant errors in determination of irrigation water requirement. Over the years, a number of newer and cost-effective technologies/tools have been developed to measure soil water status. Decision making about which technique should be used depends on

the purpose of the measurements, soil and crop conditions, desired accuracy, cost and other factors. There are several instruments and sensors available to measure *in-situ* soil moisture, but they are costly. A granular matrix sensor (GMS) has been developed for electronically measuring soil moisture and versatility of the sensor is the accuracy, easiness and effectively towards cost (Larson, 1985). This sensor is made up of a porous ceramic external shell with an internal matrix structure containing two electrodes. An internal gypsum cylindrical tablet buffers against soil salinity levels that occur in most irrigated soils. The GMS do not dissolve in the soil over the time (Irmak and Haman, 2001), which generally occurs with a gypsum block.

This instrument reduces the problems associated with the gypsum blocks since it uses a silt granular matrix that minimizes both the problems of the dissolution of the blocks and that one of the poor pore-size distribution. It also operates based on the principle of electric resistance, and has a gypsum block inserted in the granular matrix and connected to an electric current gauge. Eldredge *et al.* (1993) conducted an experiment to compare readings of soil water obtained with granular matrix sensors to tensiometer, neutron probe, and gravimetric sampling results and found granular matrix sensors very effective. According to Shock (1998), the granular matrix sensors are extremely convenient for water potential measurements because, unlike the tensiometers, they do not require fluxing the air outside the system after a long dry period, and the sensors start once again to record the data with the arrival of the new wetting front. Moreover, these sensors have a low cost and, using long electric wires, one

can minimize the disturbing effects to plants and soils caused by the monitoring process. The objective of this study was to determine if a granular matrix sensor could accurately measure soil water status at several locations, thus providing a profile of soil water content.

MATERIALS AND METHODS

The experiment on performance analysis of granular matrix sensors was conducted at research farm of Junagadh Agricultural University, Junagadh, Gujarat, India comprising latitude 21°31' N, longitude 70°36' E and altitude of 64.39 m. The granular matrix sensors manufactured by "Irrometer Inc., USA" and trade marked as "Watermark" was used in the present study. The physico-chemical properties of soil profile of experimental area are presented in Table 1. The soil of the study area was clay loam in texture having typical udorthents soil group and lime stone as a parent material. The available water and bulk density of the soil are 16.60 % and 1.43 g/cc, respectively. Soils are medium to heavy textured, shallow in depth, which is slightly alkaline in reaction and moderate organic matter and was medium in available nitrogen and phosphorous but rich in available potash. The water holding capacity of soil is medium to high and the organic carbon content, field capacity and permanent wilting point of soil were 0.52, 29.79 and 13.19 %, respectively. The soil moisture retention curve of the study area is given in Figure 1.

In the present study, Irrometer Watermark sensor was utilized and calibrated digital soil moisture meter was used to get the readings. Watermark sensors were installed at different depth (30, 60 and 90 cm) in locations with representative soil and crop conditions. After installation the

depth of the sensors was labeled on the top. Also, the edge of the field should be marked for easy location of the sensors. Before installation, sensors were soaked in water for 2 hours followed by 24 hours drying. This procedure was repeated twice before installation. Only wet sensors were installed. Wetting improves the response of sensors because it removes air from them. After pushing the sensor into place, the access hole should be backfilled and tamped to eliminate air pockets. Pouring slurry in the hole before placing the sensors is not recommended. When the slurry dries it will crack and move away from the soil, creating space between the sensor and the soil. This also may be true without using slurry, but slurry will increase the chance of poor contact between the soil and the sensors. Installing the sensors early in the growing season before the developed root system is important. Making the access hole to install the sensors after the root system is developed can damage the roots near the area where the sensor is installed. These roots may or may not re-grow and may cause non-representative readings. Readings of soil moisture potential were taken using a hand-held digital soil moisture meter every day at 11:00 AM. The measurement range of the soil moisture meter is 0 to 199 kPa and reading was taken for the sensor range only. The wet soil samples were taken with the help of screw auger at respective depth of location and at the time of recording reading of soil moisture potential. The weight of empty moisture bin (W_1) and weight of moisture bin along with wet soil sample (W_2) were recorded and then the moisture bins were put in the oven at 105°C for 24 hours. After 24 hours, the weight of moisture bin along with oven dried soil (W_3) was recorded. The gravimetric

measurement of soil moisture content (w) on dry basis was calculated using following equation

$$w = \frac{W_2 - W_3}{W_3 - W_1} \times 100 = \frac{W_w}{W_d} \times 100 \quad (1)$$

Where,

w is the water content (%)

W_w is the weight of water (g)

W_d is the weight of oven dried soil (g)

The graphs were prepared for soil moisture content against soil moisture potential in Microsoft Office Excel programme for regression analysis and soil moisture function was determined for each locations.

RESULTS AND DISCUSSION

The digital soil moisture meter was used to manually read individual watermark sensors' reading. The digital meter converts the digital output of the Watermark from resistance ($k\Omega$) to soil suction (kPa) using a non-linear equation developed by Shock (1998).

$$SWP = (4.093 + (3.213 * k\Omega)) / (1 - (0.009733 * k\Omega) - (0.01205 * T_s)) \quad (2)$$

Where,

SWP is the soil water potential (kPa),

$k\Omega$ is the sensor output, and

T_s is the measured soil temp. ($^{\circ}C$)

The graphical representation of the data of soil water potential observed by watermark sensor of respective depths of different locations are shown in Figure 2. It is revealed from the Figure 2 that the extreme level of soil moisture potential (199 kPa) was attained in 14, 18 and 21 days at 15, 30 and 45 cm depths of each location. The extreme level attained at 14 days in 15 cm depth was due to evaporation losses from the soil surface and the gravitational flow of water. In case of 45 cm depth, the extreme limit was attained at 21 days due to comparatively less evaporation losses and percolation. It is also

observed that as the days passing the soil moisture potential of respective depth increasing in similar trend for all the three locations. The extreme soil water potential was 199 kPa, which is the extreme limit of the watermark sensor.

The best fit equation for soil moisture characteristics curve with goodness of fit as 0.994 was

$$w = 57.912 \times (SWP)^{-0.187} \quad (3)$$

Where,

w is the soil water content (%)

SWP is the soil water potential (kPa)

The soil water content was estimated using Eq. (3) with observed values of soil moisture potential for all the depths of different locations. The actual soil water content was measured using gravimetric method for all the depths of different locations. The depth wise comparison of estimated and actual soil water content is graphically represented in Figure 3. From the Figure 3, it can be stated that for all the three depths the slope of the actual versus estimated water content linear equation is closer to 1 with goodness of fit more than 0.98, therefore, the watermark sensor data is valid for estimating the soil water content. As per shown in Figure 3, as the depth of sensor installation increases, the goodness of fit also increases. So it is revealed that the watermark sensors are working nicely for dipper installation. Thomson and Armstrong (1987) also reported that the deeper installation of watermark sensor give accurate results.

Figure 4 shows the relationship between soil water potential observed by watermark sensors and gravimetric moisture content. The empirical equation with goodness of fit as 0.974 from regression analysis of data for the watermark sensor for clay loam soil was found as

$$w = 60.122 \times (SWP)^{-0.19} \quad (4)$$

The above equation can be used for estimating the soil water content of clay loam soil for the observed soil water potential using watermark sensor.

CONCLUSION

Accurate measurement of soil water content is necessary in irrigation scheduling, however there are many sensors available apart from that granular matrix sensors are cost effective tool. Hence, the performance of granular matrix sensor which measure soil water potential (range of 0 to 199 kPa) was analyzed at different depths for three locations. From the study it was observed that the extreme level of soil moisture potential (199 kPa) was attained in 14, 18 and 21 days at 15, 30 and 45 cm depths of each location. As the depth of sensor installation increases, the goodness of fit also increases. So it is revealed that the watermark sensors are working nicely for dipper installation. The empirical equation from regression analysis of data for the watermark sensor for clay loam soil was found as $w = 60.122 \times (SWP)^{-0.19}$ with goodness of fit as 0.974. Therefore, it can be concluded that the watermark sensor data is valid and obtained empirical equation can be used for estimating the soil water content in clay loam soil.

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Table 1: The physico-chemical properties of the soil profile of the study area

Sr. No.	Characteristic	Unit	Depth				
			0-25 cm	26-50 cm	51-75 cm	76-100 cm	Average
1	Mechanical composition						
	1. Sand percentage	%	32.74	31.25	31.08	30.84	31.48
	2. Silt percentage	%	27.61	27.84	28.33	28.54	28.08
	3. Clay percentage	%	39.65	40.91	40.59	40.62	40.44
2	Saturation percentage	%	37.80	36.51	36.27	35.93	36.63
3	Field capacity	%	30.20	29.94	29.56	29.47	29.79
4	PWP	%	13.50	13.21	13.04	13.01	13.19
5	Bulk density	g/cc	1.45	1.43	1.42	1.42	1.43
6	Basic infiltration rate	cm/h	1.24	1.14	1.08	1.21	1.17
7	pH	-	8.87	8.84	8.88	8.51	8.78
8	EC	mmho/cm	0.39	0.35	0.37	0.38	0.37
9	Lime %	%	44.10	48.14	47.20	41.57	45.25
10	Organic carbon	%	0.55	0.51	0.53	0.49	0.52
11	Nitrogen (N ₂)	kg/ha	256	249	258	241	251.00
12	Phosphorus (P ₂ O ₅)	kg/ha	30	36	34	35	33.75
13	Potash (K ₂ O)	kg/ha	290	284	268	275	279.25

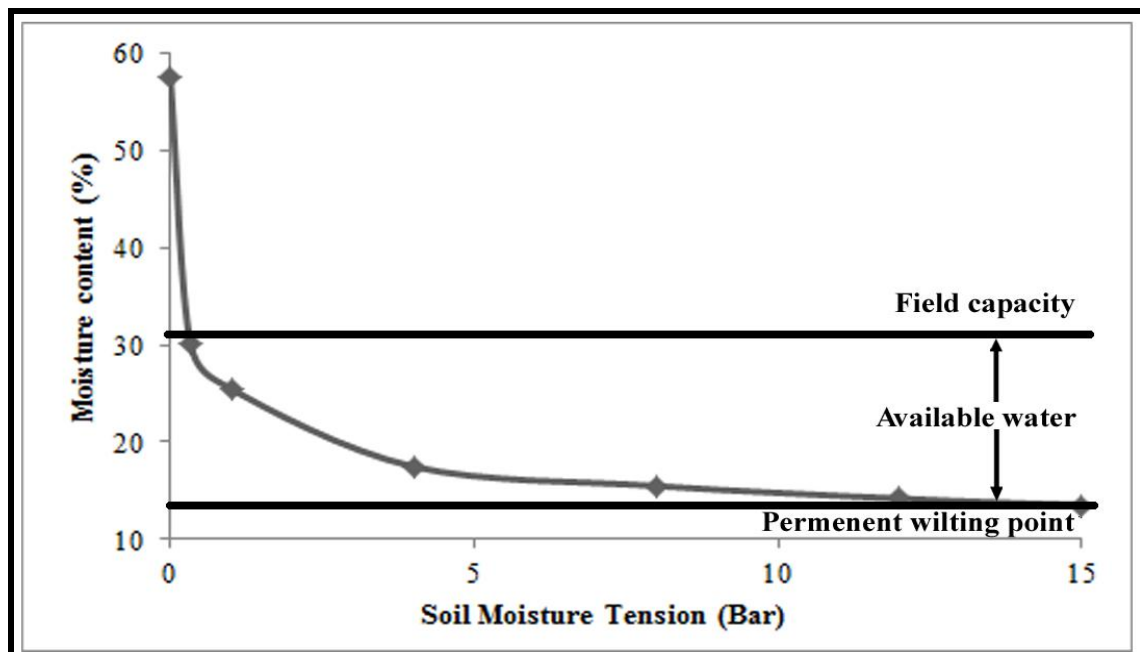
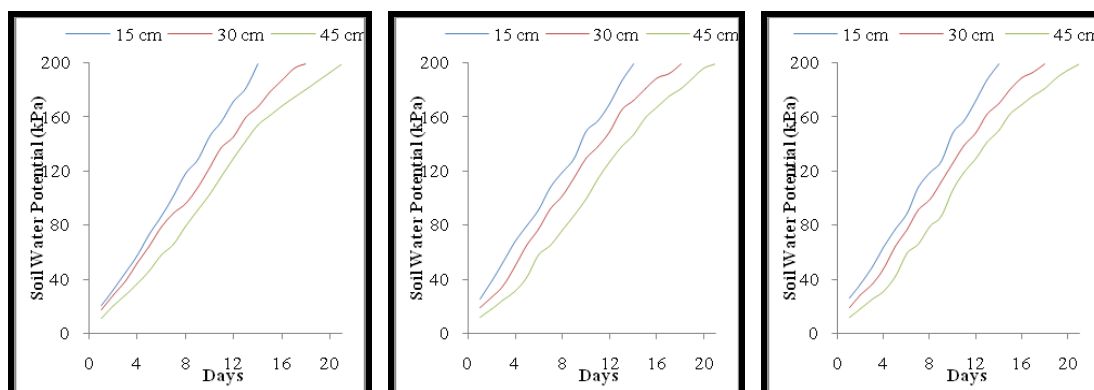


Figure 1: The soil moisture retention curve of the study area

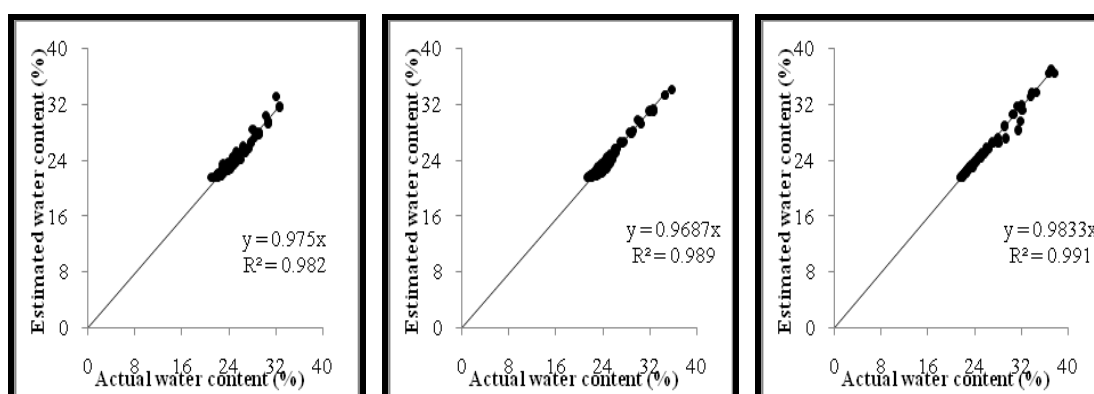


(a) Soil moisture potential observed for location A

(b) Soil moisture potential observed for location B

(c) Soil moisture potential observed for location C

Figure 2: The graphical representation of the observed data of soil water potential



(a) For 15 cm depth

(b) For 30 cm depth

(c) For 45 cm depth

Figure 3: The depth wise comparison of estimated and actual soil water content

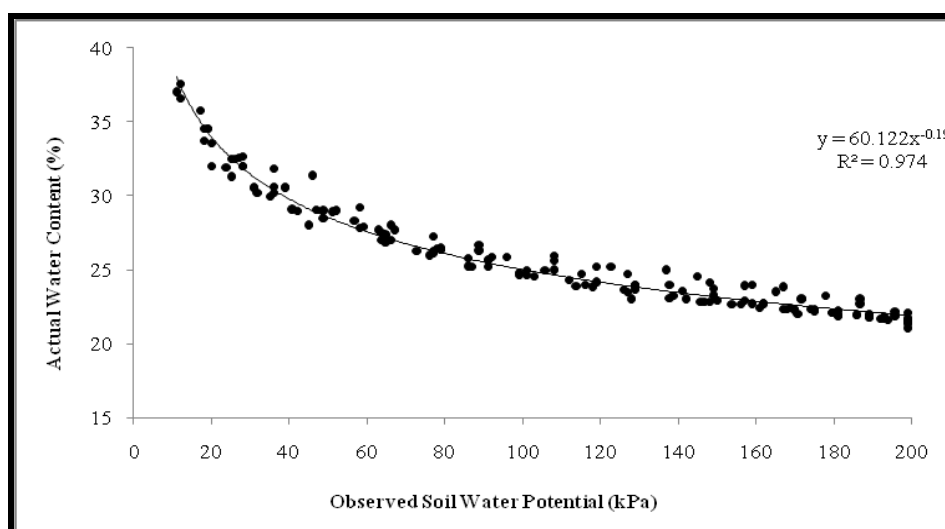


Figure 4: The relationship between observed soil water potential and actual water content

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