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Research Article

Variation of dielectric constant of dry soils with their physical constituents and available nutrients At C-band Microwave Frequency

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ABSTRACT

The objective of this paper was to study the variability of the dielectric constant of dry soils with their physical constituents and available nutrients. The soil samples were collected from 10 different locations of North Maharashtra region at the depth of 0 – 15 cm. The soils were found to be slightly alkaline, non-saline and moderately calcareous in nature. Soil samples were analyzed for physico-chemical properties and for the status of available nutrients. The dielectric constant of dry soil samples was measured at C- band microwave frequency 4.5 GHz and its variations with physical constituents and nutrients of soil samples were presented. The results were analyzed statistically, which showed the strong significant correlation between dielectric constant and texture of the soil. Similarly significant correlation was observed between dielectric constant and available nutrients in the soil except nitrogen, phosphorus and manganese.

Keywords: Dry soils, Dielectric constant, microwave frequency, texture, nutrients.

INTRODUCTION

The properties of dry soil along with its type have a great importance in agriculture. The soil has physical, chemical as well as electrical properties. Colour, texture, grain etc. comprise the physical properties, Nutrients, organic matter, pH etc. comprise chemical properties while the electrical properties include dielectric constant, electrical conductivity and permeability. For microwave remote sensing dielectric constant is the primary important electrical property for dry soil. However due to dependence of dielectric constant on the physical constituents and chemical composition of the soil, the study of its variability with physical constituents and chemical composition is required. Soil is an intimate mixture of organic and inorganic materials, water and air. The relative amount of air and water present depends on way the soil particles are packed together. Soil texture is characterized by percentage of sand, silt and clay in it.

Depending upon the percentage of each constituent, the soil texture is differently named. The colour of soil is due to the colours of their constituents. Soil provides steady supply of nutrients to plants for their growth. Soil fertility is determined by the presence or absence of nutrients. The essential macronutrients required for the growth of the plants are carbon, hydrogen, oxygen, nitrogen, phosphorous, potassium, sulphur, calcium and magnesium. Air and water are sources of carbon, hydrogen and oxygen while the other macronutrients are obtained from the soil. The essential micronutrients are zinc, copper, iron, manganese, molybdenum, chlorine and boron. The availability of nutrients is particularly sensitive to changes in soil environment.

The measurement of dielectric constant of soil as a function of moisture content has been carried out over wide frequency range in the past several years using soils of widely different texture structures by Wang and Schmugge[1]. Calla et al[2] have studied the dielectric properties of dry and wet soil at microwave frequencies and reported that the dielectric constant of soil is strongly dependent on moisture content. Sharif [3] has reported the effect of Chemical and Mineral Composition of dust on dielectric constant. Srivastava and Mishra[4] have studied the characteristics of soils of Chhaisgarh at X – band frequency and reported that dielectric constant of soils are strongly dependent on soil moisture and texture. Calla et al[5] have studied the variability of dielectric constant of dry soil with its physical constituents at microwave frequencies. Gadani and Vyas[6] have also reported the variation of dielectric constant with the sand content in the dry soil. Namdar-Khojasteh et al[7] 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 and Shinde [8] have reported that the dielectric properties of dry soil at microwave frequency in X- band are function of its chemical constituents and physical properties. Calla et al[9] have showed that the variations of dielectric constant for different soils depend on the physical composition of soil. They reported decrease in dielectric constant with increasing of sand percentages, whereas it increases with the increase in silt and clay. Sengwa and Soni[10] have studied the variation of dielectric constant with density of dry minerals of soil at 10.1 GHz. The electrical conductivity of soil water is a good indicator of amount of nutrients available for crops to absorb as reported by Resources, Martin Capewell[11].

The present work provides the information about dielectric constant of dry soil at C- band microwave frequency 4.5 GHz and its relationship with the physical constituents and nutrient concentrations of ten soil samples collected from various locations in North Maharashtra Region.

MATERIALS AND METHODS

Study Area: North Maharashtra Region is located in the Northern part of Maharashtra. The climate of this area is hot and dry. The rainfall varies between 250 mm to 700 mm annually which is mostly received during month of June to September. In summer maximum temperature ranges between 40 ^{0}C to 45 ^{0}C and in winter minimum temperature varies between 9 ^{0}C to 15 ^{0}C.

Soil Sampling: The aim of this study was to determine the dielectric constant of dry soil samples and its variation with the soil properties and available nutrients of soil in North Maharashtra region. Before sampling 15 mm topsoil was removed. Soil samples were collected from ten different locations at the depth of 15cm. in zigzag pattern across the required areas. Five pits were dug for each sample. A composite sample of about 2 Kg. was taken through mixing of represented soil sample. These soils were first sieved by gyrator sieve shaker with approximately 2 mm spacing to remove the coarser particles. The sieved out finer 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 Physical and Chemical Properties: The samples were analyzed for the status of available nutrients by standard analytical methods from Govt. College of Agriculture, Dhule. The physical properties and nutrient concentrations of soil samples are represented in **Tables 1 and 2** respectively.

Table 1: Physical Properties of Soil Samples

Sample No.	Sand %	Slit %	Clay %	WP	Wt
1	31.50	34.30	34.20	0.2117	0.2687
2	42.00	25.00	33.00	0.1993	0.2626
3	36.00	33.00	31.00	0.1935	0.2598
4	31.00	33.60	35.40	0.2178	0.2717
5	67.12	11.56	21.33	0.1272	0.2273
6	31.47	22.22	46.31	0.2699	0.2972
7	81.29	13.53	05.18	0.0406	0.1848
8	77.86	16.80	05.34	0.0435	0.1863
9	71.11	17.87	11.01	0.0751	0.2017
10	63.54	20.20	16.26	0.1051	0.2165

Table 2: Physico- chemical analysis of soil samples

Soil properties			Sample No.									
			1	2	3	4	5	6	7	8	9	10
DC			4.25	4.3	4.05	3.95	3.91	4.05	3.55	3.66	3.31	3.61
pH			7.7	7.9	7.9	8.0	7.7	7.4	7.5	7.7	7.6	8.2
EC		ds/m	0.25	0.19	0.18	0.18	0.23	0.21	0.1	0.2	0.15	0.14
Macronutrients	N	kg/ha	188	163	238	176	201	251	88	138	226	151
	P		8	4	5	4	4	3	4	4	4	4
	K		906	863	1034	991	1211	738	486	547	630	585
	Ca	meq/ 100gm	39.6	59.2	34.8	46.8	20.5	18.1	3.8	5.4	7.8	11.5
	Mg		13.8	12.4	13.3	11.6	10.2	11.2	1.8	2.4	2.7	3.8
Micronutrients	Fe	ppm	8	8.9	8	6.2	15.2	13.5	13.4	15.4	13.1	11
	Mn		19.62	10.83	14.19	9.800	18.92	16.51	17.1	19.37	18.48	14.37
	Zn		0.83	0.43	0.59	0.36	0.88	0.67	0.89	0.84	1.23	0.68
	Cu		4.29	1.92	3.71	1.71	2.65	3.06	0.9	1.48	1.41	1.65
OC		%	0.33	0.21	0.3	0.12	0.63	0.66	0.19	0.44	0.69	0.47
CaCO3			3.00	5.50	8.75	5.75	1.50	1.75	0.25	0.50	1.25	2.50

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

$$WP = 0.06774 - 0.00064 \times Sand\ (\%) + 0.00478 \times Clay\ (\%) \quad (1)$$
$$W_t = 0.49 \times WP + 0.165 \quad (2)$$

Measurement of Dielectric Constant of dry Soil Samples: The waveguide cell method is used to determine the dielectric properties of the dry soil samples. An automated C-band microwave set-up in the TE_{10} mode with Gunn source operating at frequency 4.5 GHz, 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^o-35^o C. Other details of dielectric constant measurement with C-band microwave bench set-up can also be seen from **Fig.1**

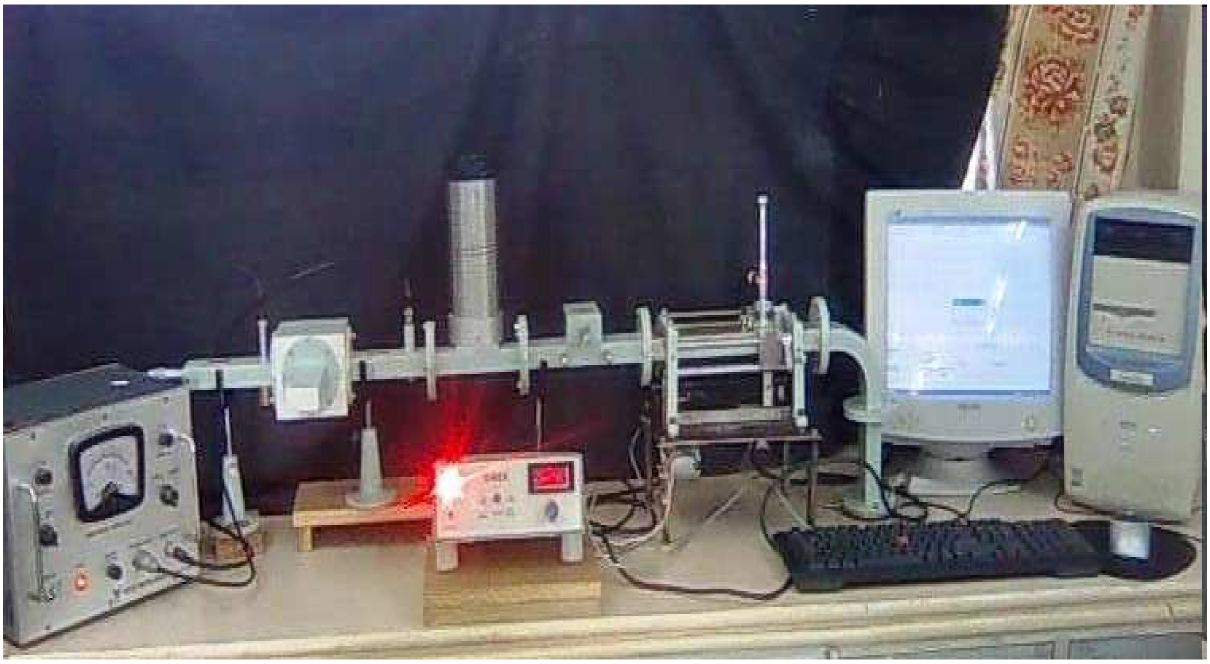

Fig.1: Photograph of C-band microwave bench set-up for measuring dielectric constant

The dielectric constant ε' of the soils is then determined from the following relation:

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

Where, a = Inner width of rectangular waveguide.

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

g_ε = real part of the admittance

Statistical analysis: The relationship between dielectric constant and nutrient concentration of soils were determined using correlation coefficient “r”.

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}} \quad (4)$$

Where n is the number of pairs of data (x, y).

Simple correlation coefficients (r) between dielectric constant and nutrient concentration of soils listed in **Table 3.**

Table 3: Simple correlation coefficients (r) between Dielectric constant (DC) and soil properties

Soil properties		Correlation Coefficient(r)
Texture	Sand	- 0.8025
	Silt	0.621
	Clay	0.8080
pH		- 0.1224
Electrical Conductivity		0.6804
Macronutrients	Nitrogen (N)	0.2738
	Phosphorus (P)	0.3949
	Potassium (K)	0.6269
	Calcium (Ca)	0.8331
	Magnesium (Mg)	0.9181
Micronutrients	Iron (Fe)	- 0.5440
	Manganese (Mn)	- 0.3420
	Zinc (Zn)	- 0.6738
	Copper (Cu)	0.7
Calcium Carbonate ($CaCO_3$)		0.5745
Organic Carbon (OC)		- 0.3577

RESULTS AND DISCUSSION

The sand, silt and clay of collected samples ranges from 31- 81.29, 11.56 - 34.3 and 5.18 - 46.31 %

respectively and these soils were categorized as sandy loam, loamy sand, sandy clay loam and clay. Six samples were lightly calcareous (0.25 - 2.5 %) while four samples were moderately calcareous (3.00 - 8.75 %) in nature. The pH (7.4 - 8.2) and electrical conductivity (0.1 - 0.25 ds/m) values indicated that soils were found to be slightly alkaline and non saline.

According to Methods Manual of Soil Testing in India[12] the critical limits of Nitrogen(N), Phosphorus (P) and Potassium (K) for normal growth of plant were 280 kg/ha, 10 kg/ha and 108 kg/ha respectively. Consideration of these the available N (88 - 251 kg/ha) and P (3 - 8 kg/ha) of soils were very low, while the available K (486 -1211 kg/ha) was very high.

All soil samples were contain adequate amount of available Calcium (Ca) (3.8 - 59.2 meq/100 gm) and Magnesium (Mg) (1.8 -13.8 meq/100 gm).

With reference to the critical limits of Iron (Fe), Manganese (Mn), Zinc (Zn) and Copper (Cu), reported by Lindsay and Norvell[13] for normal growth of plants, the soil samples appeared to be sufficient in available Fe (6.2 - 15.4 ppm), Mn (9.8 - 19.62 ppm), Zn (0.59 - 1.23 ppm) and Cu (0.9 - 4.29 ppm)

(a). Relationship between Dielectric Constant and physical constituent's sand, silt and clay of soil

Soil texture can be expressed significantly by its electrical conductivity and dielectric constant. Clay textured soil is highly conductive while sandy soils are poor conductors; reported by Marx et al[14]. Kumar M. and Babel A.L.[15] reported that the availability of micronutrients increased significantly with the increase in finer fractions (silt and clay). Similarly the availability of micronutrients indicates positive and significant correlation with electrical conductivity of soils. Further positive significant correlation (r = 0.6804) was observed between electrical conductivity and dielectric constant of soil samples.

Simple correlation studies showed high degree of relationship between dielectric constant of soil with its physical constituents viz sand, silt and clay. Strong positive and strong negative relationship of dielectric constant with clay content (r = 0.8080) and sand content (r = - 0.8025) of soil respectively was found. While positive significant correlation was observed between dielectric constant of soil and silt content (r = 0.6213).

Variation of dielectric constant as a function of sand, silt and clay content are shown in **Figs. 2, 3 and 4** respectively. From graphs it is observed that dielectric constant decreases with the increase of sand percentages, whereas it increases with the increase in percentages of silt and clay.

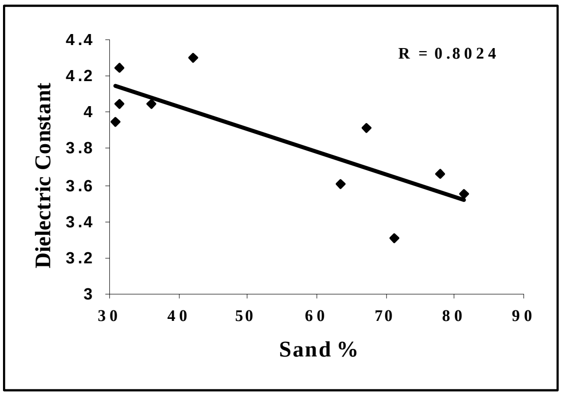

Fig.2: Variation of Dielectric Constant as a function of Sand content

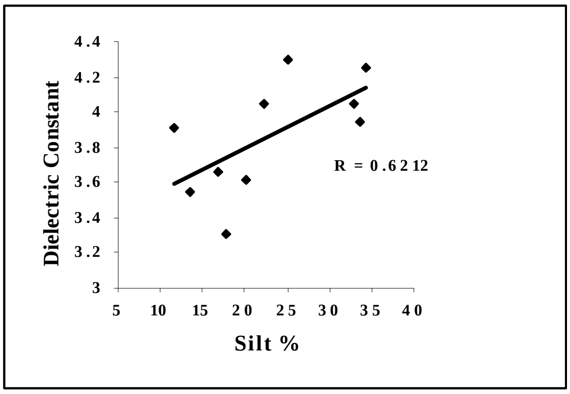

Fig.3: Variation of Dielectric Constant as a function of Silt content

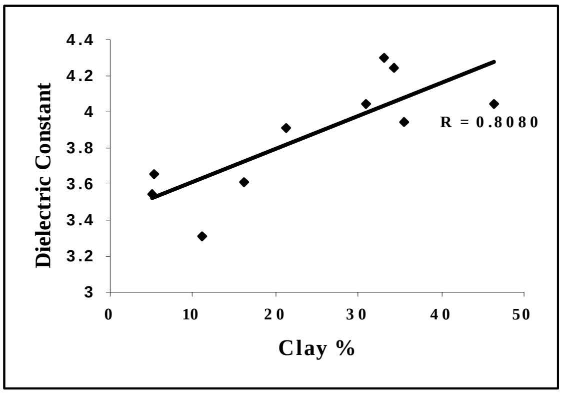

Fig.4: Variation of Dielectric Constant as a function of Clay content

(b).Relationship between Dielectric Constant, pH and Macronutrient status of soil

(i).Available N, P, K – Correlation studies of available nitrogen, phosphorus and potassium with pH of soil samples did not show any relationship. Positive but not so significant correlation was found between dielectric constant of soil samples and available nitrogen (r = 0.274) and phosphorus (r = 0.395) while positive significant correlation between dielectric constant and available potassium (r = 0.6269) was observed.

(ii).Available Ca and Mg – Positive but not significant correlation was observed between Ca and Mg content of soil with its pH. Strong positive correlation was found between Ca (r = 0.8331) and Mg (r = 0.9182) content of soil with its dielectric constant.

(c).Relationship between Dielectric Constant, pH and Micronutrient status of soil

(i).Available Cu, Fe, Mn, and Zn – Strong positive correlation was observed between dielectric constant and available Cu (r = 0.7) while significant negative correlation of dielectric constant was observed with available Fe (r = - 0.544) and available Zn (r = - 0.674). Negative but not significant correlation was found between dielectric constant and available Mn (r = - 0.342).

Negative significant correlation of available Fe (r = - 0.5664), available Mn (r = - 0.607) and available Zn (r = - 0. 5371) with pH of soil was found. There was no any significant correlation between available Cu and pH of soil.

(d).Relationship of Dielectric Constant with Organic Carbon and $CaCO_3$ content of soil

Dielectric constant was found to be negatively correlated with organic carbon content (r = - 0.358) of soil samples but not so significant. Positive significant correlation between dielectric constant and $CaCO_3$ content (r = 0.5745) of soil samples was observed.

CONCLUSIONS

The conclusions obtained from the study are as follows

1. The dielectric constants of soils are strongly dependent on the physical constituents of soil i.e. the percent content of sand, slit and clay.
2. High degree of positive correlation of dielectric constant with clay content of soil and negative correlation with sand content of soil was observed.
3. The dielectric constant of soil varies with the status of nutrients available in it.
4. Strong positive correlation of dielectric constant of soil with available Ca, Mg and Cu was found.
5. Dielectric constant of soil has positive significant correlation with available K and $CaCO_3$ of soil while negative significant correlation with available Fe and Zn.

These results are very useful for the scientists working in the field of microwave remote sensing for soils and also for agriculture scientists. From these estimated values of dielectric constant one can estimate emissivity and scattering coefficient that will provide the tools for designing the microwave remote sensing sensors.

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