Effect of Chemical Fertilizers on Dielectric Properties of Soils at Microwave Frequency

VidyaD.Ahire*, D.V.Ahire*^ and P.R.Chaudhari*

*Microwave Research Laboratory, Department of Physics, Z. B. Patil College, Dhule - 424002, India

Email: dvahire@rediffmail.com (Correspondence Author)^

***Abstract*-**Fertilized black soil samples are prepared by mixing desired amounts of fertilizers in the black soils having 10% gravimetric moisture content. Two black soil samples were collected from two different locations of Maharashtra State (India). Three different chemical fertilizers viz., Urea, Di-Ammonium Phosphate and Potash are used. Measurements of complex dielectric constants of these soil samples have been carried out at C-band microwave frequency 4.6 GHz by using waveguide cell method. The average values of dielectric constant and dielectric loss of two unfertilized moist black soil (10% MC) samples at frequency 4.6 GHz are 7.6 and 0.43 for sample A and 9.6 and 0.38 for Sample B, respectively. The variation in values of dielectric constant and dielectric loss of these moist black soil samples mixed with different fertilizer contents are then measured at fixed frequency 4.6 GHz. The concentrations of fertilizers in the soil samples are varied over a range from 0 to 0.12 %. The dielectric constant and dielectric loss are found to increase with increase in fertilizer contents. Out of these three fertilizers, relative increase in dielectric properties is found highest for Urea and lowest for Potash. Other electric parameters such as a. c. conductivity (σ) and relaxation time (τ) also show increase in their values with respect to increase in the fertilizer concentrations. The physical and chemical properties of the black soil samples are also provided. Possible applications and extensions of this study are also outlined.

***Index Terms*-** Complex dielectric constant, soil, chemical fertilizers, ac conductivity, relaxation time, microwave frequency.

I. INTRODUCTION

Soil depletion occurs when the components which contribute to fertility are removed and the conditions which support soil fertility are not maintained. This leads to poor crop yields. In agriculture, depletion can be due to excessively intense cultivation and improper utilization of soil. Topsoil (depth ranging 0-20 cm) depletion occurs when the nutrient-rich organic topsoil, which takes hundreds to thousands of years to build up under natural conditions, is eroded. Therefore, in order to sustain soil fertility, nutrients removed from the soil by crops must be restored by the application of manures and fertilizers. Thus, fertilizers supply plant food and help to increase the yield of different crops through the improvement of soil fertility. Fertile soil produces abundant crops under suitable environmental conditions. However, addition of different fertilizers may change the physical, chemical and dielectric properties of the soil.

Several researchers have reported the findings of their studies on the variation of dielectric characteristics of fertilized soils at microwave frequencies. Wang J. R. and Schmugge T. J. [1] showed that the dielectric constant is directly proportional to pore- space of soil. Results of Yadav V. et al. [2] have further showed that, due to more pore space the grains of the crops get the sufficient space for growth, so fertility of soil is also increased.Heiniger R. W. et al. [3] outlined the necessity of soil test to determine status of available nutrients and to develop fertilizer recommendations to achieve optimum crop production. Experimental results of Yadav V. et al. [2] at X-band frequency show increase in the values of dielectric constant, dielectric loss, a.c. conductivity and relaxation time with increase in the concentration of fertilizers in the soil. Yadav, et al. [4] have further experimentally studied the variation in the dielectric constant of mixture of water content with fertilizers. Navarkhele V. V. et al. [5] and Shaikh A. A. and Navarkhele V. V. [6] have also studied the dielectric properties of black soil with inorganic and organic matters at X-band microwave frequencies. Chaudhari H. C. and Shinde V. J. [7] have determined a. c. electrical conductivity (σ), and relaxation time (τ) of soil from experimentally measured values of complex dielectric constants of red and black soils. Gadani D. H. et al. [8] have studied the dielectric properties of wet and fertilized soils at radio frequencies using precision LCR meter. Their results show increase in the values of dielectric constant and dielectric loss with increase in the concentration of fertilizers in the soil.

Research of this kind enriches our knowledge of soil science and thus is very much beneficial to the farmers. Therefore, the present study reports the experimental results on the variations of dielectric constant, dielectric loss, a. c. conductivity and relaxation time of black soils for different fertilizer contents at C-band microwave frequency (4.6 GHz). Most of the earlier investigators have studied dielectric properties of fertilized soils by adding fertilizers in dry soils at X-band microwave frequencies. However, as per agricultural norms, the fertilizer addition is more effective in moist soils than in dry soils for efficient nutrients transportation to the crops/plants. Therefore, in the present work, fertilized soil samples are prepared by mixing desired amount of fertilizers in the soil having 10% gravimetric moisture content.

II. MATERIALS AND METHODS

A. *Preparation of soil samples*

Two soil samples (A and B) having black colour and of wide marginal textural difference were collected from two places, viz., from Amalner (Dist. Jalgaon) and Nandurbar (Dist. Nandurbar). Both of these districts are located in the northern region of Maharashtra State (India). Soils were first sieved by gyrator sieve shaker to remove the coarser particles. The sieved out finest particles are then oven dried to a temperature around 110^{o}C for several 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. Soil samples of 10% gravimetric moisture contents are prepared by adding an exact amount of distilled water to the known mass of the oven dry soil. The fertilized soil samples are then prepared by mixing different concentrations of fertilizers in the black soil having 10% MC. These mixtures are kept in a closed container and allowed for few hours to facilitate internal drainage,homogenous mixing and proper settlement. These fertilized soil samples are then inserted into the solid dielectric cell for measuring their dielectric properties. Extreme care was taken to expose them to the atmospheric air as little as possible. Three different chemical fertilizers used in these experiments are Urea, Di-Ammonium Phosphate (D.A.P.) and Potash. The concentrations of fertilizers are varied over a range from 0 to 0.12 %. These concentration levels nearly match with the norms specified by the agricultural department.

B. *Soil physical and chemical properties*

The physico-chemical soil analysis reports of the two black soil samples (A and B) used in this study were obtained from Soil Testing Laboratory, Government Agricultural College, Pune. Table 1 presents the physical and chemical properties of these black soil samples. It indicates that both the soil samples used are alkaline in nature and their electrical conductivity values lie within the normal range.

Table 1: Physical and chemical properties of unfertilized black soils

(a) Physical properties

Soil Propeties		Soil Sample Name	
		Sample-A	Sample-B
Texture	Sand	20	61
	Silt	31	20
	Clay	49	19
Textural Class		Clay	Sandy loam
Bulk Density		1.27	1.55
Paricle Density		2.5	2.61
Soil Colour		Black	Black
WP		0.29	0.12
W_t		0.31	0.224
Porocity		49.2	40.6

(b) Chemical properties

Soil Propeties	Soil Sample Name	
	Sample-A	Sample-B
pH	7.2	8.25
EC (dS/m)	0.33	0.10
OC %	0.65	0.23
$CaCO_3$ %	4	6.4
N (Kg/ha.)	238	163
P (Kg/ha.)	16.9	6.2
K (Kg/ha.)	610	412

The Wilting Point (WP) and Transition Moisture (W_t) of the soils are calculated by using the Wang J. R. and Schmugge T. J. Model [1] as follows:

$$WP = 0.06774 - 0.00064 \times Sand (\%) + 0.00478 \times Clay (\%) \quad .... (1)$$

$$W_t = 0.49 \times WP + 0.165 \quad .... (2)$$

C. Method of measurement of dielectric properties

The waveguide cell method is used to determine the dielectric properties of the fertilized black soil samples. An automated C-band microwave set-up in the TE_{10} mode with Gunn source operating at frequency 4.6 GHz, PC-based slotted line control and data acquisition system is used for this purpose. Experiments were performed at room temperatures ranged between 30^o-35^o C. 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. The dielectric constant ε' and dielectric loss ε'' of the fertilized soils are then determined from the following relations:

$$\varepsilon' = \frac{g_\varepsilon + (\lambda_{gs}/2a)^2}{1 + (\lambda_{gs}/2a)^2} \quad \ldots \quad (3)$$

$$\varepsilon'' = -\frac{\beta_\varepsilon}{1 + \left(\lambda_{gs}/2a\right)^2} \quad \ldots \quad (4)$$

From the measurement of dielectric constant and dielectric loss, other electric parameters like a. c. conductivity and relaxation time can be obtained by using equations (5) and (6)

$$\sigma = \omega\varepsilon_o\varepsilon'' \quad \ldots \quad (5)$$

$$\tau = \varepsilon''/\omega\varepsilon' \quad \ldots \quad (6)$$

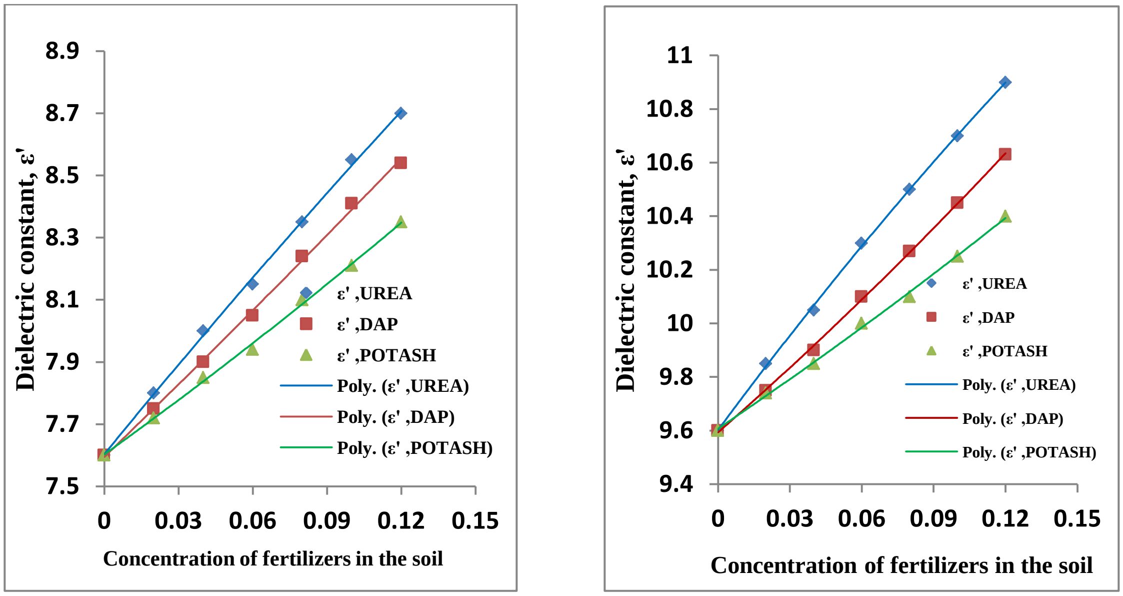
Where, a = inner width of rectangular waveguide.
λ_{gs} = wavelength in the air-filled guide.
g_ε = real part of the admittance
β_ε = imaginary part of the admittance
ω = 2πf = angular frequency, f = 4.6 GHz
ε_o = permittivity of free space.

III. RESULTS AND DISCUSSION

The initial average values of dielectric constant and dielectric loss of two unfertilized oven-dry black soil samples at frequency 4.6 GHz are 3.85 and 0.16 for sample A and 3.1 and 0.1 for sample B. Further, the average values of dielectric constant and dielectric loss of two unfertilized moist black soil (10% MC) samples at frequency 4.6 GHz are 7.6 and 0.43 for sample A and 9.6 and 0.38 for Sample B. Our experimental results on the variations of dielectric constant, dielectric loss, a. c. conductivity, and relaxation time for these two black soil samples having constant value of MC (10%), with the concentration of different fertilizers are summarized in Figs. 1 to 4.

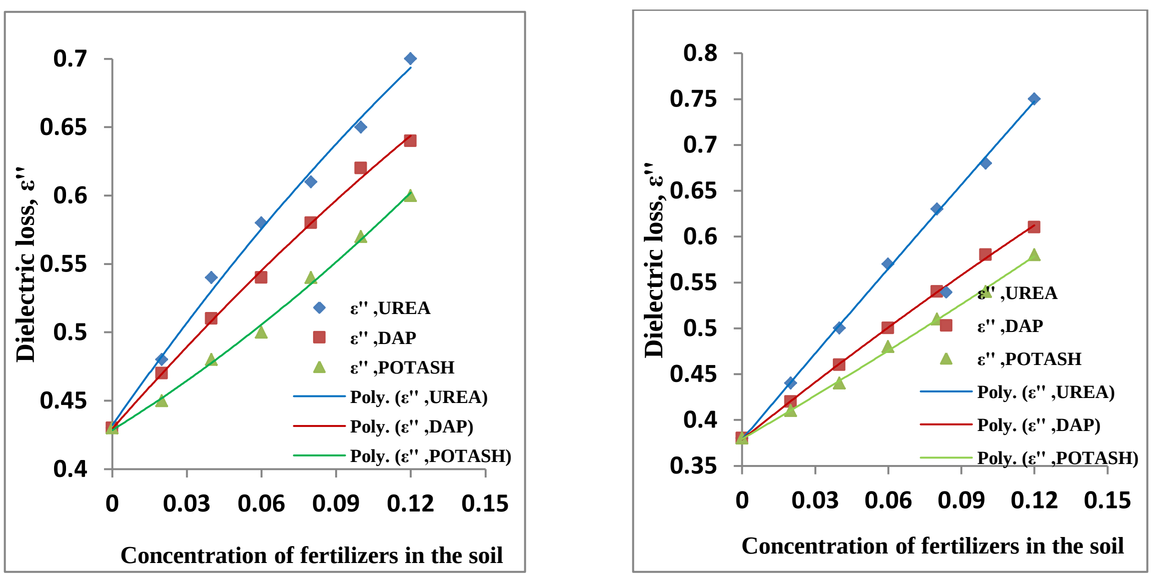
Fig. 1(a) shows the variations of dielectric constant of soil sample A for different fertilizer concentrations (%) at 4.6 GHz. The dielectric constant is found to increase with increase in fertilizer concentrations from 0 to 0.12 %. This variation is approximately linear and the trend is almost similar for all the three fertilizers used in these measurements, except the little differences in the relative magnitudes of dielectric constant. Out of these three fertilizers, relative increase in dielectric constant is found highest for Urea and lowest for Potash. The departures in the curves for three fertilizers are more for higher fertilizer concentrations. For fertilized moist soil samples prepared by using Urea, the values of ε' ranges from 7.6 to 8.7 for its concentration changed from 0% to 0.12%. Whereas, when the fertilized moist soil samples are prepared by using D.A.P. and Potash, the corresponding values of ε' ranged from 7.6 to 8.54 and 7.6 to 8.35 respectively, for their concentrations changed over the same range. Fig. 1(b) shows the variations of dielectric constant of soil sample B for fertilizer concentrations (%) at 4.6 GHz over the same range. The results show almost similar trends except the differences in their relative magnitudes. For this case, when fertilized moist soil samples are prepared by using Urea, the values of ε' ranges from 9.6 to 10.9 for its concentration changed from 0% to 0.12%. Whereas, when the fertilized moist soil samples are prepared by using D.A.P. and Potash, the corresponding values of ε' ranged from 9.6 to 10.63 and 9.6 to 10.4 respectively, for their concentrations changed over the same range. However, the reaction of urea in presence of soil is acidic but less acid producing than D.A.P. Therefore, excessive use of these two fertilizers may cause acidity in soils. On the other hand, Potash fertilizer is neutral in reaction and hence can be found more effective in acidic soils.

Fig. 2 (a) and (b) show the variations of dielectric loss with different fertilizer concentrations (%) for soil samples A and B respectively. In both cases, the dielectric loss is found to increase with increase in fertilizer concentrations over a range from 0 to 0.12 %. The trend of variations is almost similar as that for dielectric constant discussed in Fig. 1, except the differences in their magnitudes. Thus, value of dielectric constant and dielectric loss of these soils increases with fertilizer contents. However, it is further observed that the relative increase of dielectric loss is comparatively more than dielectric constant over the range of fertilizer concentration studied.



(a) Sample A (b) Sample B

Figure 1. Variation of dielectric constant of soil (10% MC) with different fertilizers contents at frequency 4.6 GHz.

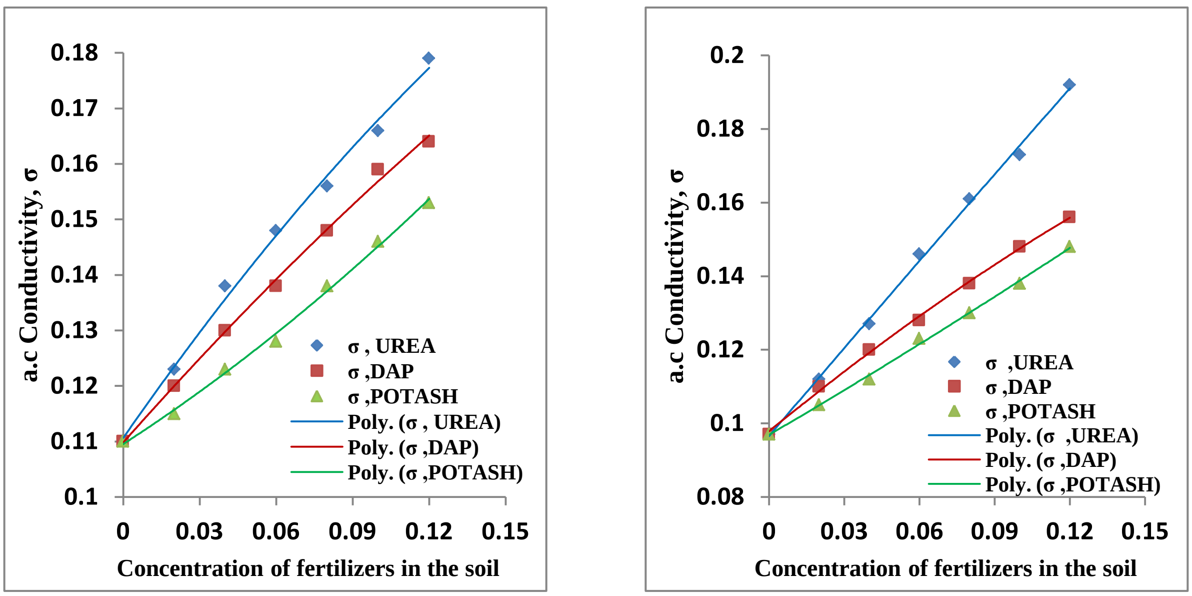


(a) Sample A (b) Sample B

Figure 2. Variation of dielectric loss of soil (10% MC) with different fertilizers contents at frequency 4.6 GHz.

Our results presented in Figs. 1 and 2 show fairly good agreements with the results of the several investigators [2,4,5,6,7,8,9,10]. However, the soil moisture, type and amount of fertilizer added, operating frequency, etc. are different. We know that dielectric constant has strong dependence on the moisture content present in the soil. It increases with the increase in the amount of moisture content in the soil. Addition of fertilizers in the soil having constant MC (10%) also show approximately linear increase in the ε' with increase in the concentration of fertilizers. This may be due to the fact that the added fertilizers matter forms a chemical composition of low concentration along with the chemicals present in the soil. According to the theory of electrolyte, in the limit of low concentration the dependence of ε' is approximately linear. By adding fertilizer the water holding capacity of soil improves. The dielectric loss of soil is also found to increase with increase in the concentration of fertilizers. The reason may be that ε" is a parameter which describes the motion of electric charge leading to the conduction phenomenon [5,6].Certain dielectrics display conduction which arises from the actual charge transport rather than due to the displacement current. Such conduction is described by volume conductivity which adds an additional term to the dielectric loss ε". Due to this additional term the dielectric loss increases with increase in fertilizer content in the soil.

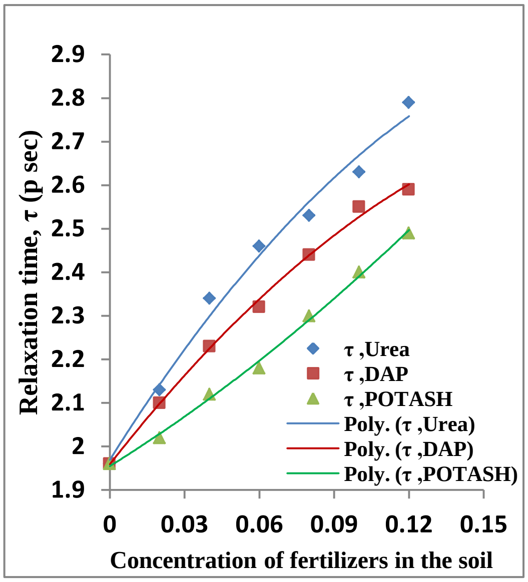
Fig. 3 (a) and (b) show the variations of a. c. conductivity of soils for different fertilizer concentrations (%) for sample A and B respectively. In both cases, the a. c. conductivity is found to increase with increase in fertilizer concentrations over a range from 0 to 0.12 %. This variation is approximately linear and the trend is almost similar for all the three different fertilizers used in these measurements. Out of these three fertilizers, relative increase in σ is found highest for Urea and lowest for Potash. This result is expected, because the motion of charges in the dielectric (soil) gives rise to the conduction current and hence polarizes the dielectric. This dielectric polarization is thus found to increase with the concentration of fertilizers. This shows that the conduction is by displacement current and therefore contributes to the dielectric attenuation/loss. Further, the measured values of σ for the black soil samples used in this study are of higher range and it may be due to their high clay percentages. This shows the presence of large number of weakly bound ions in these clayey or soft materials. Such dielectric studies of materials, thus is a powerful tool in assessing the structure and behaviour of molecular materials [11,12].



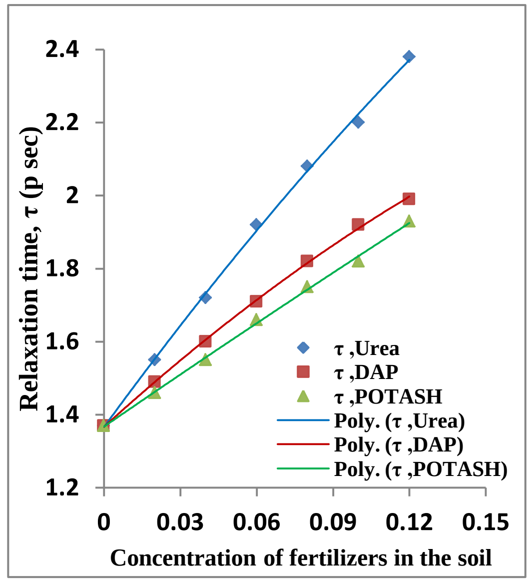
(a) Sample A (b) Sample B

Figure 3: Variation of a. c. electrical conductivity of soil (10% MC) with different fertilizers contents at frequency 4.6 GHz.

Fig. 4 (a) and (b) show the variations of relaxation time of soils for different fertilizer concentrations (%) for sample A and B respectively. In both cases, the relaxation time is found to increase with increase in fertilizer concentrations over a range from 0 to 0.12 %. This suggests that the mobility of the molecules (dipoles) of soils decreases with addition of fertilizers in it. However, this variation is nonlinear and the trend is almost similar for all the three different fertilizers used in these measurements. Out of these three fertilizers, relative increase is found highest for Urea and lowest for Potash. This result is expected, as τis proportional to the dissipation factor (ε"/ε'). Molecular relaxation time is assumed to be due to the inner friction of the medium that hinders the rotation of the polar molecules. Therefore τ is also a function of MC. The increase in the relaxation time with MC is due increase in hindrance to the polarization process in soils. Our results further indicate that hindrance to polarization process in the soils having fixed MC is directly proportional to the amount of fertilizer content. Our results discussed here found good agreement with the experimental results of earlier investigators [2,4,5,6,7,8,9,13,14].



(a) Sample A



(b) Sample B

Figure 4: Variation of relaxation time of soil (10% MC) with different fertilizers contents at frequency 4.6 GHz.

Our results given in Figs. 1 to 4 have little higher values of dielectric parameters for the black soil sample B compared to sample A. This can be explained from their physical and chemical properties listed in Table-1. This shows that dielectric constant of oven-dry (0% MC) soil samples is positively correlated with electrical conductivity, macronutrients (N,P,K) and organic carbon, while it is negatively correlated with pH and $CaCO_3$. Results shown in Figs. 1 to 4 further indicate that the values of dielectric constant, dielectric loss, a. c. conductivity, and relaxation time of the moist black soil samples increases with increase in fertilizer concentrations. In all cases, the relative increase in these parameters is found highest for Urea and lowest for Potash. Further, this effect is more pronounced at higher concentrations of these three fertilizers used. Thus, addition of fertilizers increases the pore-space and hence the fertility of the soil [1]. The different types of fertilizers have different chemical compositions. Therefore, the above experimental results clearly show that urea increases relatively more pore-space in the given soil as compared to D.A.P. and potash. Such studies on dielectric properties of fertilized soils are not only useful in understanding the structural behavior of soil but also for its efficient use in crop production. Further, these results may find uses in deciding the correct types and amounts of fertilizers for the supply of the specific nutrients. Such studies may be extended over different frequencies, for various soil types and by taking large number of samples.

Our results also give comparatively higher values of dielectric parameters for the unfertilized as well as fertilized moist (10% MC) black soil sample B compared to sample A having same MC value. This shows the dependence of dielectric parameters and also effectiveness of fertilizers studied on the texture/structure and chemical properties of soils.

IV. CONCLUSIONS

This study indicates that the values of dielectric constant, dielectric loss, a. c. conductivity, and relaxation time of the moist black soil samples increases with increase in fertilizer concentrations. The relative increase in these parameters is found highest for Urea and lowest for Potash. Further, this effect is more pronounced at higher concentrations of these three fertilizers used. This shows that the fertilizer increase generates more pore-space into the soil. Due to more pore-space, the dielectric constant and hence fertility of soil is also increased. Our results also give little higher values of dielectric parameters for the black soil sample B compared to sample A. This can be explained from the differences in their physical and chemical properties.The results of this study may find uses not only in understanding the soil microstructure but also in deciding the correct types and amounts of fertilizers for the supply of the specific nutrients.

ACKNOWLEDGEMENT

The authors are very much grateful to the Principal, Z. B. Patil College, Dhule, for providing research facilities and also thankful to Prof. OPN Calla, ICRS, Jodhpur, for his kind suggestions during the course of this research work.

REFERENCES

[1] Wang J. R. and Schmugge T. J., *IEEE Trans. Geosci. Remote sens.*,vol. 18, 1980, pp288- 295.

[2] Yadav, V., Anil Kumar, A. Sharan, S. Sinha, A.K. Yadav, M. Gupta, V.K. and Jangid, R. A., *Journal of Agricultural Science,* vol.42, 2009, pp 42-49.

[3] Heiniger, R. W. McBride, R. G. and. Clay, D. E., *Agronomy Journal,* vol. 95, 2003, pp508-519.

[4] Yadav, V. Kumar, A. Sharan, S. and Sinha, A. K, *International Journal of the Physical Sciences,* vol. 5(16), 2010, pp2466- 2470.

[5] Navarkhele, V. V. Shaikh, A. A. and Ramshetti, R. S., (2009), *Indian J. of Radio and Space Physics,* vol. 38, 2009, pp112-115.

[6] Shaikh A. A. and Nawarkhele V. V., Frontiers of Microwaves and Optoelectronics, *Proceedings of International Conference on Microwaves and Optoelectronics, Anamaya Publishers, New Delhi, India*, 2008, p879.

[7] Chaudhari, H. C. and Shinde, V. J., *International Journal of physical Science,* vol. 3(3), 2008, pp75-78.

[8] Gadani D. H., Vyas A. D. And Rana V. A., *Indian J. of Radio and Space Physics*, vol. 52, 2014, pp399-410.

[9] Chaudhari H.C., Deshmukh S.B., Agrawal P.R. and Shinde V.J., *Proceedings of International Conference on Microwaves and Optoelectronics (ICMO-2007), Aurangabad (Maharashtra),* 2007, pp891- 896.

[10] Bottcher C. J. F., *Elsevier Pub. Com. Ams. Houston, London*, p415.

[11] Roberts, S. and Hippel A. Von, *Journal of Applied Physics,* vol. 17, 1946, pp610-616.

[12] Hippel A. Von, Dielectric Materials and Applications, *John Wiley and Sons, Inc.*, 1961, p314.

[13] Sengwa R. J.andSoni A., *Indian Journal of Radio and Space Physics*, vol. 37, 2008, p57.

[14] Sengwa R. J., and Soni A., *Geophysics,* vol. 71/5, 2006, pG269.

AUTHORS

First Author –Dr. Mrs. Vidya D. Ahire, M.Sc. Ph.D. (Physics), Associate Professor, Microwave Research Laboratory,Department of Physics, JET's Z. B. Patil College, Dhule

Second Author--Dr. D.V.Ahire, M.Sc. ,Ph.D.(Physics), Associate Professor and Ex. Head, Microwave Research Laboratory,Department of Physics, JET's Z. B. Patil College, Dhule

Third Author – Dr. P. R. Chaudhari, M.Sc. ,Ph.D.(Physics), Associate Professor,Microwave Research Laboratory,Department of Physics, JET's Z. B. Patil College, Dhule

Correspondence Author – Dr. D.V.Ahire, M.Sc. ,Ph.D.(Physics),
Associate Professor and Ex. Head, Microwave Research Laboratory,
Department of Physics, JET's Z. B. Patil College, Dhule 424002
Email: dvahire@rediffmail.com
Mobile Number: +91 9423979468