IRJSE *Int. Res. J. of Science & Engineering*, 2018; Special Issue A2: 76-82
ISSN: 2322-0015
SJIF Impact Factor 4.11
UGC Approved Journal No. 63628
RESEARCH ARTICLE OPEN ACCESS

Relationship between Dielectric Constant and Water Content of Soil from Western Ghat of Maharashtra, India

Dhiware MD[1], Nahire SB[2], Deshmukh Sushant[3]

[1]G.M.D. Arts, B.W. Commerce and Science College, Sinnar, Nasik, Maharashtra, India 422 103
[2]Arts, Science & Commerce College, Ozar (Mig) Dist- Nashik. 422 206 INDIA
[3]J.E.S. College, Jalana, Maharashtra, India 431 203
E-mail:- sushant.d59@gmail.com

Manuscript Details
Available online on http://www.irjse.in
ISSN: 2322-0015

Editor: Dr. Arvind Chavhan

Cite this article as:
Dhiware MD, Nahire SB, Deshmukh Sushant. Relationship between Dielectric Constant and Water Content of Soil from Western Ghat of Maharashtra, India, *Int. Res. Journal of Science & Engineering,* January 2018; Special Issue A2 : 76-82.

ABSTRACT

Microwaves play important role in the moisture detection in soil, plants and other agricultural products. Electrical properties such as dielectric loss, dielectric constant of soils has been measured at an automated x band microwave setup in TE_{10} mode operating at 9.56 GHz. It is measured for different moisture content. Soil samples are collected from agricultural land of Western Ghat of Maharashtra. Soil samples were analyzed for physical and chemical properties for the status of available micro nutrients. The measurement is very sensitive to volumetric water content. It is observed that there is slow increase in dielectric constant at lower per cent of water content, whereas it increases sharply at higher water content and becomes constant at certain value of water content in soil. It is observed that dielectric constant increases with increase in moisture content slowly up to transition moisture then it increases rapidly with increase in moisture content. The result shows the change in the electrical properties of soil before and after the addition of water. Also dielectric loss is directly proportional to the ac microwave conductivity and transition temperature. It has been found that emissivity decreases with increase in moisture content. In the field of remote sensing and agriculture, results obtained are useful.

Keywords: Moisture content, Dielectric constant, Dielectric loss, Micronutrients, Microwave frequency

INTRODUCTION

Soil is the loose collection of broken and chemically weathered rock mixed with organic and living matter on the earth’s surface capable of supporting plants. Contrasts in texture are common in soils formed from alluvium where watercourses have deposited layers of sand and silt. Varying texture with depth usually indicates a soil may have formed one or more materials. With mineral soils the top soil is often dark in color, due to partially decomposed organic matter from plant and animal remains known as humus. Below the top soil is subsoil which may be various colors such as red, yellow, white, brown, orange or even blue. The upper half of the subsoil often differs in color from that of the lower half. Subsoil may also have mottles or blotches of another color through it. The arrangement and organization of soil particles in the soil, and the tendency of individual soil particles to bind together in aggregates. Soil moisture and roughness parameters play a key role in hydrological and climate studies. All essential elements are by definition required for plant growth and completion of the plant life cycle from seed to seed. Some essential elements are needed in large quantities and others in much smaller quantities. However, from a practical standpoint, three of the six essential macronutrients are most often "managed" by the addition of fertilizers to soils, while the others are most often found in sufficient quantities in most soils and no soil amendments are required to supply adequate supplies. From a management perspective only, the **primary nutrients** are N, P, and K, because they are most often limiting from a crop production standpoint. All of the other essential macronutrient elements are **secondary nutrients** because they are rarely limiting, and more rarely added to soils as fertilizers. Whether a macronutrient or micronutrient, or whether a primary or secondary nutrient, the most growth-limiting nutrient will limit growth, no matter how favorable the nutrient supply of other elements. For example, a deficiency of Fe or Mn (most common in soils containing calcium carbonate) can severely limit plant growth in spite of adequate N, P, and K. The ability of soils to supply secondary nutrients to plants indefinitely is subject to the law of conservation of matter and is therefore dependent upon nutrient cycling. Continued crop removal of Ca, Mg, and S requires replenishment just as surely as primary nutrients, but most likely less frequently. Calcium and magnesium are often supplied by mineral weathering, either of natural soil materials or of **aglime**, ground limestone added to correct soil acidity. Sulfur is often added to soil as either atmospheric deposition (associated with air pollution) or as impurities in fertilizers, particularly common P fertilizers.

Soil colour gives an indication of the various processes going-on in the soil as well as the type of minerals in the soil. For example the red colour in the soil is due to the abundance of iron oxide under oxidised conditions (well-drainage) in the soil; dark colour is generally due to the accumulation of highly decayed organic matter; yellow colour is due to hydrated iron oxides and hydroxide; black nodules are due to manganese oxides; mottling and gleying are associated with poor drainage and/or high water table. Abundant pale yellow mottles coupled with very low pH are indicative of possible acid sulphate soils. Colours of soil matrix and mottles are indicative of the water and drainage conditions in the soil and hence suitability of the soil for aquaculture.

Soil colour is described by the parameters called hue, value and chroma. Hue represents the dominant wave length or colour of the light; value, refers to the lightness of the colour; chroma, relative purity or strength of the colour. The colour of the soil in terms of the above parameters could be quickly determined by comparison of the sample with a standard set of colour chips mounted in a note-book called MUNSELL SOIL COLOUR CHARTS (Munsell Soil Colour Charts, 1973). In these charts, the right hand top corner represents the Hue; the vertical axis, the value; and the horizontal axis, the chroma. Different percentage of fertilizer content in soil gives large variation dielectric constant which is important for efficient use of soil [1]. Calla O. P. N. et. al. (2007) have carried out dielectric study, emissivity, scattering coefficient of dry and wet soils of Rajasthan with different moisture content using Waveguide Cell Method [2]. Microwave remote sensing of natural earth materials such as soil, water and plants has a very close dependence on their electrical parameters. This thesis discusses the use of microwaves and its response to red soils and associated moisture content.

Remote sensing of soil moisture depends on measurement of electromagnetic energy that has been reflected or emitted from soil surface. Bapna and Joshi. [3] studied the dielectric constant at different moisture that whatever be the moisture condition and type of soils, the dielectric constant decreases with increase in frequency. Gadani [4] have studied the effect of saline water on the emissivity of different soils with C band microwave frequency. Chaudhri from his paper [5] explains that a comprehensive study of complex permittivity of soils of Maharashtra and Karnataka state has been undertaken. The dielectric properties of urea and diammonium phosphate fertilizers in aqueous solution at different temperatures in microwave frequency are reported [6]. The characteristics of the soil of Chhattisgarh at X-band frequency are studied using Infinite sample method [7]. Microwave emission depends upon the dielectric constant of the soil [8]. Mohan et al. [9] explores the relevance of usage of microwave frequencies for the dielectric-property extraction of soil. Many important soil processes take place in soil pores (the air or water-filled spaces between particles). As the dielectric permittivity of water is an order of magnitude grater than the corresponding values of soil constituents, changes in dielectric constant can be attributed to change in water content in nonexpanding soils [10]. Due to this increase in soil moisture there is small increase in dielectric constant. The variation in dielectric constant and soil water content with increasing volumetric water for the three samples is very similar to the work of Behari [11], Vyas and Gadani [12], and Srivastava and Mishra [13]. Soil texture and structure influence porosity by determining the size, number and interconnection of pores. Coarse textured soils have many large (macro) pores because of the loose arrangement of larger particles with one another. Fine-textured soils are more tightly arranged and have more small (micro) pores. Macro pores in fine-textured soils exist between aggregates. Because fine-textured soils have both macro- and micropores, they generally have a greater total porosity, or sum of all pores, than coarse-textured soils. In the frequency range from 2 GHz to 20 GHz, Calla et al. [17] measured the complex dielectric constant of loamy sand for various moisture contents by weight. The measurements were carried out using HP network analyzer and an HP dielectric probe employing coaxial probe method. It is observed that the dielectric constant increases slowly up to certain moisture contents after which it increases rapidly. It has been observed that the change in loss factor is more at higher frequencies than that at lower frequency.

METHODOLOGY

The soil samples are collected from Western Ghat of Maharashtra state. Soil samples are collected from different locations of agricultural land at the depth of ranging between 0-20 cm. in zigzag pattern across the one site areas. Five pits were dug for each sample. A composite sample of about 3 to 4 Kg representing one site was taken after thorough mixing of all above soil samples. This procedure was repeated while preparing composite samples representing all ten sites covering Western Ghat of Maharashtra. These topsoil samples are first sieved by gyrator sieve shaker (size 425 µm) to remove the coarser particles. The sieved out fine particles are then dried in the hot air oven to a temperature around 110oC for about 24 hours in order to completely remove any trace of moisture. Such dry sample is then called as oven dry or dry base sample when compared with wet samples. The Physical and chemical properties of the soil are measured at soil analysis laboratory.

A study of soil profile supplemented by physical and chemical properties of the soil will give full picture of soil fertility and productivity. Every soil has its natural fertility, which differs from soil-to-soil. In the world, cropping pattern is not same; it changes from one place to another place with response to types of their soil and its characteristics.

Number of soil samples of different physical and chemical properties are used for study. The field capacity (FC) can be approximated by the empirical formula on soil composition [14].

$$FC = 25.1 - 0.21\ (\%\ Sand) + 0.22\ (\%\ Clay)$$

Wilting coefficient (Wp) is calculated by using the Wang and Schmugge model [15].

$$Wp = 0.06774 - 0.00064\ (\%\ Sand) + 0.00478\ (\%Clay)$$

The details of the land are given in the table below:

Name of the farmer	Survey No.	Area	Latitude	Longitude
Kondaji Khandu Tokade	35	Deole	19°72"39'	73°65"11'
Dinanath Pandurang Bhagat	53	Take(Ghoti)	19°70"42'	73°61"09'
Gopal Dharma Jagtap	7477	Talegaon	19°68"73'	73°55"92'
Arun Haribhau Jadhav	350/3	Alwand	19°71"59'	73°60"86'
Nivrutti Namdeo Chaudhari	572	Khambale	19°74"06'	73°63"78'
Shravan Savliram Potkule	118	Senvad	19°77"82'	73°67"31'
Dashrath Muralidhar Malunjkar	54	Wadiwarhe	19°86"13'	73°67"87'
Kailas Thakaji Mate	375	Morambi	19°85"10'	73°65"52'
Santu Rama Sarai	316/B	Kushegaon	19°86"42'	73°57"87'
Trimbak Kishan Mahale	29	Wanjole	19°83"60'	73°56"66'

The complex dielectric constant is calculated using the relation

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

The two point method described by Altschuler [16] is used for the measurement of dielectric constant (ε′) and dielectric loss (ε′′).

Theory:

The interaction of electromagnetic energy with matter is affected by the characteristics of the material and by the frequency of the electromagnetic energy. Frequency dependent dielectric properties can be characterized in terms of losses of energy due to relaxation mechanisms that operate at different frequencies. The relaxations are caused by different forms of atomic- or molecular-scale resonance [18]. In a soil mixture the relaxation mechanisms may be attributed to the solid material and the pore water as well as to interfacial phenomena.It summarizes some of the different types of relaxation mechanisms that play a role in wet soils. Many geophysical tools for detection of subsurface objects operate in frequency ranges between 0.1 and 10 GHz, which makes bound water relaxation the major resonance mechanism of interest.

Measurement of Dielectric Constant of dry Soil Samples:

The waveguide cell method is used to determine the dielectric properties of the dry soil samples. X-band microwave bench set-up for measurement of dielectric constant of soil samples is used. An automated X-band microwave set-up in the TE10 mode with Reflex Klystron source operating at frequency 9 .56 GHz is used for measuring dielectric constants .PC-based slotted line control and data acquisition system is used for this purpose. The solid dielectric cell with soil sample is connected to the opposite end of the source. The signal generated from the microwave source is allowed to incident on the soil sample. The sample reflects part of the incident signal from its front surface. The reflected wave combined with incident wave to give a standing wave pattern. These standing wave patterns are then used in determining the values of shift in minima resulted due to before and after inserting the sample. Experiments were performed at room temperatures ranged between 25° -35° C. The dielectric constant ε' of the soils is then determined from the following relation:

$$\varepsilon' = \frac{g_\varepsilon + \left(\lambda_g / 2a\right)^2}{1 + \left(\lambda_g / 2a\right)^2}$$

and

$$\varepsilon'' = \frac{\beta_\varepsilon}{1 + \left(\lambda_g / 2a\right)^2}$$

Where, a = Inner width of rectangular waveguide. λ_{gs} = wavelength in the air-filled guide. g_ε = real part of the admittance, β_ε = imaginary part of the admittance

The sample holder for X band measurements was fabricated from the standard waveguides available. At the one end of the sample holder a metallic flange was connected, so that it can be connected to the main line and the other end was shorted. Length of X band is 3 cm. Initially, with no dielectric in short circuited line the position of the first minimum D_R in the slotted line was measured. Now the soil sample of certain length ($l\epsilon$) having certain moisture content was placed in the sample holder, such that the sample touches the short circuited end. Now the position of the first minimum D on the slotted line and the corresponding VSWR, r were measured. This procedure was repeated for another soil sample of same moisture content for another soil sample length ($l\epsilon'$).Now the propagation constant (in the empty waveguide) is calculated as

$$k = \frac{2\Pi}{\lambda g}$$

where λg = 2x (distance between successive minima

with empty short circuited waveguide sample holder). Then, from impedance matching at the air –powder boundary, we obtain

$$\frac{\tan\beta\,(DR-D+l\varepsilon)}{\beta l\varepsilon} = \frac{\tan\,\beta\varepsilon l\varepsilon}{\beta\varepsilon l\varepsilon}$$

Where Phase factor $\beta = (2\pi / \lambda_g)$, λ_g being the guide wavelength for the waveguide containing air.
The phase factor β_ε for the waveguide filled with the dielectric is given by

$$\beta_\varepsilon = (2\pi / \lambda_0)\,\{\varepsilon_r \mu_r - (\lambda_0 / \lambda_c)^2\}^{1/2}$$

Here λ_0 represents free space wavelength, λ_c is the cut off wavelength of the waveguide and for the non-magnetic materials μ_r =1. The phase difference φ in the waves travelling in the guide with and without dielectric material in the cell is given by

$$\varphi = 2\beta\,(\text{“}\ x - l\varepsilon)$$

where x is the shift in minimum.

Voltage standing wave ratio(S) is determined for the load and then magnitude of the reflection coefficient is computed by employing the relation

$$\tau = \frac{s-1}{s+1}$$

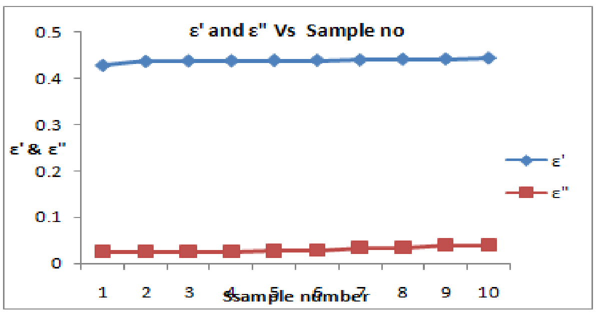
In the two point method, the complex dielectric constant is given by

$$C\,\angle{-\psi} = \frac{1}{j\,\beta\,l\varepsilon}\,\frac{1-|\tau|\,e^{j\varphi}}{1+|\tau|\,e^{j\varphi}} = \frac{\tan X\angle\theta}{X\angle\theta} \quad \text{..........(A)}$$

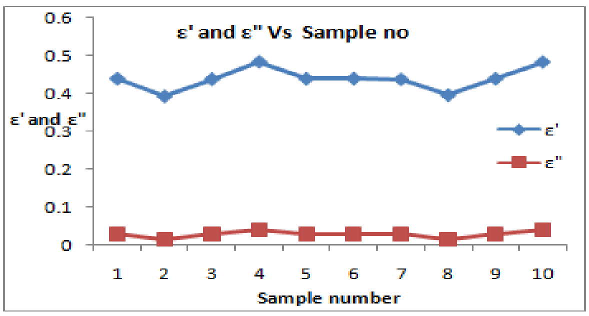
Where, C and Ψ represent respectively the magnitude and phase of the complex quantity in θ represents the∠the middle of Eq. (A) and X solution of this transcendental equation .

This equation provides several solutions for X_θ, which can be found by employing graphs and tables provided for solution of such equations by Hippel [1953] or alternatively the problem can be solved by using a computer based mathematical tool like MATLAB/ M+athematica.

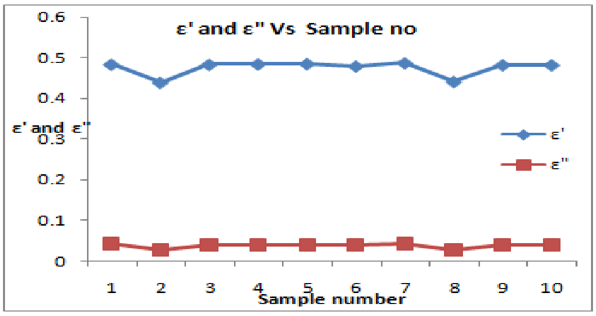
Graphical Representation:
For moisture content below transition moisture in the soil, most water molecules are tightly bound to the soil particles. It is difficult to polarize these bound water molecules and the bulk of water shows a smaller dielectric constant ' ∈ than that of free water [15]. The present values of dielectric constant are in good agreement with the values reported by other authors. It is observed that dielectric constant increases with increase in moisture content slowly up to transition moisture then it increases rapidly with increase in moisture content. The result shows the change in the electrical properties of soil before and after the addition of water.



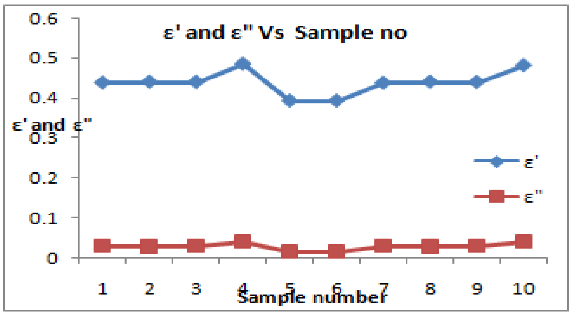
Dry soil



10% moisture content soil



20% moisture content soil



30% moisture content soil

RESULT AND DISCUSSION

Correlation coefficient (r) between soil parameters and regression equations			
Relation of Soil parameters with DC	Correlation Coefficient (r)	Level of significance	Regression Equations
DC(x)-Sand %(y)	0.5123	Positive	y= 31.26x-29.86
DC(x)-Silt %(y)	-0.4682	Negative	y= -21.02+79.66
DC(x)-clay %(y)	-0.4389	Negative	y= -12.18x+50.03
DC(x)-BD (y)	0.3819	Positive	y= 0.132x+1.001
DC(x)-Porosity(y)	-0.4429	Negative	y= -5.963x+63.35

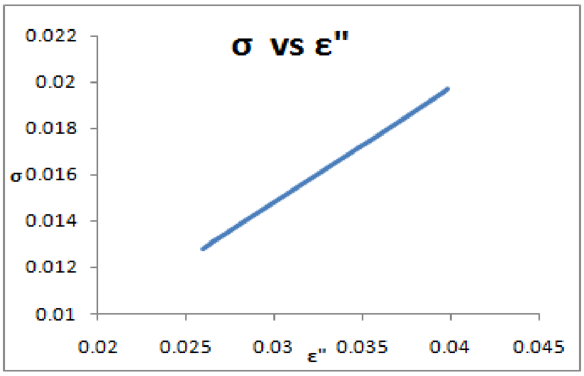


Fig. 2 (a):dielectric loss vs microwave conductivity

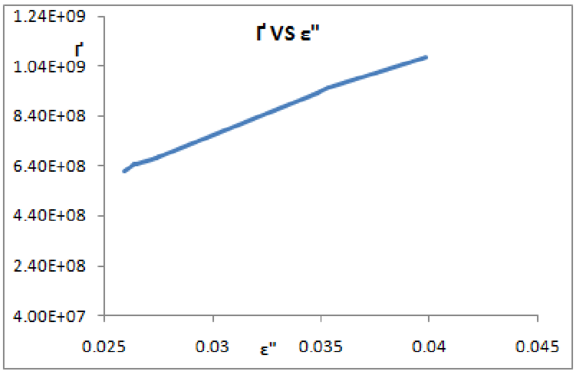


Fig.2 (b) : dielectric loss vs transition temperature

Relation between dielectric constant and percentage of sand, silt, clay in soil :
As per our data, it is observed that dielectric constant of soil has significant positive correlation (r = 0.5123) with percentage of sand and significant negative correlation of dielectric constant with percentage of silt (- 0.4682) and clay (- 0.4389). Also significant negative correlation (-0.4429) with porosity of soil. The graphical of representation shows that, dielectric loss is directly proportional to the ac microwave conductivity and transition temperature.

CONCLUSION

It is observed that there is slow increase in dielectric constant at lower per cent of water content, whereas it increases sharply at higher water content and becomes constant at certain value of water content in soil. The measurement is very sensitive to volumetric water content. The dielectric constant of Western Ghat of Maharashtra soil is dependent on the texture of soil i.e. the percent content of sand, slit and clay. It is observed that the dielectric constant has significant positive correlation with sand content of soil and negative correlation with clay and silt content of soil. The dielectric constant of Western Ghat of Maharashtra soil depend on the bulk density of soil and hence on porosity and wilting point of soil. Dielectric constant has positive correlation with bulk density of Western Ghat of Maharashtra and negative correlation with their porosity and wilting point.

Conflicts of interest: The authors stated that no conflicts of interest.

REFERENCES

1. Yadav Vivek, Kumar Anil, Sharan Sudeep and Sinha AK. Measurement of Dielectric Behavier of Fertilized soil at Microwave frequency", *Journal of Agricultural Science*, 2009; 1(2).
2. Calla OPN, Applications of Microwave in Remote Sensing", A special Issue from IJCA
3. Bapna PC and Joshi S. Measurement of Dielectric Constant of Soils of Marble Mining Areas of Mewar Region, Rajasthan State at X-band. IJETEE3, 66-69 (May-2013.).
4. Gadan DH, A. DV. Measurement of complex dielectric constant of soils of Gujarat at Xand C-band microwave frequencies. *Indian J. Radio Space Phys*., 2008; 7, 221-229.
5. Chaudhri HC. Dielectric Properties of Soils with Inorganic Matter at S-Band Microwave Frequency. IJCPSl 2014 3, 59-66.
6. Vivek Yadav, Anil Kumar, Sudeep Sharan, A.K.Sinha, "Analysis of Dielectric Properties of Fertilizers (urea and diammonium phosphate) in Aqueous Solution at Different Temperatures in Microwave Frequency", *International journal of the physical sciences*, 2010; 5(16), pp. 2466-2470.
7. Srivastava SK and. Mishra GP. Study of the Characteristics of the Soil of Chhattisgarh at Xband Frequency", *Sadhana*, 2004; 29(4), pp. 343-347.
8. Calla OPN, Vivek Ranjan, Chetan Bohra, Naik GL. Estimation of Dielectric constant of soil from the given texture at microwave frequency", *Indian Journal of Radio and Space Physics*, 2004; 33, pp. 196-202.
9. Rajesh. Mohan. R, SM., Mohanan P. Study and Analysis of Dielectric Behavior of Fertilized Soil at Microwave Frequency. *Euro. J. Adv. Engg. Tech*., 2015; 2, 73-79.
10. Bilskie J. Using dielectric properties to measure soil water content, *Sensors Mag*., 1980l 14, 26–32.
11. Behari J. Frequency dependent variation of dielectric parameters of wet soil, Microwave measurement techniques and applications, pp. 71–79, *Anamaya Publishers*, New Delhi (2003).