ISSN 2320-5407 International Journal of Advanced Research (2014), Volume 2, Issue 8, 560-571

ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

FABRICATION OF LOW COST SOIL MOISTURE SENSOR FOR IRRIGATION WATER MANAGEMENT

Shruti Suriyakumar[1], Beulah J M Rajkumar[2]*, G. Jayanthi Kalaivani[3]

1,2 Department of Physics, Lady Doak College, Madurai

3 Department of Chemistry, Lady Doak College, Madurai

Manuscript Info

Manuscript History:

Received: 18 June 2014
Final Accepted: 29 July 2014
Published Online: August 2014

Key words:
soil moisture, sensor, gypsum block, sodicity

***Corresponding Author**

Beulah J M Rajkumar

Abstract

The study was aimed at fabricating a low cost soil moisture sensor which can help in optimizing the use of water. The sensor was made using gypsum blocks. The moisture content in the soil was indicated by an LED attached to an LM339 comparator circuit which glows when the moisture level in the soil falls below an optimum value. A comparative study on the effect of chemical and organic fertilizer on moisture retention capacity of soil was made. Soil samples for the study were collected from the main campus and satellite campus of Lady Doak College, Madurai, India. The soil and water from both the campuses have been tested for pH, Electrical Conductivity, TDS, sodicity. The NPK levels of soil were also determined before and after the addition of organic and chemical fertilizers. It has been found that the nutrient content, sodicity and hence the water holding capacity of the soil collected from the satellite campus was greater than that collected from the main campus. The developed sensor was found to be effective in determining the moisture content of the soil.

INTRODUCTION

Soil is the medium through which plants take their nutrients. For the growth of plants three factors are important – the soil nutrients, the quality of the seeds that are used and finally the moisture content in the soil. Soil moisture is an essential environmental, hydrological and climate variable (Heidi Mittelbach et al., 2012).If the soil moisture goes down despite having good seeds and a nutrient–rich soil, the crop will be lost. The optimum growth of plant and the yield of crop depend not only on the total amount of nutrients present in the soil but also on their availability (Kumar M et al., 2011). The response of a Plant to irrigation depends on the physical condition, fertility, and biological status of the soil. The extent to which a plant root system grows and uses available moisture and nutrients is determined by soil condition, texture, structure, depth, organic matter, bulk density, salinity, sodicity, acidity, drainage, topography, fertility, and chemical characteristics of soil (Patrick Lavelle et al., 2007).All soils contain soluble salts with major dissolved inorganic ions of Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-, and CO_3^{2-}. Soils are considered saline if they contain high levels of soluble salts, which can have negative impacts on crop growth through the reduction in water availability to the plant or toxic effects of individual ions such as $H_2BO_3^-$ and Ba^{2+} under hyper saline conditions. Soil salinity is generally characterized by determining total dissolved (TDS) or electrical conductivity (EC) of the soil solution (Peacock, W.et al., 2000).

Soil sodicity is generally characterized by exchangeable sodium percentage (ESP) based on sodium saturation of cation exchange capacity (CEC).High level of sodicity causes clay to swell excessively when wet. The clay particles move so far apart that they get separated. This weakens the aggregates in the soil, causing structural collapse and closing-off of soil pores. For this reason water and air movement through sodic soils is severely restricted. In vegetable crops, sodic layers or horizons in the soil may prevent adequate water penetration during irrigation, making the water storage low. Additionally, water logging is common in sodic soil, since swelling and dispersion closes the pores, reducing the internal drainage of the soil. Sodicity of the surface soil is likely to cause dispersion of surface aggregates, resulting in surface crusts (Udom B.E et al., 2010).

As urbanization increases, the demand for water also increases. It is therefore necessary to prevent both under and over watering thereby maximizing the crop growth and conserving water (Armstrong, C.et al., 1987).The present study is therefore aimed at fabricating low cost soil moisture sensors using gypsum blocks and using it to optimize the water used for potted plants at two different sites viz., main and satellite campus of Lady Doak College, Madurai. The electrical resistance of gypsum depends on its moisture content (Walker et al., 2002) and it increases with increase in the dryness (Campbell J.M et al., 1993). This property was exploited in the design and fabrication of low cost moisture sensors using gypsum blocks in a simple electronic circuit using an LED as an indicator (Das et al., 2011; Erbach, D.C., 1983)**.** The study was also focused on analyzing pH, electrical conductivity, sodicity and nutrient content of soil. The effect of organic and chemical fertilizers on soil moisture content was also studied.

MATERIALS AND METHODS

Study area:

The soil samples were collected from two sites viz., the main campus and the satellite campus of Lady Doak College, Madurai. The Latitude and Longitude of the main campus and satellite campus are 9.9378099°N - 78.131304°E and 10.051780°N- 78.147228°E, respectively. The map of the study area is shown in Fig.1.

Soil sampling and analysis

The representative soil samples were collected from both the main and the satellite campus at different sites in a zigzag random fashion at a depth of 2 feet. A composite sample of about 1 kg was taken by mixing each of the soil samples separately. All composite samples were dried, ground and sieved. The samples were then stored for laboratory investigations and used for the analysis of various physico -chemical parameters viz., pH, electrical conductivity, N, P, K, Na, Ca, Mg and Fe (Walworth J.L., 2010).

pH

Acidity or alkalinity of a soil can be determined by measuring the soil pH. The soil sample is mixed with water and left for equilibration for at least an hour, and then the pH was measured. There are several factors which affect the pH measurement. The salt concentration of a soil is one among these. It may vary with the season or with fertilizer application, and is generally greater immediately after fertilizer application than before.

pH values were determined using digital pH meter for which 20g soil sample was mixed with40ml distilled water in 1:2 ratio. The resulting suspension was stirred intermittently for 30 minutes with glass rod and allowed to stand for one hour. The pH values were recorded by inserting combined electrode into the supernatant solution (Hendershot. W. H et al., 2008).

Electrical Conductivity (EC)

The level of soluble salts present in the extract can be determined using EC value. The standard method is to saturate the soil sample with water, filter to separate water from soil, and then measure EC of the saturated extract. The result is referred to as EC and is expressed in units of deci Siemens per meter (dS/m) (Wagh G. S. et al., 2013).

EC is a very reliable test for soil salinity. The electrical conductivity values of the soil samples were determined by using digital Equiptronics conductivity meter Model EQ 664A,for which 20g soil was shaken with 40ml distilled water. This 1:2 soil water suspension was filtered through Whatmann No. 41 filter paper. The suspension was then stirred intermittently for complete dissolution of soluble salts and was allowed to stand for 30 minutes. After the soil settled, conductivity cell was inserted into the solution to record the EC values.

Nitrogen (N) , Phosphorus(P) and Potassium(K) levels in soil.

Nitrogen, Phosphorus and Potassium levels in soil were determined using luster leaf test kit (Agarwal et al., 2013) which uses colour comparators (Fig2.).

Analysis of Exchangeable cations

The four major exchangeable cations present in soil samples are K, Ca, Mg, and Na. All of them are essential plant nutrients except Na but it plays an important role in soil physical properties. It is required for calculations of cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) (Peacock, W.et al., 2000).The level of sodium and potassium present in soil samples were determined using Flame Photometer while the levels of Ca and Mg were determined using Atomic absorption Spectrophotometer (Jayanthi Kalaivani G et al., 2010).

Sodicity

Soil sodicity is generally characterized by exchangeable sodium percentage (ESP) based on sodium saturation of cation exchange capacity (CEC).

Cation Exchange Capacity (CEC)

Cation exchange capacity is often determined by summing the major exchangeable cations (K, Ca, Mg, and Na).

$$CEC = [K + Ca + Mg + Na] \quad (1)$$

Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR)

ESP and SAR are measures of soil Na content relative to other cations present in soil. ESP is the concentration of Na divided by the CEC.

$$ESP = Na/ [K + Ca + Mg + Na] \quad (2)$$

The sodium hazard of soil is expressed as the Sodium Absorption Ratio (SAR).SAR is roughly comparable to ESP, but is a ratio of Na to Ca plus Mg. SAR is calculated as follows:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad (3)$$

The concentration of metal ions in this equation are expressed in milli equivalents per liter (meq/L) and are converted from ppm by dividing it by 23 for Na^{+}; 20 for Ca^{2+}; and 12.2 for Mg^{2+}.

Water samples from both campuses were collected and tested for pH, TDS, conductivity and for the presence of sodium, potassium and calcium (Majid, H. et al., 2009; Mc kim, H.L. et al., 1986). For water samples, the values for EC and TDS are related to each other and can be converted with an accuracy of about 10% using equation (4)

$$TDS\ (mg/l) = 640 \times EC\ (dS\ m^{-1} \text{ or } mS\ cm^{-1}) \quad (4)$$

Fabrication of soil moisture sensor

Fabrication of Gypsum blocks

A long transparent plastic tube of 2cm diameter was cut into small tubes of 2 inch height each. A slant cut was made longitudinally in each tube with a knife and then stuck with tape for easy removal. This was serving as the mould. A mixture of 1:1 ratio of Plaster of Paris and water was made and poured into the tubes without air bubbles. Galvanized nails of 1.5 inch were carefully placed inside the mould such that there was no contact between the nails and one fourth of each nail was projected outward. These served as electrodes (Fig 3.). The entire set up was left to set for 24 hours after which the plastic tube was removed. Six such blocks were fabricated.

Calibration of the gypsum blocks

The prepared blocks were calibrated using the oven-drying technique which was the most widely used of all gravimetric methods for measuring soil moisture(Evangel, V. 1998 ; Ferdo S. et al., 1994; Gardner, W.H.1986), blocks were labeled, soaked in distilled water for 24 hours and then weighed. The block acts as one of the resistors of a two resistor voltage divider circuit and the voltage developed across it was measured. The resistance corresponded to a moisture content of 100%. A constant resistor of 27 KΩ and a supply voltage of 5V were used for this voltage divider circuit (Fig.4)

The water content in the blocks was gradually removed by drying them in hot air thermal oven, at about 40°C. At every stage the block was weighed and its percentage wetness was determined using the following formula,

$$\%\ \text{wetness} = \frac{m_{wet} - m_{in}}{(m_{wet} - m_{dry})} \times 100\ \% \qquad (5)$$

Where m_{wet} (g) is the mass of the fully wet block, m_{in}(g) is the mass of the block at a given time, m_{dry}(g) is the mass of the completely dry block.

The resistance of the gypsum blocks was calculated from the formula

$$R_{gyp} = \frac{R_1}{\frac{V_S}{V_{gyp}} - 1} = \frac{27\ K\Omega}{\frac{5}{V_{gyp}} - 1} \qquad (6)$$

Design of Sensor Circuit

The moisture content sensor circuit is basically a comparator built using an LM339 as shown in Fig 5. With the premise that a plant should not be left to wilt completely, 30% wetness was chosen as the reference. An LED connected to the circuit glows when the moisture content falls below 30%.The circuit was built first on a breadboard after which it was mounted on a PCB. The value of R_3 was chosen from the calibration curve obtained, so that the LED glows when the moisture level drops to 30%.

The gypsum in the designed sensor was then soaked in distilled water for 24 hours before installation to remove any air from the pores and kept such that its base was 3 inches beneath the top layer. The time for which water was retained (Campbell J.M et al., 1993),was observed by noting the time after which the LED lights up. A comparative study was made by using different kinds of fertilizers for both the soil samples with distilled water and water from the respective locality.

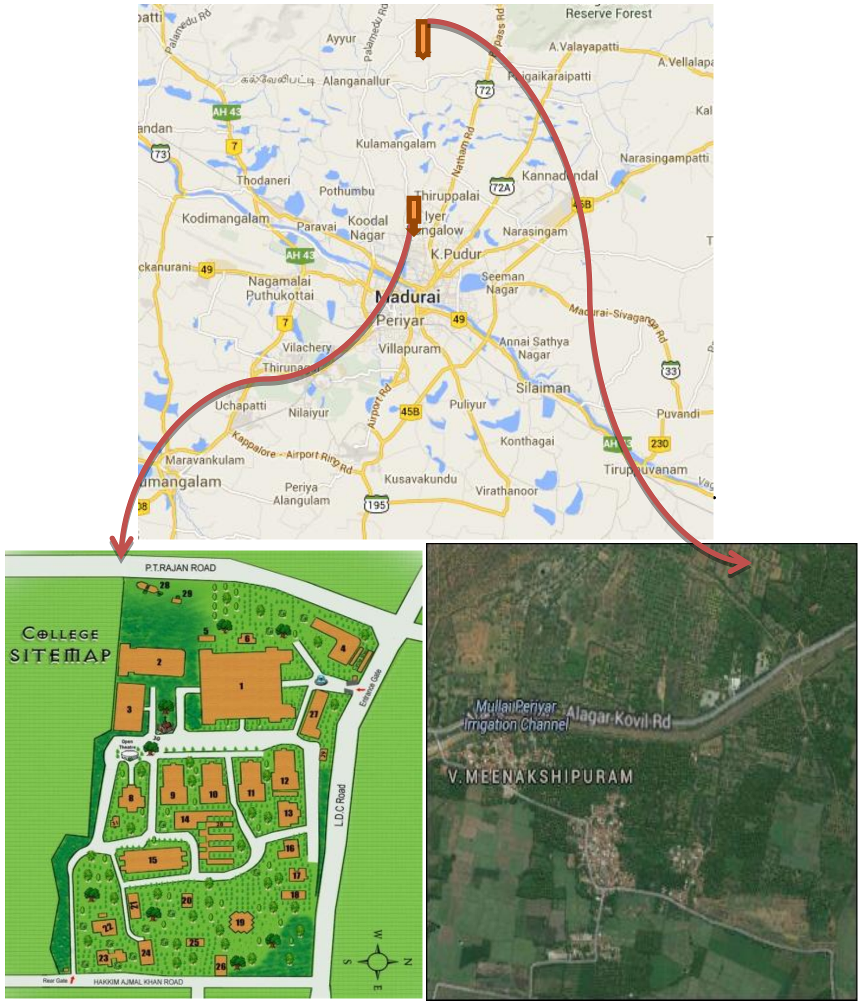
RESULTS AND DISCUSSION

Physico chemical characteristics of soil and water samples:

The pH (7.4 to 7.7) and EC (0.26 to 0.65 dSm^{-1}) values indicated that soil samples were found to be moderately alkaline and slightly-saline in nature. If the SAR is above 13, the soil is classified as sodic (Table 3). However, sodium can cause soil structure deterioration and water infiltration problems at SAR levels below 13 in some cases. In the present study, the SAR values were less than 13, hence the soil samples were classified as non-sodic. The severity of symptoms with high SAR soils depends upon many site specific factors including soil type, texture, drainage conditions and irrigation water quality. An ESP (exchangeable sodium percentage) of more than 15% is sometimes used to classify a soil as sodic (Davis J. G et al., 1996). In the present study, the ESP values were found to be below 15% indicating that the soil samples were non-sodic. SAR values also support this observation.

The result of the observations of the content of nitrogen, phosphorous and potassium was collected in table 1. It was concluded that the main campus soil was found to have excess amount of nitrogen and phosphorous contents and adequate amount of potassium content. The satellite campus soil was found to be more electron rich in comparison with that of main campus.

The K, Ca, Mg and Fe content in both soil and water samples were found to be less compared to that of Na.

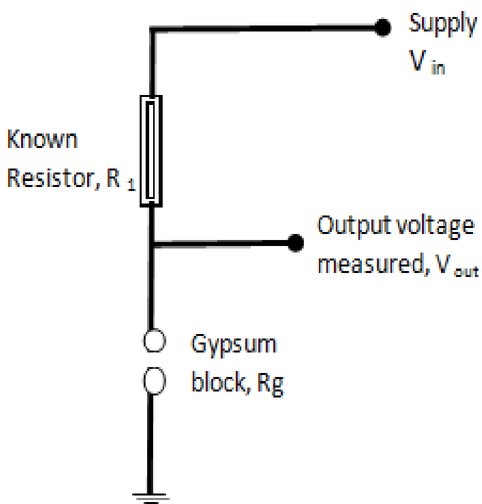


(a) (b)

Fig. 1.Map of study area(a) satellite campus and (b) main Campus

Fig.2. Soil testing kit

Fig 3. Gypsum blocks



$$Rg = \frac{R1}{\left(\frac{Vin}{Vout} - 1\right)} \text{ in } \Omega$$

Fig 4. Circuit for calibration

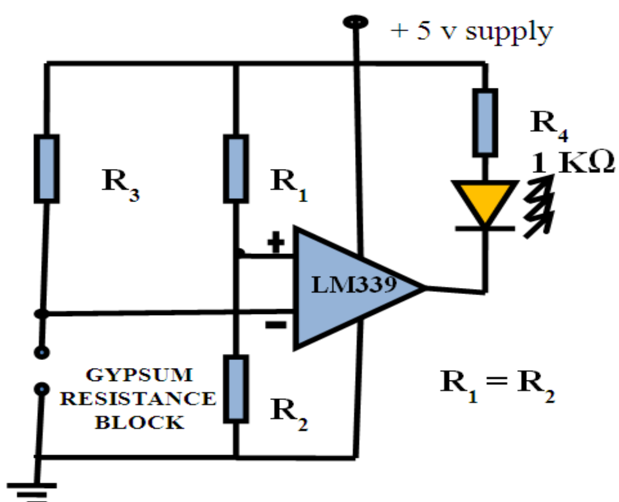
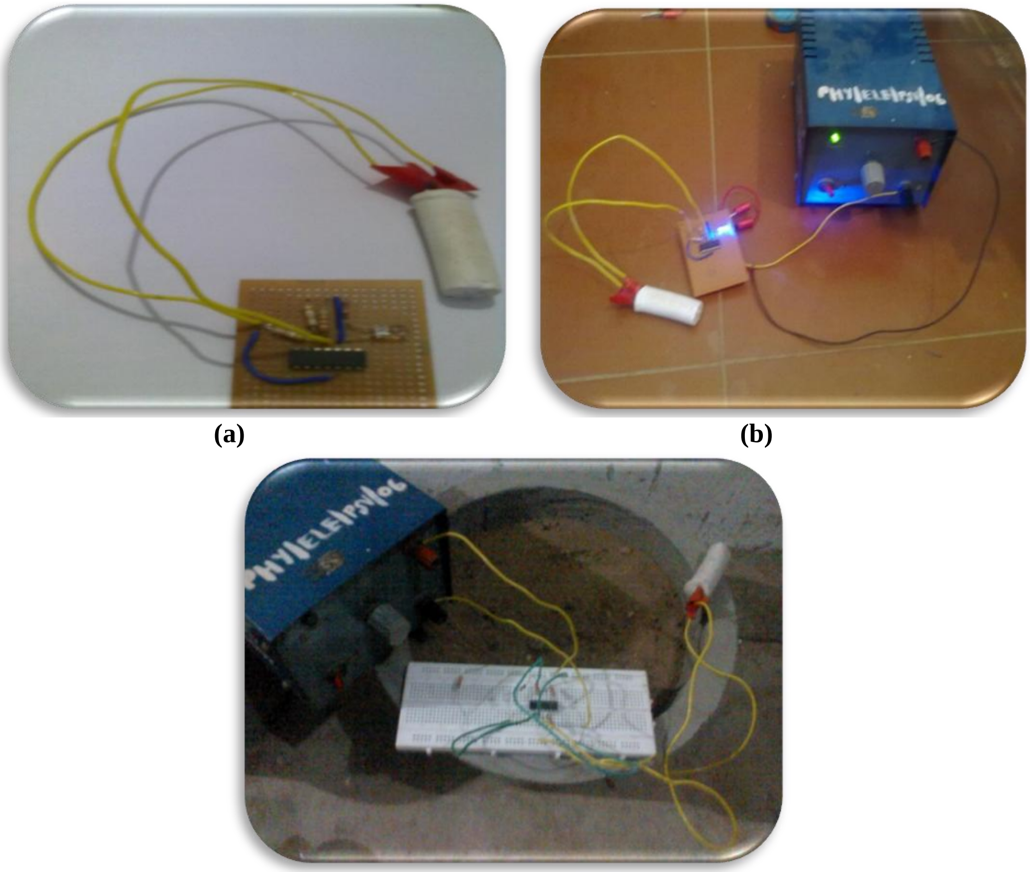


Fig.5. Sensor circuit



(a) (b)

(c)

Fig.6. (a) Circuit on PCB board and (b) Working board and (c) Circuit before installation

Table 1.Effect of fertilizers on NPK levels of soil samples.

SAMPLE		**NITROGEN**	**PHOSPORUS**	**POTASSIUM**
MAIN	Control	Adequate	Adequate	Deficient
	Chemical Fertilizer	Surplus	Surplus	Adequate
	Organic Fertilizer	Surplus	Surplus	Adequate
SATELITTE	Control	Surplus	Surplus	Deficient
	Chemical Fertilizer	Surplus	Surplus	Adequate
	Organic Fertilizer	Surplus	Surplus	Adequate

Table 2 : Physico-chemical parameters of soil and water samples.

AREA	SAMPLE	TDS (ppm)	Amount (ppm)				
			Na	K	Ca	Mg	Fe
Main campus	Water	1601	7.2	0.91	4.8	10.39	0.00
Satellite campus		620	28.6	8.6	20.3	9.82	0.00
Main campus	Soil	164.4	110.8	12.7	42.4	12.11	0.11
Satellite campus		415.7	320.9	17.5	46.2	13.23	0.56

Table 3. pH, EC and SAR of soil and water samples.

AREA	SAMPLE	pH	EC (dS m^{-1})	CEC	ESP	SAR
Main campus	Water	6.8	2.50	23.3	0.30	-
Satellite campus		7.5	0.97	67.3	0.42	-
Main campus	Soil	7.4	0.26	178.0	0.62	3.80
Satellite campus		7.7	0.65	397.8	0.80	10.71

Calibration of soil moisture Sensor:

Gypsum blocks were buried in the soil to achieve good contact with the soil. The moisture content of the block varied with soil moisture. As the soil samples get dried, water was drawn from the block. When the soil becomes wet, water was drawn back into the block.

The resistance of the six gypsum blocks labeled A, B, C, D, E and F for different moisture content recorded in table 4and the calibration curve for each of the blocks is depicted in Fig.7. From the curves it is evident that all the blocks behave in a similar fashion except for some minor variations which can be attributed to differences in the fabrication process. The Resistance R_3 to be used in the sensor circuit was read offfrom these curves at a moisture content of 30%. These values were indicated on the corresponding curves.

The time taken by the gypsum block embedded in the soil to retain 30% of its maximum moisture from an initial of 100% was observed. This was indicated by lighting of the LED. These observations were depicted as a histogram in Fig.8.The first two sets of the histogram represent the behavior of the control and sample at main campus while the next two sets indicated the same for soil samples collected from the satellite campus. The control in both cases was watered with distilled water. The samples were then watered with water from the respective campuses to identify the uptake of the water that would be used in the respective campuses for irrigation. Samples with and without fertilizers (both chemical and organic) were considered.

In the absence of fertilizer, not much difference in the water retention properties of the soil for the control and the locality water was observed. It was found that the moisture retention capacity was more for soil in satellite campus as compared to that in the main campus. The change in moisture retention on average remains the same on addition of urea but increases considerably on the addition of vermicompost – the increase being much greater in the soil from the main campus as compared to that from the satellite campus. This indicates that an additional benefit of using organic fertilizers is that the ability of soil to retain water for a longer time can help in the conservation of water.

The developed sensor was found to be effective in monitoring the level of soil moisture. Such a sensor can be used in farm fields not only to monitor the soil moisture level but also to conserve the water. It was found to be cost effective too.

Table 4.Calibration of Gypsum Blocks by Oven dry Technique.

BLOCK	WT OF BLOCK IN GRAMS	MOISTURE IN %	VOLTAGE ACROSS BLOCK IN V	RESISTANCE IN KΩ	BLOCK	WT OF BLOCK IN GRAMS	MOISTURE IN %	VOLTAGE ACROSS BLOCK IN V	RESISTANCE IN KΩ
A	31.73	100	0.27	1.45	D	32.58	100	0.35	1.9
	31.29	90.6	0.31	1.68		32.15	91.2	0.36	1.96
	30.30	69.6	0.33	1.8		31.25	73.2	0.44	2.44
	28.93	40.5	0.36	1.97		29.72	41.97	0.48	2.68
	28.17	24.4	0.40	2.2		28.91	25.5	0.50	2.81
	27.40	8	0.69	4.04		28.02	7.7	0.86	5.23
	27.13	2.3	1.2	7.9		27.75	2	2.11	17.85
	27.02	0	5.15	300		27.65	0	5.15	900
B	32.31	100	0.36	1.97	E	32.05	100	0.23	1.22
	31.86	91.5	0.37	2.02		31.66	92.1	0.30	1.62
	30.93	74.1	0.40	2.2		30.71	72.92	0.33	1.81
	29.32	43.5	0.52	2.94		29.31	41	0.42	2.32
	28.38	25.7	0.60	3.45		28.31	24.6	0.58	3.25
	27.44	7.93	1.20	7.9		27.43	6.67	0.90	5.52
	27.12	2.07	2.04	16.9		27.19	2	2.68	27.6
	27.06	0	5.13	680		27.10	0	5.15	900
C	30.51	100	0.68	3.97	F	30.37	100	0.28	1.50
	30.12	92.7	0.72	4.24		30.01	91.67	0.28	1.50
	29.15	74.9	0.77	4.59		29.19	72.7	0.31	1.68
	27.44	43.4	0.80	4.8		27.42	31.2	0.37	2.03
	26.52	26.5	0.93	5.74		26.77	16.08	0.45	2.56
	25.37	5.3	1.0	6.35		26.22	3.26	0.90	6.28
	25.13	1.1	4.00	18.0		26.10	2.7	4.95	38.18
	25.08	0	5.15	810		26.08	0	5.15	900

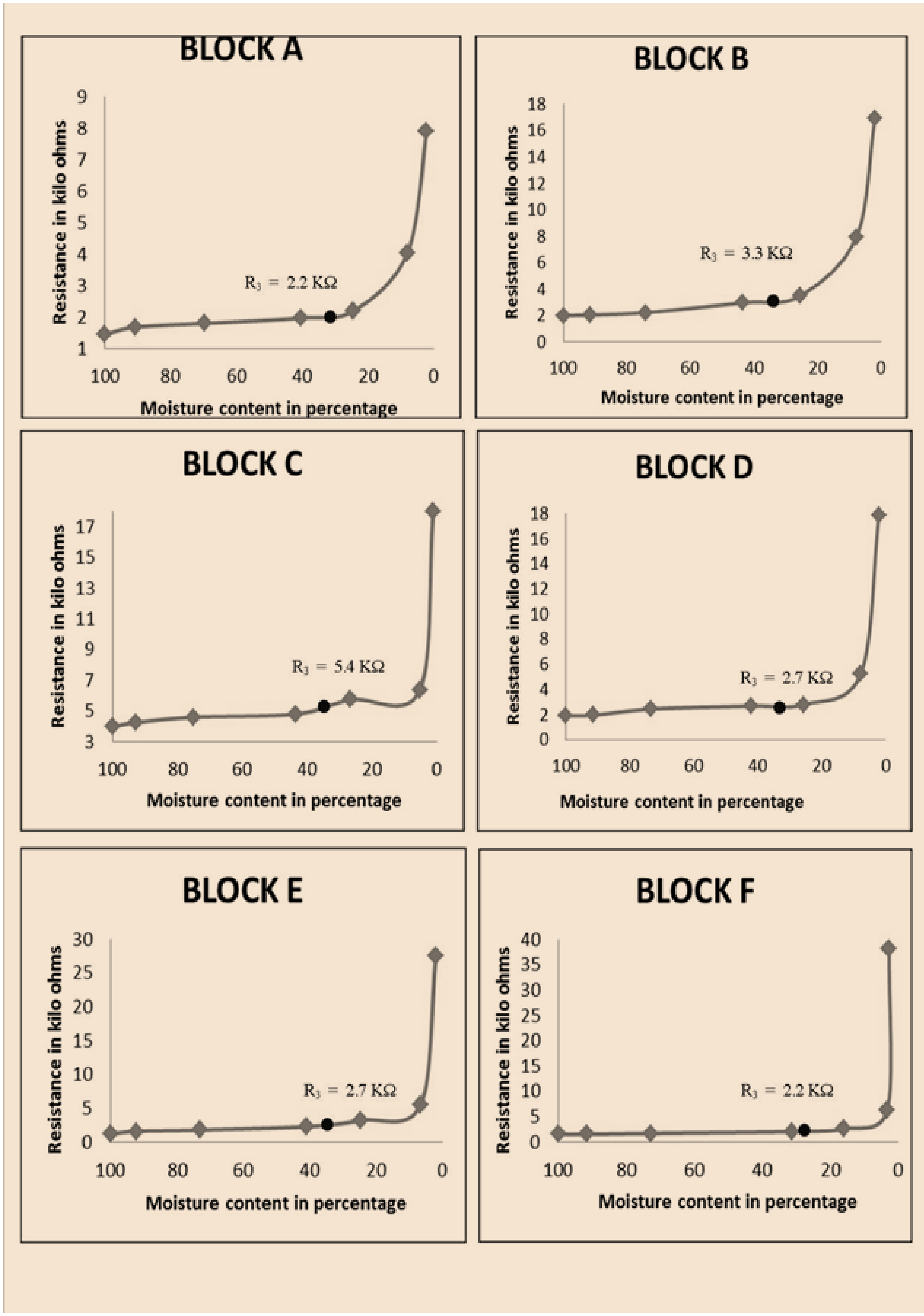


Fig.7. Calibration curves of the gypsum blocks

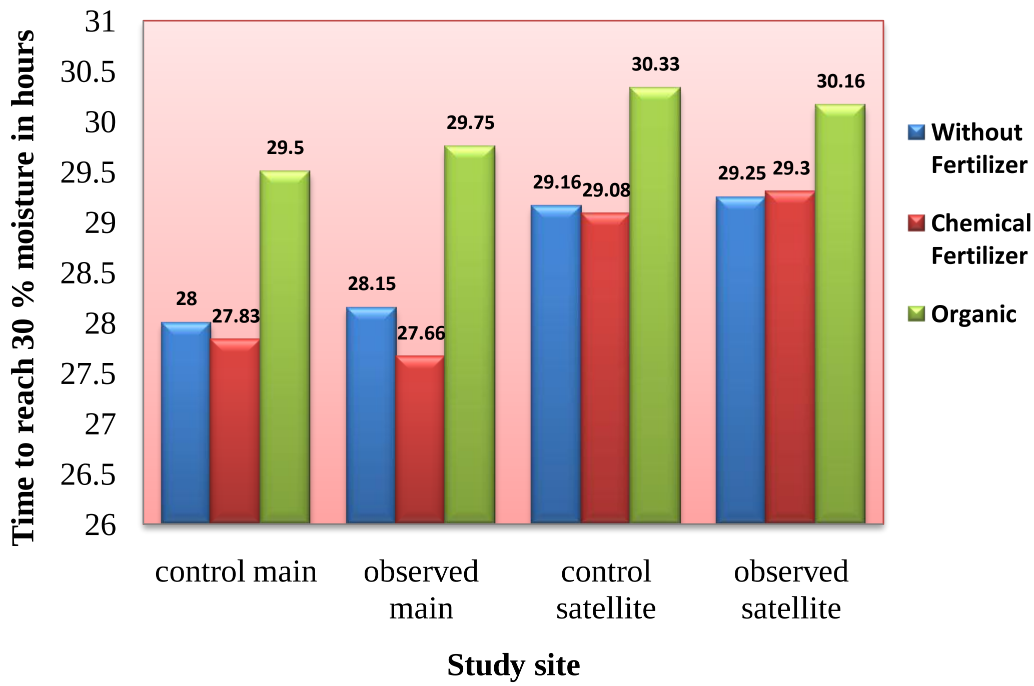


Fig.8. Effect of soil type, water type and Fertilizer on the moisture retention capacity of soil.

CONCLUSION

Gypsum blocks were effectively used to sense the moisture retention capacity of the soil samples. The fabricated sensor was found to be both cost effective and efficient. The type of soil samples taken for the study was found to be slightly alkaline and slightly saline. Analysis of soil nutrients will help in supplementing the soil with the essential nutrients through suitable fertilizer recommendations. Monitoring the soil moisture will help in the uptake of the essential nutrients by the soil. Hence sensing the soil moisture content along with analysis of nutrients in soil will help not only in improving the crop growth but also in conserving water.

ACKNOWLEDGEMENT:

The authors greatly acknowledge the Management, the department of Physics and the department of Chemistry, Lady Doak College, Madurai, for providing the necessary facilities to carry out the study.

REFERENCE:

Agarwal, Arsh, Bradford, Allie Cheng, Kerry Dewan (2013). Interactive effects of plant species and organic carbon on nitrate removal in chesapeake bay treatment wetlands, Digital Repository at the University of Maryland .http://hdl.handle.net/1903/13888.

Armstrong, C. Fletcher, J.T. Ligon and M.F. Mcleod.(1987). Automated system for detailed measurement of soil water potential profiles using watermark brand sensors. International Conference on Measurement of Soil and Plant Water Status.Utah State Univ: 201-206.

Campbell J.M, Clause (1993). Using gypsum blocks to measure soil moisture in vineyards, Department of agriculture & food Farm note.3: 98

Das, Subir(2011).Design and fabrication of a soil Moisture meter, Agricultural water Management Journal :1.

Davis J. G , R.M Waskom T.A Bauder(1996). Managing sodic soils, Colorado State University.

Erbach, D.C(1983).Measurement of soil moisture andbulk density. ASAE, 83-153.

Evangel, V(1998).Environmental soil and water chemistry, John Wiley& sons, NewYork.

Ferdo S. Zazuet A &JiannongXin(1994). Soil moisture sensor, University of Florida, Bulletin: 292

Gardner, W.H.(1986).Water content, In Methods of Soil Analysis.Part 1. Physical and mineralogical Methods, Agronomy Series No. 9. Am. Soc. Agronomy, 2nd edition: 493-544.

Heidi Mittelbach , Irene Lehner, Sonia I. Seneviratne(2012).Comparison of four soil moisture sensor types under field conditions in Switzerland, Journal of Hydrology 430–431:39–49.

Hendershot. W.H Lalande. H (2008). Soil sampling and methods of analysis, Second edition,McGill University, Canada.

Jayanthi Kalaivani G, Mahalakshmi S and Sridevi V.(2010). Analysis of macro and micro nutrients in Soolapuram soil of Usilampati, Tamil Nadu, Journal of current sciences. 15(2) .

Kumar M and A. L. Babel (2011) , Available Micronutrient Status and Their Relationship with Soil Properties of Jhunjhunu Tehsil, District Jhunjhunu, Rajasthan, India,Journal of Agricultural Science..3:2.

Majid,H. A., N. Razali, Sulaiman, M. S (2009). Water measurements, world Academy of science, Engineering and Technology. 55:636-639.

Mckim, H.L., J.E. Walsh and D.N. Arion, Gardner, W. H. (1986).Water content. In:Methods of Soil Analysis, part 1. Physical and Mineralogical Methods. Agronomy Series, 9 Am. Soc. Agronomy, 2nd edition:493-544.

Patrick Lavelle, Alister V.(2007). Spain.Soil Ecology, first edition, Springer private limited, New Delhi.

Peacock, W. and Christensen, L.P(2000). Interpretation of Soil and Water Analysis,Raisin Production Manual, University of California Division of Agricultural and Natural Resources Publication. 3393

Udom B.E and Akamigbo F.O.(2010). Changes in soil water characteristics and salinity hazards in spent oil-contaminated soil bioremediated with legumes andOrganic waste. Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension. 9: 1119-7455

Wagh G. S. Sayyed, M. R. G,(2013). Assessment of Macro and Micronutrients in Soils from Panvel Area, Maharashtra, India, Universal Journal of Environmental Research and Technology.3(1):72-78

Walker, Jeffrey P. and Houser, Paul R(2002). Evaluation of the ohm mapper instrument for soil Moisture measurement, Soil Science Society of American Journal. 66: 728-734.

Walworth J.L(2010). Soil sampling and analysis, the University of Arizona, College of Agriculture and life science: AZ1412