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Dielectric properties of black soil with chemical fertilizers at X-band

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Dielectric properties of black soil with the addition of chemicals were measured at microwave frequency. The dielectric measurements have been achieved by using X-band set up. The dielectric properties, that is dielectric constant (ε') and dielectric loss (ε'') have been measured for two frequencies (8 and 10 GHz) at room temperature. From the experimental data, it is confirmed that the dielectric constant and dielectric loss increase with increasing percentage volume of chemical fertilizers and decrease with increase in frequency of oscillation. The results also show that the dielectric constant and dielectric loss are higher for the urea than that of potassium carbonate.

Keywords: Dielectric constant, Dielectric loss, Urea, Potassium carbonate, Black soil

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1 Introduction

The real part of complex dielectric constant is an important parameter through which soil water content can be determined. The knowledge of the behaviour of soil water is useful since it affects intensively a number of physical and chemical reactions of the soil as well as plant growth. Amount of water present in a soil plays a vital part in the hydrological cycle as it supplies water for growth of the plant ecosystem. The theoretical basis for soil moisture measurement is based on large contrast between dielectric constant of water (80) and that of dry soil[1,2]. The dependence of dielectric constant on moisture can be measured with time domain reflectometry (TDR), frequency domain reflectometry (FDR) or number of sensors available in the market[3-6].

The soil water content is most important physical property of the soil, which is used to characterize the availability of water for plants. There are variety of techniques and equipments available to measure this. The aim of these methods is either to provide measurement value immediately or to provide value for continuous measurements over large period. All approaches need calibrations for individual soil if absolute values are actually needed and they can have a restricted linearity at high or low moisture ranges. Most alternative methods describe the physical properties of a very restricted solid volume, which then becomes the representative for a large volume. Several reviews of soil water content measurements have been published[7-10].

The aim of the present work is to determine the effect of chemical fertilizers, viz. urea and potassium carbonate, on dielectric properties of soil at microwave frequency, which are useful in microwave remote sensing and increasing agricultural productivity.

2 Theory

Theoretically, dielectric properties of the material depend on the concentration, activity of permanent electrical dipole molecules, ionic conduction and degree of dipole alignment with the applied time varying electric field. Therefore, when sample holder is filled with material, the dielectric properties are affected by the composition of the material and temperature, which affects molecular movement.

The microwave soil dielectric measurement uses absorption of microwave energy corresponding to rotational energy of water molecules. When electromagnetic field is applied to dielectric material, electromagnetic energy is dissipated in dielectric materials as a result of dielectric relaxation process; and the interaction of electromagnetic field depends upon the complex dielectric permittivity relative to the free space.

In an alternating electric field, complex dielectric permittivity varies with applied frequency. This frequency dependence can be described by complex permittivity[11]:

$$\varepsilon^* = \varepsilon' - j\,\varepsilon'' \qquad \dots (1)$$

The real part of the relative complex permittivity (ε′) is called dielectric permittivity and the imaginary part (ε″) is called the dielectric loss factor. The dielectric permittivity describes the ability of a material to store electromagnetic energy, while dielectric loss factor represents loss of electromagnetic field in the material. When a plane wave is incident normally upon a dielectric medium in free space, part of it is transmitted into the medium and part is reflected at the interface between free space and dielectric medium. The dielectric permittivity and loss factor are given by the Eqs (2) and (3) as[11]:

$$\varepsilon' = \lambda^2_O\left[\frac{1}{\lambda^2_c} + \frac{\beta^2 - \alpha^2}{4\Pi^2}\right] \qquad \dots (2)$$

$$\varepsilon'' = \frac{\lambda_0{}^2\alpha\beta}{2\Pi^2} \qquad \dots (3)$$

where, λ_0, is free space wavelength; λ_c, cutoff wavelength; α and β, attenuation and phase constants, respectively and can be obtained experimentally[11]. Using the experimental values in Eqs (2) and (3), the dielectric permittivity (ε′) and loss (ε″) can be determined.

3 Experimental procedure

Roberts & Von Hipple[12] experimental technique was used to measure the dielectric properties of the soil sample. A least squares fit programme of Sobhanaderi[13] was used to determine the dielectric properties. The measurements have been carried out at 8 and 10 GHz frequency. The soil sample under study was collected from Sharnapur, which is 25 - 35 km away from Aurangabad city, having latitude 19°53'N, longitude 75°23'E and altitude 582 m. To get acquainted with the status of the chemical fertilizers of the whole agricultural land, the soil samples were collected from different locations on the farming land, mixed them and used as a composite sample. The collected soil sample was a mixture of sand, silt and clay. The nearby field location was selected to study its physical and chemical properties and effect of chemical fertilizers on the same soil. The analyzed physical and chemical properties of the said soil sample are presented in Tables 1 and 2, respectively.

The soil sample of known volume was placed in the empty dielectric cell and connected to the opposite end of the source of the microwave bench set up. The signal generated from the microwave source was allowed to incident on the soil sample. The soil sample reflects part of the incident signal through the soil from its front surface. The values of power (current) at different points of standing waves have been measured as a function of probe position. About 80–100 points were recorded for a single standing wave pattern.

Firstly, switching on the microwave transmission line waveguide set up, the standing wave pattern was recorded for empty cell. Similar standing wave patterns were recorded for air soil sample. Measurement of air soil sample was repeated at least for three different lengths. The dielectric properties were evaluated for each length and an average value of the three was taken as dielectric constant and dielectric loss of the soil sample. Then the measurements were repeated with increasing percentage volume of chemical fertilizers of the same soil. From the experimental measurements the parameters, $\lambda_0\left(\frac{c}{f}\right)$, $\lambda_c(2a)$, $\alpha(0.05)$ and $\beta\left(\frac{2\pi}{\lambda g}\right)$ were determined. Fitting these parameters in Eqs (1) and (2), the dielectric constant and dielectric loss has been determined, similar to author's previous study[14,15].

Table 1 — Physical properties of the soil

S No	Physical property	Amount present in soil	Remark
1	Coarse sand	16.20 %	
2	Fine sand	8.24 %	
3	Silt	23.31 %	
4	Clay	52.25 %	
5	Water holding capacity	53.80 %	
6	Bulk density	1.30 g cm^{-3}	
7	Soil type		Clayey

Table 2 — Chemical properties of the soil

S No	Chemical composition	Amount present in soil	Remark
1	Organic carbon	0.57 %	Medium
2	Available phosphorus	25.00 Kg $hect^{-1}$	Low
3	Available potassium	349 Kg $hect^{-1}$	Very high
4	Combined calcium	58.24 %	Medium
5	Combined magnesium	14.20 %	Medium high
6	Free calcium carbonate	2.50 %	Medium
7	pH	7.10	Slightly basic
8	Total soluble salinity	0.780	General

4 Results and Discussion

The experimental observations of Sharnapur black soil with increasing percentage volume of chemical fertilizers (urea and potassium carbonate) are presented in Tables 3 and 4, respectively. The increasing percentage volume of urea and potassium carbonate has been added to the soil and the total volume of the mixture (soil + chemical fertilizer) was kept constant. According to the data obtained, the dielectric permittivity decreases with increase in frequency of oscillation. This is because the molecules have harder time to rotate with increasing frequency that reduces its polarization.

From the data noted in Tables 3 and 4, it is observed that the variation in dielectric permittivity is approximately linear with increasing percentage volume of the chemical fertilizers. The added fertilizer may form a chemical composition of low concentration along with the chemicals present in the soil. It has been hypothesized that in the limit of low concentration, the dependence of dielectric permittivity is approximately linear. The results are in agreement with the results of electrolyte given by Hasted[16].

Table 3 — Variation in dielectric constant and dielectric loss of the black soil with urea

Percentage volume of urea	8 GHz		10 GHz	
	ε'	$\varepsilon'' \times 10^{-2}$	ε'	$\varepsilon'' \times 10^{-2}$
0	4.82	63.71	3.92	10.59
2	4.88	67.45	3.98	15.06
4	4.96	69.19	4.01	18.75
6	5.11	71.12	4.09	20.05
8	5.36	76.38	4.20	25.67
10	5.52	80.21	4.51	28.79
12	6.18	88.62	4.83	32.04
14	6.67	91.23	5.01	37.37
16	7.30	98.16	5.31	41.15
18	7.82	100.30	5.58	48.09
20	8.48	112.60	6.04	51.21

Table 4 — Variation in dielectric constant and dielectric loss of black soil with potassium carbonate

Percentage volume of potassium carbonate	8 GHz		10 GHz	
	ε'	$\varepsilon'' \times 10^{-2}$	ε'	$\varepsilon'' \times 10^{-2}$
0	4.82	63.71	3.92	10.59
2	4.82	66.23	3.97	12.02
4	4.85	69.42	4.03	15.63
6	4.88	69.87	4.07	18.26
8	4.92	70.02	4.12	20.13
10	4.96	74.20	4.17	24.24
12	5.00	79.26	4.22	27.16
14	5.41	80.23	4.27	31.21
16	6.06	85.16	4.31	37.87
18	6.82	88.27	4.49	41.03
20	7.33	90.23	4.60	49.97

The experimental values noted in Tables 3 and 4 confirm that the dielectric permittivity is higher for urea than that for potassium carbonate. This may be because the added urea decomposes very slowly as compared to the potassium carbonate. When urea is added to soil, it may work like an organic matter added to soil and decays to humus. The humus molecules form cement particles of sand, silt, clay and organic matter into aggregates, which will not breakdown in water. The cementing effect, together with weaving and binding effects of roots and fungal strands in decomposing organic matter, makes the soil aggregates stable in water or improve its water holding capacity. The dielectric permittivity directly depends on amount of water present in the soil. Therefore, the increase in dielectric permittivity is higher for urea than that for potassium carbonate. The results are in good agreement with the earlier results[17-20].

The experimental reported results show lower values of dielectric permittivity with the addition of potassium carbonate. Because slightly strong chemical reaction may takes place in the soil due to the addition of potassium carbonate. Even though the soil was air dried, it still contained an unknown and unspecified amount of water (hygroscopic and crystal-bound water) that was approximately equal to 0.2% volumetric. Therefore, the soil used for the experimental work was fertile moist soil. Also, the potassium carbonate may decompose quickly with the chemicals present in the soil and form a stronger electrolyte compound. As per the theory of electrolyte, there is decrease in dielectric permittivity with higher concentration. These results are also in agreement with the results of electrolyte given by Hasted[16].

From the reported results, it is also observed that the dielectric loss (ε'') of the studied soil increases with increasing percentage volume of chemical fertilizers and its nature is same for both the frequencies studied. The dielectric loss is a parameter, which describes the motion of electric charge, i.e. a conduction phenomenon. Certain dielectrics are found to display conduction, which arises not from the effect of polarization on the displacement current but from the actual charge transport (the ionic conduction in electrolytes). Such conduction is normally described by volume conductivity, and the effect of it may be to add an additional term to the dielectric loss[16].

The dielectric loss of the studied soil decreases with increase in frequency of oscillation. This is due to volume conductivity. The volume conductivity is inversely proportional to the frequency. The same has been observed from the experimental results noted in Tables 3 and 4.

5 Conclusion

Variation in dielectric constant and dielectric loss of black soil sample has been reported with the addition of the chemical fertilizers, like urea and potassium carbonate at 8 and 10 GHz frequencies. The dielectric constant and dielectric loss of the soil decrease with increasing frequency of oscillation. The dielectric constant and dielectric loss of the soil increase with the addition of percentage volume of urea and potassium carbonate. But the variation is higher for urea than for potassium carbonate. The dielectric loss (ε'') of the studied soil increases with increasing percentage volume of chemical fertilizers and decreases with increasing frequency of oscillations. This may be due to the volume conductivity.

Such study of soil is useful in microwave remote sensing and agriculture in order to increase its productivity.

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