Correlations of Electrical Conductivity and Dielectric Constant with Physico-Chemical Properties of Black Soils

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Abstract- In the present research work, studies on correlation factors of electrical conductivity and dielectric constant of black soils with physical properties and macro- and micronutrients of black soils are reported. Soil samples are collected from eight different locations covering North Maharashtra Region (India). An automated C-band and X -band microwave set-ups in the TE_{10} mode with Gunn source operating at frequencies 4.6 GHz in C - band and 10 GHz in X - band , are used for measuring dielectric properties. Our results show significant positive correlation of electrical conductivity and dielectric constant with majority of soil parameters except those with sand, bulk density, pH and $CaCO_3$. Further, values of correlation factor are relatively more at C-band microwave frequency than X-band. Besides agricultural applications, such studies may find importance in better understanding of soil physics and also for analyzing the satellite data in remote sensing.

Index Terms- Dielectric constant, Electrical Conductivity, Black soils, Soil physical properties, Macro- and micro nutrients in soils

I. INTRODUCTION

The soil has physical, chemical as well as electrical properties. Colour, texture, grain size, bulk density etc., comprise the physical properties; Nutrients, organic matter, pH, etc., comprise chemical properties while, electrical properties include dielectric constant, electrical conductivity and permeability. The quality of soil is controlled by physical, chemical and biological components of a soil and their interactions [1]. The concept of soil health and soil quality has consistently evolved with an increase in the understanding of soils and soil quality attributes. Perveen S. et al. [2] have studied micronutrient status of soils and their relationship with various physico-chemical properties. Chhabra G. et al. [3] have shown that available manganese decreased with soil pH and available copper increased with clay and organic carbon content. Results of physical and chemical tests provide information about the capacity of soil to supply mineral nutrients. Martin C. et al. [4] have shown that the electrical conductivity of soil water is a good indicator for absorbing the amount of nutrients available for crops.

Bell R. W. and Dell B. [5] have showed that the deficiency of nutrients has become major constraint to productivity, stability and sustainability of soils. The status of available micronutrients in soils and their relationship with various physico-chemical properties have been attempted by several investigators [6,7,8]. Avnimelech Y. et al. [9] estimated the organic content and bulk density of flooded mineral soils and found that the sediment bulk density was inversely related to the organic carbon concentration.

The measurements of dielectric constant of soils as a function of moisture content over wide microwave frequency range were carried out in the past by many investigators [10-17]. These investigators have used soils covering different parts all over world and with different texture/structures. Almost all these investigators have concluded that the dielectric constant of soils is strongly dependent on moisture content. Further, Sami S. [18] has reported the effect of Chemical and Mineral Composition of dust on dielectric constant. Srivastava S. K. and Mishra G. P. [12] studied the characteristics of soils of Chhatisgarh at X – band frequency and shown the dependence of dielectric constant of soils on its texture of soils. Calla O. P. N. et al. [19] have studied the variability of dielectric constant of dry soil with its physical constituents at microwave frequencies. Dawood N. K. et al. [20] have evaluated the dielectric constant by clay mineral and soil physico – chemical properties and showed that texture and mineral content of soil had different impact on dielectric constant. Chaudhari H. C. and Shinde V. J. [21] have reported that the dielectric properties of dry soil at microwave frequency in X- band are function of its chemical constituents and physical properties. In a detailed study, Sengwa R. J. and Soni A. [22] have reported the variation of dielectric constant with density of dry minerals of soil at 10.1 GHz.

The properties of dry soil along with its type have a great importance in agriculture. For microwave remote sensing applications, dielectric constant is the primary important electrical property for dry soil. It is now confirmed that the dielectric properties of soils are mainly depend on their MC. Further, due to dependence of dielectric constant on the physical constituents and chemical composition of the soil, the detailed study of its variability with these soil parameters will be useful for better understanding of soil physics. Therefore, in the present work, we have made the measurements on dielectric constant and electrical conductivity of dry black soils and studied their statistical correlation factors with physical and chemical properties. The black soil samples are collected from various locations covering North Maharashtra Region (India). The dielectric constant of dry black soils are measured at C- band (4.6 GHz) and X- band (10 GHz) microwave frequencies by waveguide cell method using automated microwave set-ups.

II. MATERIALS AND METHODS

A. Study Area and Soil Sampling

Eight black soil samples from eight different locations were collected from North Maharashtra region. Details about geographical parameters and soil sampling sites are given in Tables 1 and 2. Soil samples are then collected from ten different locations 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 eight sites covering four districts of North 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 110°C 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.

Table 1: Geographical parameters of North Maharashtra Area

Districts of North Maharashtra	**Latitude**	**Longitude**	**Altitude (m)**	**Average Rainfall/Year (mm)**
Jalgaon	21^0 01' N	75^0 34' E	209	690
Dhule	22^0 53' N	74^0 46' E	239	640
Nandurbar	21^0 22' N	74^0 25' E	209	780
Nasik	19^0 58' N	73^0 47' E	569	730

Table 2: Details of soil sampling sites and soil samples

Districts of North Maharashtra	Sampling Sites	Soil Colour	Sample Nos. Assigned as per Clay %	Irrigated/ Non-irrigated	Crops Grown
Jalgaon	Amalner	Deep Black	S1	Semi-Irrigated	Cotton, Jwari
	Erandol	Deep Black	S2	Irrigated	Cotton, Jwari
Dhule	Shirpur	Deep Black	S3	Irrigated	Cotton, Corn
	Dhule	Deep Black	S4	Non-irrigated	Bajara, Jwari
Nandurbar	Shahada	Black	S5	Irrigated	Bajara, sugar cane
	Nandurbar	Black	S8	Non-irrigated	Bajara, groundnuts
Nasik	Kalwan	Black	S6	Semi-Irrigated	Onion, Corn
	Satana	Black	S7	Semi-Irrigated	Wheat, Corn

B. Soil Physical and Chemical Properties

The analysis of soil physical and chemical properties is usually carried out in the well reputed soil testing laboratories. The soil parameters like pH and EC are measured in our laboratory by using soil testing kit (Model-161). The detailed soil analysis reports for

Table 3: Physical Parameter Analysis of Black Soils

Sample No. and Location	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural Class**	**Bulk Density ($Mg\ m^{-3}$)**	**Particle Density ($Mg\ m^{-3}$)**	**Porosity**

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1. Amalner	20	31	49	Clay	1.27	2.5	49.2
2. Erandol	33	25	42	Clay	1.3	2.5	48
3. Shirpur	19	48	33	Silty Clay Loam	1.27	2.4	47.08
4. Dhule	43	25	32	Clay Loam	1.45	2.54	42.91
5. Shahada	34	40	26	Loamy	1.36	2.46	44.72
6. Kalwan	40	35	25	Loamy	1.4	2.5	44
7. Satana	56	23	21	Sandy Clay loam	1.54	2.6	40.76
8.Nandurbar	61	20	19	Sandy Loam	1.55	2.61	40.6

Table 4: (a) Chemical Analysis of Black Soils

Sample No. and Location	**pH (1:2.5)**	**E.C. (dSm^{-1})**	**Macro Nutrients**				
			Available Nitrogen (N) ($kgha^{-1}$)	**Available Phosphorus (P) ($kgha^{-1}$)**	**Available Potassium (K) ($kgha^{-1}$)**	**Ca (meq $100g^{-1}$ soil)**	**Mg (meq $100g^{-1}$ soil)**
1. Amalner	7.2	0.33	238	16.9	610	200	47
2. Erandol	7.6	0.30	223	15.2	579	195	46
3. Shirpur	8.0	0.26	211	12.0	542	168	49
4. Dhule	8.0	0.17	193	10.4	490	176	40
5. Shahada	7.9	0.20	183	9.3	522	120	35
6. Kalwan	8.4	0.18	197	11.8	456	143	23
7. Satana	7.8	0.15	160	8.0	510	116	27
8. Nandurbar	8.25	0.10	163	6.2	412	98	18

Table 4: (b) Chemical Analysis of Black Soils

Sample No. and Location	Organic Carbon (OC) (%)	Calcium Carbonate ($CaCO_3$) (%)	Micro Nutrients			
			Available Iron (Fe) (ppm)	Available Maganese (Mn) (ppm)	Available Zinc (Zn) (ppm)	Available Copper (Cu) (ppm)
1. Amalner	0.65	4.0	4.6	15.0	1.2	2.1

2. Erandol	0.70	4.2	4.8	13.2	1.34	1.4
3. Shirpur	0.42	4.9	3.4	9.3	1.1	1.56
4. Dhule	0.50	5.5	2.7	11.0	1.0	1.5
5. Shahada	0.43	5.8	3.5	11.0	0.94	0.8
6. Kalwan	0.30	5.7	2.0	9.5	0.52	1.42
7. Satana	0.40	3.9	3.9	8.0	0.76	0.65
8. Nandurbar	0.23	6.4	2.1	5.6	0.32	0.85

the remaining parameters of the eight black soil samples used in this study were obtained from Soil Science Division, College of Agriculture, Pune. These soil analysis reports includes the chemical analysis of OC, available macronutrients N, P, K, Ca, Mg and micronutrients Fe, Mn, Zn, Cu. It also includes properties like texture, structure, pH, bulk density. The detailed results on physical and chemical parameter analysis of black soils are presented in Tables 3 and 4 respectively.

C. Measurement of Dielectric Constant of dry Soil Samples

Wave-guide cell method is used to determine the dielectric properties of these dry black soil samples. An automated C-band and X -band microwave set-ups in the TE_{10} mode with Gunn source operating at frequencies 4.6 GHz in C - band and 10 GHz in X - band , are used for this purpose. Automation of these set-ups includes PC-Based slotted line control and data acquisition system. The main advantages obtained due to atomization are increased resolution of output, reduction of backlash error in slotted line, visual representation of standing wave pattern. The sample lengths are usually taken in the multiples of $\lambda/4$. The solid dielectric cell with black soil sample is connected to the opposite end of the source. The black soil 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 of dry black soils is calculated by measuring the standing wave ratio of the dielectric material and the shift in minima of the standing wave pattern in a rectangular waveguide. The dielectric constant ε' of the soils is then determined from the following relation:

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

Where, a = inner width of rectangular waveguide.

λ_{gs} = wavelength in the air-filled guide.

g_{ε} = real part of the admittance

III. RESULTS AND DISCUSSION

A. Physical and chemical properties of soils

From Table 3, we conclude that the sand, silt and clay of the soil samples used for this study ranged between 19 - 61, 20 - 48 and 19 - 49 % respectively. Majority of these soils have Clay, Clay Loam and Loamy texture. pH values listed in Table 4 (a) ranged between 7.2 - 8.4 which indicate that these soils are slightly alkaline in nature. Further, all the eight samples (S1-S8) are found nonsaline in nature and their electrical conductivity values lie in the range 0.10–0.33 dS/m. From Table 4 (b), it can be further observed that the all eight soil samples have moderately calcareous (3.9 – 6.4 %) nature. According to Methods Manual, Soil Testing in India [23], the critical limits of (N), (P) and (K) for normal growth of plant are 280 kg/ha, 10 kg/ha and 108 kg/ha respectively. Comparing our data with these critical limits show low values of available N (160 - 238 kg/ha), low to high for P (6.2 - 16.9 kg/ha), while the available K (412 - 610 kg/ha) values are very high. All soil samples were containing adequate amount of available (Ca) (98-200 meq/100 gm) and (Mg) (18 – 49 meq/100 gm). According to Lindsay W. L. and Norvell W. A. [24], 4.5 ppm of Fe is considered as the critical limit for normal growth. Comparing our data with this critical limit, only two soil samples S1 and S2 (Table 4,b) found to contain sufficient amount of Fe (4.6 and 4.8 ppm) while the remaining soil samples are found to be deficient of available Fe (2.0 – 3.9 ppm). Shukla J. B. and Gupta S. P. [25] and Annual Progress Report by ICAR [26] reported the range of 3.00 ppm to 4.7 ppm as the critical limit for available Mn. However, as can be seen from Table 4 (b), all the soil samples studied are having relatively high values of available Mn (5.6 - 15 ppm). Further, Lindsay W. L. and Norvell W. A. [24] suggested the critical limit of Zn as 0.5 to 1.00 ppm. Zn values for majority of our samples either lie or quite close to this critical limit. Further, Sakal R. et al. [27] have found 0.66 ppm as critical limit of Cu for normal growth of plant. Results in Table 4 (b) are more or less agrees with this critical limit and the reported soils contain adequate amount of available Cu (0.65-2.1 ppm).

B. Relationship between electrical conductivity and dielectric constant of soils

Variation of Electrical Conductivity with Dielectric constant of black soil samples (S1-S8) are shown in Fig. 1. Our results give a strong positive statistical correlation between dielectric constant and electrical conductivity (Rc=0.895; Rx=0.662) for the eight soil samples. It is further seen from Fig. 1 that the correlation factor for dielectric constant with electrical conductivity of soil samples is comparatively more positive at microwave frequency 4.6 GHz (C–band) than at 10 GHz (X-band). This clearly indicates the frequency dependence of the correlation factor between these two soil parameters.

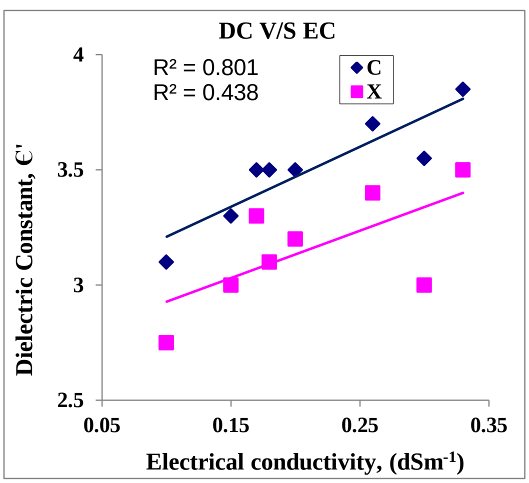


Figure 1: Variation of Electrical Conductivity with Dielectric constant of black soil samples (S1-S8)

Our experimental results are found to agree with the theoretical models developed by many investigators working in this field [28-30]. These models also give a strong linear relationship between dielectric constant and electrical conductivity of the soils. Brovelli A. and Cassiani G. [31] further constituted the model that can be used to parameterize electrical conductivity and permittivity and to evaluate whether the information carried can be used to identify soil parameters.

C. Relationship of electrical conductivity and dielectric constant of soils with physical constituents

(i) Relationship of electrical conductivity and dielectric constant with soil texture

Simple correlation studies showed high degree of relationship of electrical conductivity and dielectric constant of soil with its physical constituents; viz., sand, silt and clay. Fig. 2 (a-c) shows variation of electrical conductivity with sand, silt and clay of black soil samples (S1-S8) respectively. Our results thus show that the electrical conductivity has strong positive and strong negative relationship with clay content (R=0.938) and sand content (R= - 0.886) of soil samples respectively, whereas there is positive but less significant correlation was observed between electrical conductivity of soil with silt content (R=0.385).

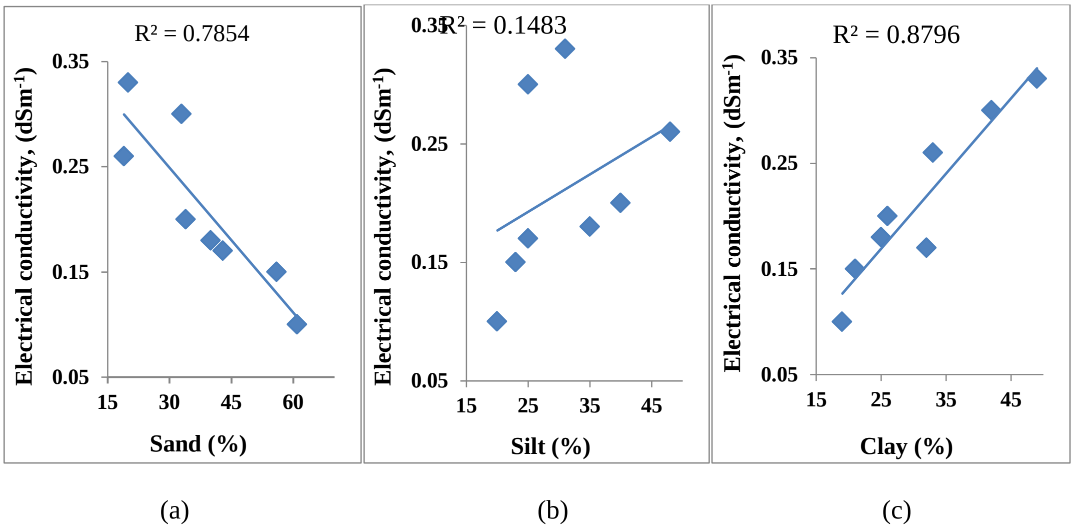
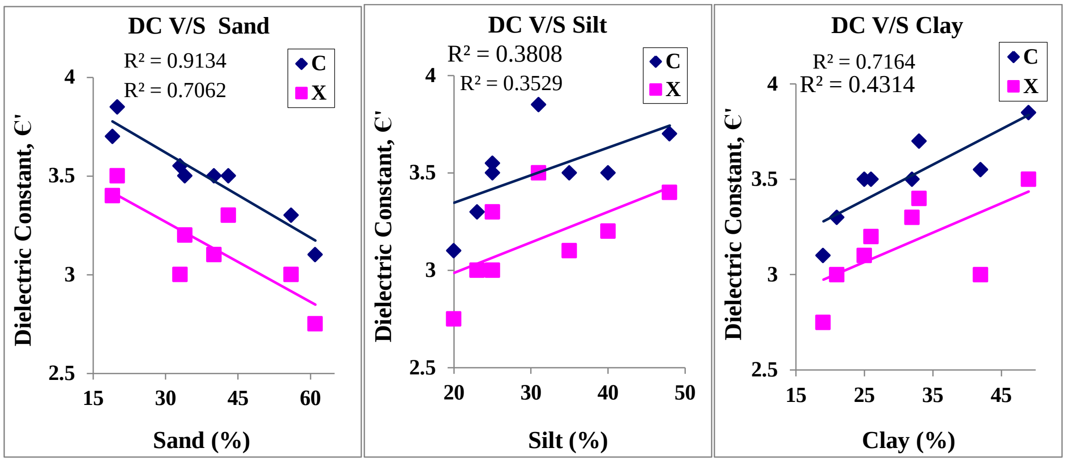


Figure 2: Variation Electrical Conductivity with texture of black soil samples (S1-S8)

Fig. 3 (a-c) shows variation of dielectric constant with sand, silt and clay of black soil samples (S1-S8) respectively. Our results, thus show that the dielectric constant has a strong positive relationship with clay content (Rc=0.846; Rx=0.657) and strong negative with sand content (Rc= - 0.956; Rx= - 0.840) of soil samples respectively, while relatively less positive but significant correlation was observed between dielectric constant of soil with silt content (Rc = 0.594; Rx = 0.617). From these correlations it was noted that relationship of dielectric constant with clay content and sand content of soil samples was comparatively more significant at frequency 4.6 GHz (C-band) than at 10 GHz (X-band). While correlation between dielectric constant and silt content of soil samples was slightly stronger at frequency 10 GHz (X–band) than at 4.6 GHz (C-band). This clearly indicates the frequency dependence of the correlation factor between dielectric constant and soil texture.

Thus, soil texture can be expressed significantly by knowing its electrical conductivity and dielectric constant. Our experimental results are in consistence with the studies and predictions of many earlier investigators [10,19,32-36]. These investigators have also found positive correlation of electrical conductivity and dielectric constant with silt and clay content of soil and negative with sand content. Their studies also show that the clay textured soils are highly conductive while sandy soils have poor conductivity.

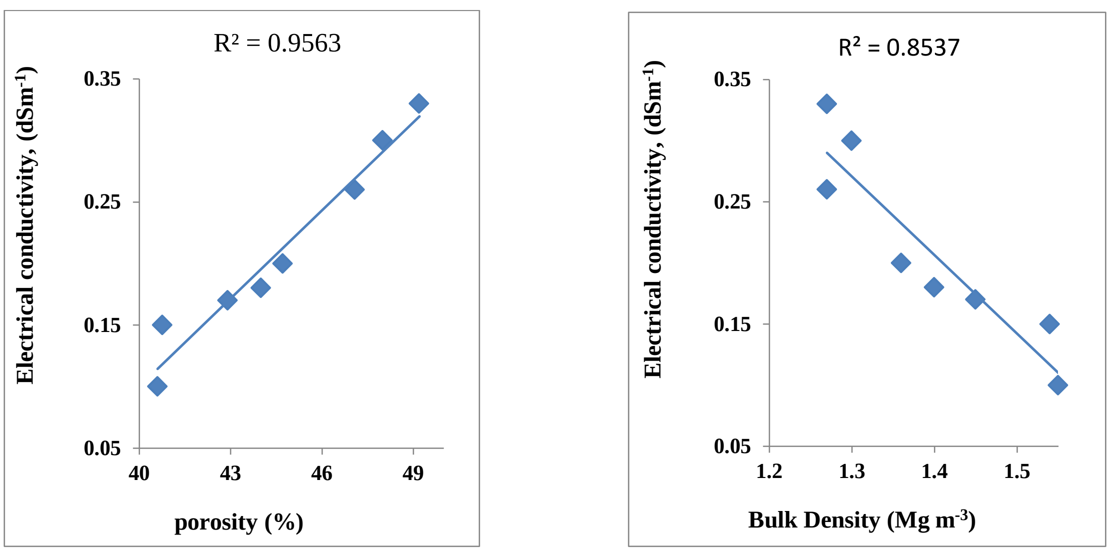


(a) (b) (c)

Figure 3: Variation of dielectric constant with texture of black soil samples (S1-S8)

(ii) Relationship of electrical conductivity and dielectric constant with bulk density and porosity of soil

Fig. 4 (a, b) shows the variation of electrical conductivity with bulk density and porosity of black soil samples (S1-S8). Fig. 4 (a) shows a strong positive correlation of electrical conductivity with porosity (R=0.978) and Fig. 5.4 (b) gives a strong negative correlation with bulk density (R= - 0.924) of soil samples. Our results on correlation of EC with porosity and bulk density presented here are in close agreement with the results reported by various investigators [34,36]. They have also concluded that the porosity and bulk density of soils are the most important properties affecting the soil electrical conductivity.

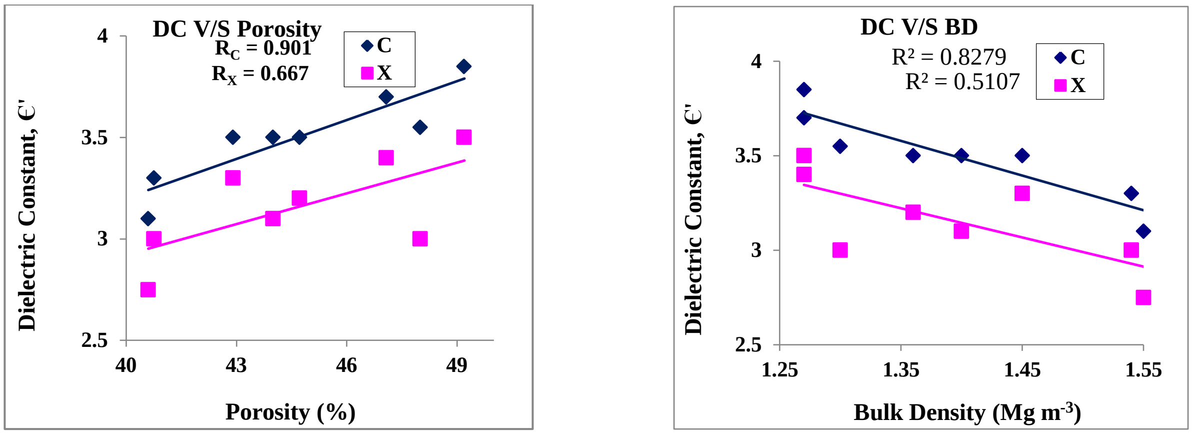


(a) (b)

Figure 4: Variation of Electrical Conductivity with porosity and bulk density of black soil samples (S1-S8)

Further, Fig. 5 (a) shows a strong positive correlations of dielectric constant with porosity (Rc=0.901; Rx=0.667) and Fig. 5 (b) gives a strong negative correlations with bulk density (Rc= - 0.91; Rx= - 0.715) of soil samples respectively. It is further observed that the relationships of dielectric constant with porosity and bulk density of soil samples are relatively more positive and more negative at frequency 4.6 GHz in C-band than at 10 GHz in X-band. This also gives the frequency dependence of the correlation factor among dielectric constant and porosity and bulk density.

It is thus concluded that the electrical conductivity and dielectric constant of dry soils show strong positive correlation with porosity and strong negative correlations with bulk density of soil. The magnitude of correlation factor of dielectric constant with porosity and bulk density is relatively more at comparatively lower microwave frequency.



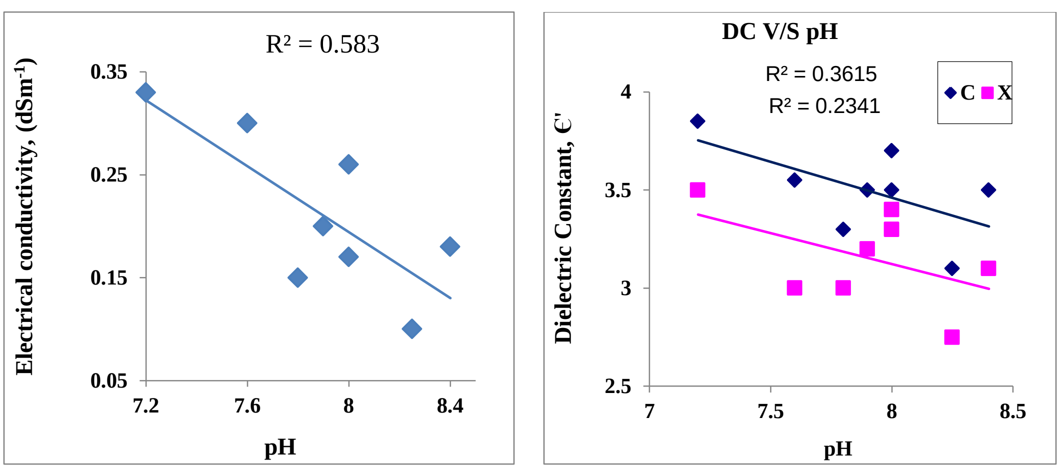
(a) (b)

Figure 5: Variation of dielectric constant with porosity and bulk density of black soil samples (S1-S8)

D. Relationship of electrical conductivity and dielectric constant of soils with its chemical properties

(i) Relationship of electrical conductivity and dielectric constant of soil with its pH

Most of the crops generally grow best if pH is close to neutral (pH= 6 to 7.5) although a few crops prefer acid or alkaline soils. The nutrition, growth, and yields for most of the crops decrease when pH is low and increase as pH rises to an optimum level. In the present work, almost all soils are alkaline (pH = 7.2 to 8.4) in nature. Alkaline soils are usually deficient with phosphorus, iron, copper, zinc, and boron.



(a) (b)

Figure 6: Variation of Electrical Conductivity and dielectric constant with pH of black soil samples (S1-S8)

Form Fig. 6 (a), it can be seen that the electrical conductivity has strong negative correlation with pH (R=-0.764) of soil samples. Dielectric constant has comparatively less but significant negative correlation with pH (Rc = - 0.601; Rx= -0.484) of these soil samples (Fig. 6, b). Again from Fig. 6 (b), it is evident that the correlation of dielectric constant with pH of soil samples is relatively more negative at frequency 4.6 GHz (C-band) than at 10 GHz (X-band). Thus both, the electrical conductivity and dielectric constant of soils have negative relationship with pH. Similar results were reported by several investigators [6,27,28,37]. However, the studies reported by few other investigators [38,39] showed exactly opposite trends. Again, it is further noted that the correlation between dielectric constant and pH of soils is also frequency dependent and its magnitude is higher for relatively lower frequency.

(ii) Relationship of electrical conductivity and dielectric constant with status of Macronutrients in the soil

Our results presented in Fig. 7 (a-e) show strong positive correlations of electrical conductivity of soil samples with available macronutrients such as nitrogen (R = 0.941), phosphorus (R=0.947), potassium (R=0.932), Ca (R=0.860) and Mg (R=0.865) content.

Figure 7: Variation of Electrical Conductivity with macronutrients N, P, K,Ca and Mg of black soil samples (S1-S8)

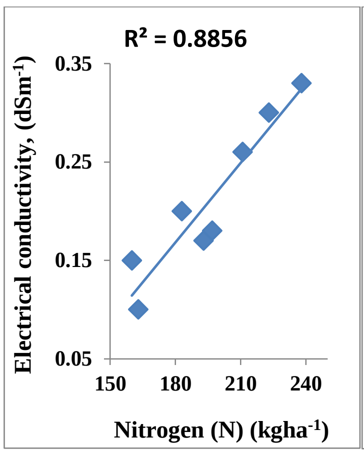


Fig. 7 (a)

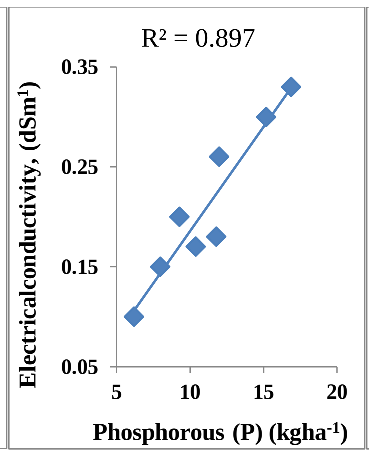


Fig. 7 (b)

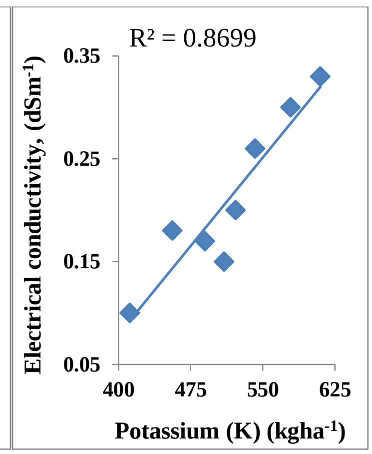


Fig. 7 (c)

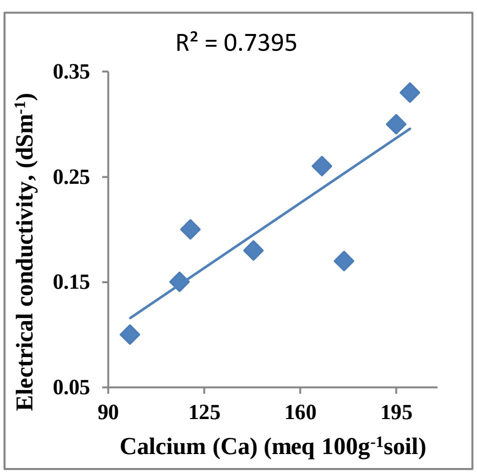


Fig. 7 (d)

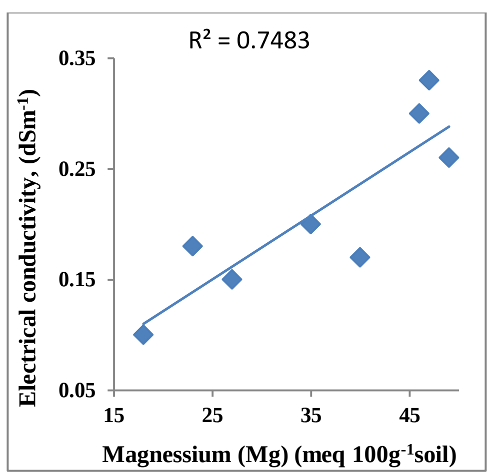


Fig. 7 (e)

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Similarly Fig. 8 (a-e) show strong Positive correlations of dielectric constant of soil samples with available nitrogen (Rc=0.898; Rx=0.679), phosphorus (Rc=0.877; Rx=0.628), potassium (Rc=0.822; Rx=0.658), Ca (Rc=0.830; Rx=0.668) and Mg (Rc=0.843; Rx=0.760) content. Comparing the correlation values of Rc and Rx for each of these macronutrient with dielectric constant confirm the frequency dependence. Thus, the correlations between dielectric constant and available macronutrients in the soils are stronger at frequency 4.6 GHz (C-band) than at 10 GHz (X-band). Our results discussed here also show good agreement with the results of earlier investigators on soil characteristics [37].

Figure 8: Variation of Dielectric Constant with macronutrients N, P, K, Ca and Mg of black soil samples (S1-S8)

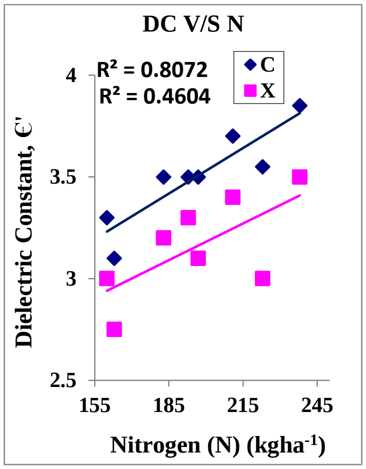


Fig. 8 (a)

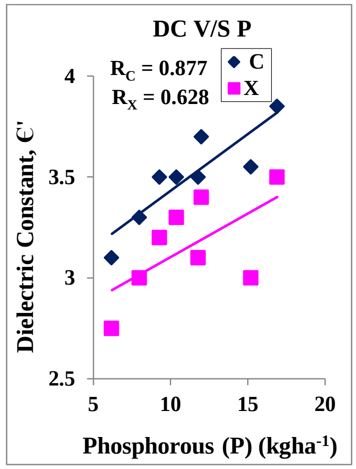


Fig. 8 (b)

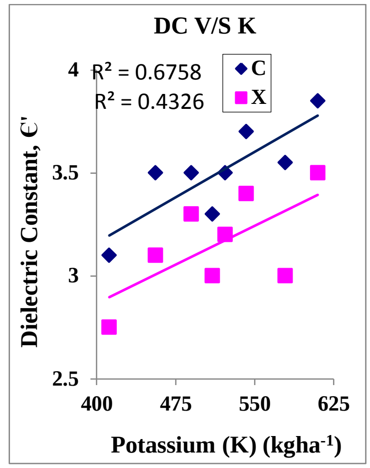


Fig. 8 (c)

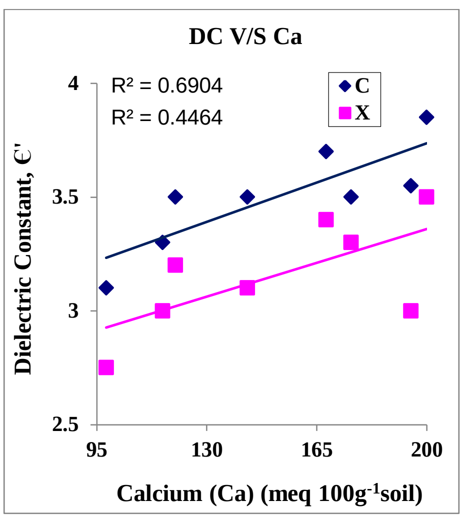


Fig. 8 (d)

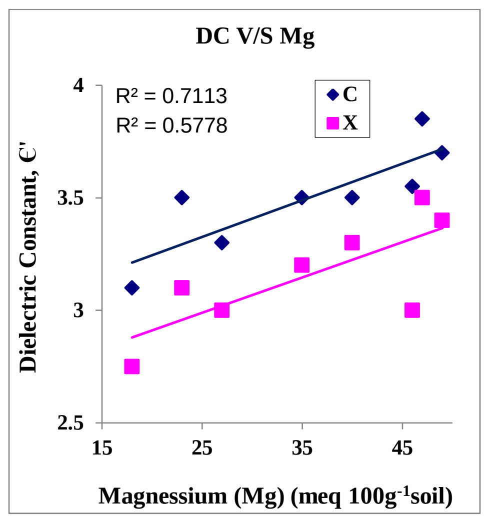


Fig. 8 (e)

(iii) Relationship of electrical conductivity and dielectric constant with status of Micronutrients in the soil

Results on correlations of Electrical conductivity with Micronutrients in the soils are graphically shown in Fig. 9 (a-d). It gives strong positive correlations of electrical conductivity with available micronutrients such as Fe (R = 0.779), Mn(R=0.876), Zn (R=0.867) and Cu (R=0.749) in the soil. Similarly Fig. 10 (a-d), show strong positive correlations of dielectric constant with available micronutrients such as Fe (Rc=0.54; Rx=0.347), Mn (Rc=0.836; Rx=0.770), Zn (Rc=0.773; Rx=0.640) and Cu (Rc= 0.835; Rx=0.733). These results clearly indicate the frequency dependence of correlation coefficient of dielectric constant of soils with their available micronutrients. The relative values of correlation coefficients of dielectric constant with available micronutrients for black soil samples are comparatively more at frequency 4.6 GHz (C-band) than at 10 GHz (X-band). Results presented in Figs. (9-10) are in close agreement with the results of Rana L. et al. [37] and Vijayakumar R. et al. [38], while partially agree with the results of Mali V.S., et al. [39] and Sillanpää M. [40].

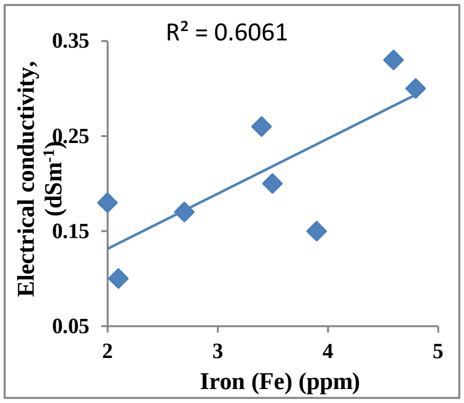


Fig. 9 (a)

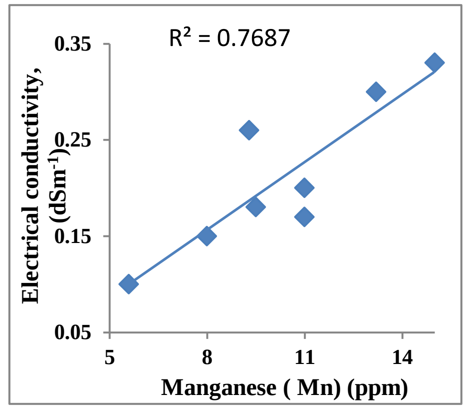


Fig. 9 (b)

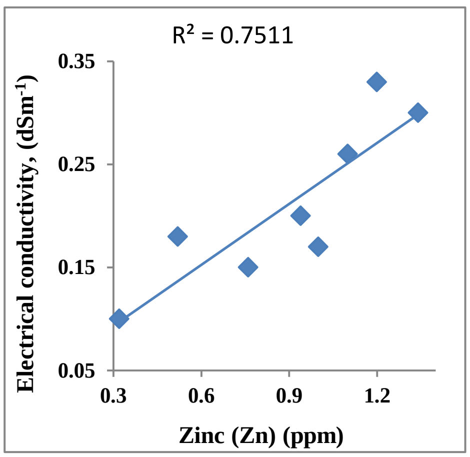


Fig. 9 (c)

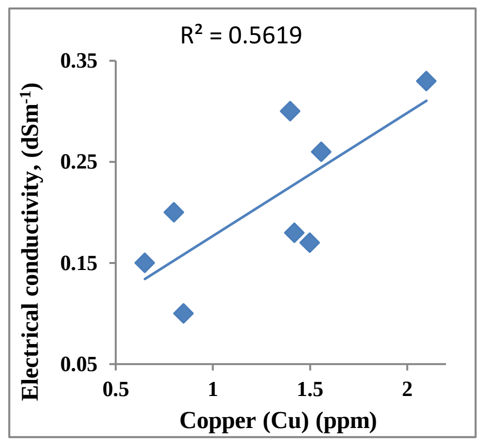


Fig. 9 (d)

Figure 9: Variation of Electrical Conductivity with micronutrients Fe, Mn, Zn and Cu of black soil samples (S1-S8)

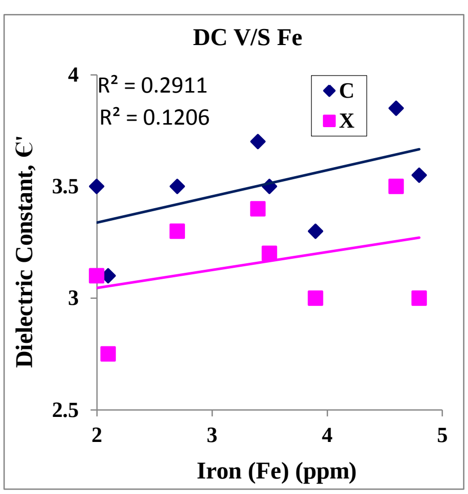


Fig. 10 (a)

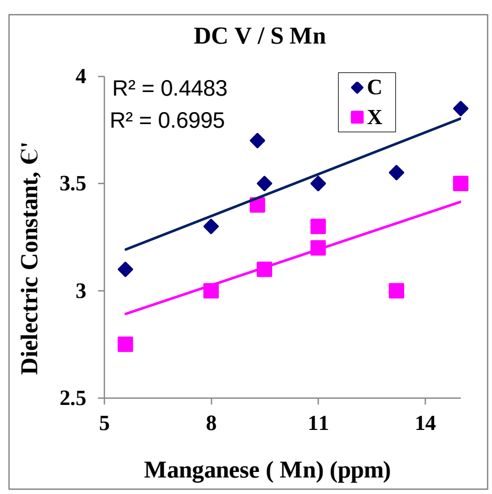


Fig. 10 (b)

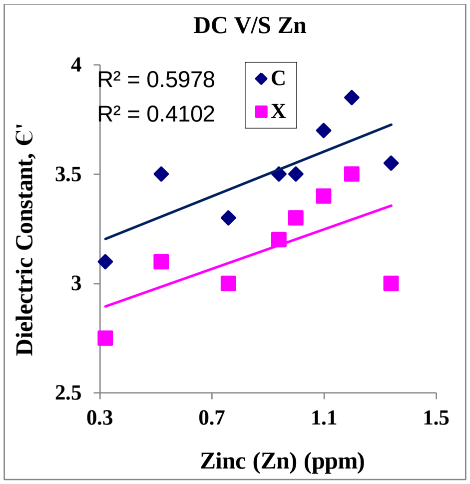


Fig. 10 (c)

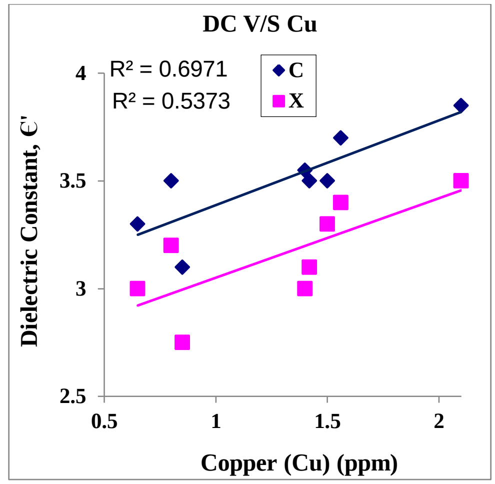
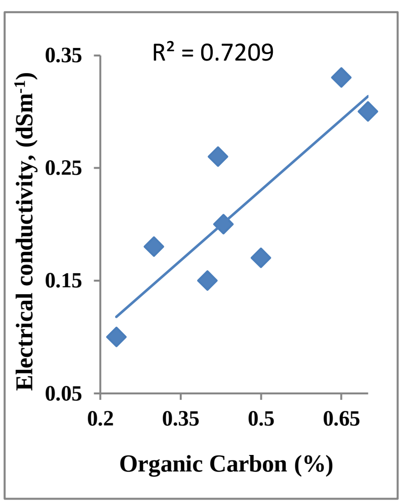


Fig. 10 (d)

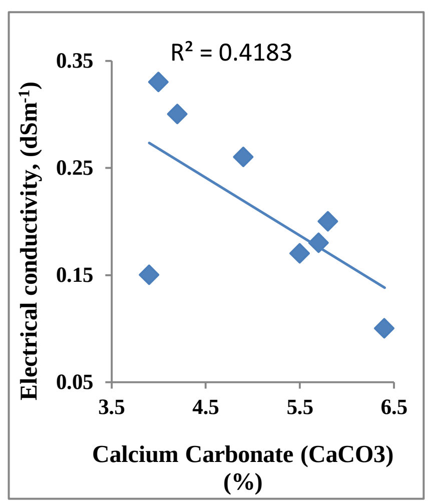
Figure 10: Variation of Dielectric Constant with micronutrients Fe, Mn, Zn and Cu of black soil samples (S1-S8)

(iv) Relationship of electrical conductivity and dielectric constant of soils with organic carbon and $CaCO_3$

The availability of plant nutrients is influenced by the amount of carbonates in the soil. This is due to the effect of carbonates on soil pH and also on nutrient availability. The work reported by Pe´rie´ C. and Ouimet R. [41] and Sakin E. [42] have indicated the negative correlation between bulk density and organic carbon content of soil. Our results reported in Figs. 4 (b) and 5 (b) also show negative correlation of bulk density with electrical conductivity and dielectric constant of soil. Thus, it is quite evident that electrical conductivity and dielectric constant of soil should be correlated positively with organic carbon content of soil.

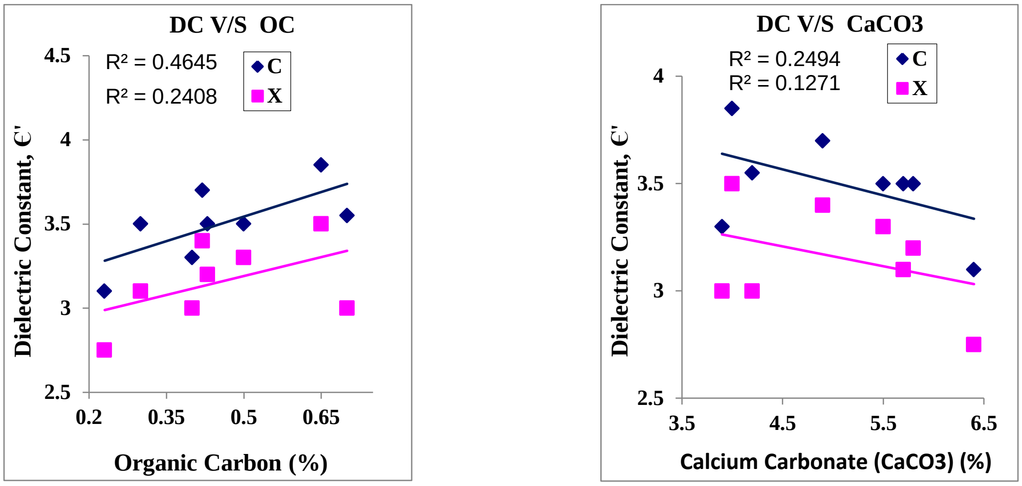


(a)



(b)

Figure 11: Variation of Electrical Conductivity with Organic Carbon and $CaCO_3$ of black soil samples (S1-S8)



(a) (b)

Figure 12: Variation of Dielectric constant with Organic Carbon and $CaCO_3$ of black soil samples (S1-S8)

Fig. 11 gives the variation of electrical conductivity with organic carbon and $CaCO_3$ while Fig. 12 shows the variation dielectric constant with organic carbon and $CaCO_3$ of black soil samples (S1-S8). Our study gives a strong positive and strong negative correlations of electrical conductivity with organic carbon content (R=0.849) and $CaCO_3$ content (R= -0.647) for black soil samples. It further show a positive significant correlation of dielectric constant with organic carbon content (Rc=0.682; Rx=0.491) and negative but less significant correlation with $CaCO_3$ content (Rc=-0.499; Rx=-0.357) for black soil samples. Thus, electrical conductivity and dielectric constant of soil samples are positively correlated with organic carbon content and negatively correlated with $CaCO_3$. Also the correlations of organic carbon and $CaCO_3$ with dielectric constant have frequency dependence. The magnitude of correlation coefficient in both cases is relatively more at frequency 4.6 GHz (C-band) than at 10 GHz (X-band). Thus, our results are found to closely agree with the predictions by earlier investigators [41,42].

IV. CONCLUSIONS

Results of our study presented in Figs. (1-12) are summarized in Table 5. Our results show significant positive correlation of electrical conductivity and dielectric constant with majority of soil parameters except those with sand, bulk density, pH and $CaCO_3$, the correlation factor is negative. Further, values of correlation factors among these soil parameters are relatively more at C-band microwave frequency than X-band, thereby showing their frequency dependence nature. Studies reported here have lot of importance not only for better understanding of soil physics but also in remote sensing applications. Especially, by knowing the correlation coefficient of various soil properties and nutrients with dielectric constant help to understand and analyze the satellite data. The present work thus, will be helpful for the prediction of the soil texture, nutrients type and their concentrations present in the soils from the knowledge of electrical conductivity and dielectric constant.

Table 5: Correlation coefficient of electrical conductivity and dielectric constant for dry soils (S1-S8) with their physical constituents and nutrient concentrations

Correlation with / Soil Parameter	Electrical Conductivity	Dielectric Constant	
	Correlation Coefficient R	**Correlation Coefficient Rc (C- band)**	**Correlation Coefficient Rx (X-band)**
Sand	-0.886	-0.956	-0.840
Silt	0.385	0.594	0.617
Clay	0.938	0.846	0.657
Porosity	0.978	0.901	0.667
BD	-0.924	-0.91	-0.715
EC	---	0.895	0.662
pH	-0.764	-0.601	-0.484
N	0.941	0.898	0.679
P	0.947	0.877	0.628
K	0.932	0.822	0.658
Ca	0.860	0.831	0.668
Mg	0.865	0.843	0.760
Fe	0.779	0.540	0.347
Mn	0.876	0.836	0.770
Zn	0.867	0.773	0.641
Cu	0.749	0.835	0.733
OC	0.849	0.682	0.491
$CaCO_3$	-0.647	-0.499	-0.357

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