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Dielectric Study of Soil at X Band Microwave Frequency and Physiochemical Properties

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Abstract:

Dielectric constant of soil collected from Niphad tehsil of Nasik districts for various moisture content have been measured at X band microwave frequency. Electrical properties of soils has been measured at an automated X band microwave setup in TE_{10} mode operating at 9.55 GHz. From the reflected wave it is possible to reveal the information, which is useful for the measurement of dielectric properties. The dielectric properties of material are function of its chemical constituents and physical properties. Soil samples are collected from agricultural land of Niphad of Nasik region. Soil samples were analyzed for physical and chemical properties for the status of available micro nutrients. It has been observed that the dielectric constant of soil depend on the moisture content in the soil. Dielectric constant of soil increase slowly with increase in moisture content in the soil. The observed complex permittivity is used to calculate emissivity of soils for various moisture content.Soil of Niphad tehsil is good for production of grapes as pH range is 5.5-7.0 and it is sandy loam type.

Keywords — **Dielectric constant, Microwave frequency, Emissivity**

INTRODUCTION

Soil is the natural covering on most of the earth's land surface. Soil in its traditional meaning is the natural medium for the growth of land plants. 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. The interaction of electromagnetic waves with the geological material depends upon the complex dielectric permittivity, relative to the free space. The dielectric properties of soil are function of its physical properties such as sand, silt, clay and the chemical properties such as nitrogen, sodium, potassium, iron, magnesium also on the available micronutrients. Researchers working on dielectric properties of soils studied dielectric parameter of different materials with various methods [1-12]. 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.

Every material has a unique set of electrical characteristics that are dependent on its dielectric properties.Accurate measurements of these properties can provide scientists and engineers with valuable information to properly incorporate the material into its intended application. Soil dielectric constant measurements are reviewed and the dependence of the dielectric constant on various soil parameters is determined. Moisture content is given special attention because of its practical significance in remote sensing and because it represents the single most influential parameter as far as soil dielectric properties are concerned. 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. [13] showed that the dielectric constant is directly proportional to pore- space of soil. Results of Yadav V. et al. [14] 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. [15] outlined the necessity of soil test to determine status of available nutrients and to develop fertilizer recommendations to achieve optimum crop production. Navarkhele V. V. et al. [16] and Shaikh A. A. and Navarkhele V. V. [17] 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. [18] 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. [19] 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. In a non-homogeneous medium such as soil, the dielectric constant is combination of individual dielectric constant of its constituents such as sand, silt, clay, organic and inorganic matter etc. Different studies predict that the dielectric properties of soil at microwave frequencies are the function of its physico-chemical constituents[20-24].

MATERIALS AND METHODS:

Study Area:

Niphad's latitude and longitude coordinates are 20^{0}5’0”N 74°7′0″E. Located northeast of Nashik city Niphad is one of the district's most fertile and flood-prone talukas. Its major rivers are the Godavari and its tributary, the kadwa sugarcane is one of the most important agricultural products and the basis for a sugar refining and alcohol distilling industry,conducted at two cooperative sugar factories..Other major crops include onions, grapes, soybean, tomatoes and flowers, all exported internationally, as well as wheat, gram, and other vegetables and grains (bajra,jowar,tur).Niphad is the largest grape processing location in India.

Soil Sampling:

Soil samples are collected from different locations of Niphad tehsil’s agricultural land at the depth of ranging between 0-20 cm. in zigzag pattern . 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 sites .These topsoil samples are first sieved by gyrator sieve shaker 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.

Theory

The Physical and chemical properties of the soil are measured at soil analysis laboratory. Number of soil samples of different physical and chemical properties are used for study. Out of these physico-chemical and dielectric properties of soils are presented in this paper. The field capacity (FC) can be approximated by the empirical formula on soil composition .

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

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

$$Wp = 0.06774 - 0.00064 \times sand + 0.00478 \times clay$$

$$Wt = 0.45 \times Wp + 0.165$$

The complex dielectric constant is calculated using the relation

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

Where ε'=dielectric constant, ε"=dielectric loss factor Since the dielectric constant of a soil depends on the moisture, the presence of salts in water will also affect its dielectric properties. In irrigation, soil salinity makes it more difficult for plants to absorb soil moisture which affects the plant growth and ultimately crop yield. To keep track of changes in salinity and anticipate further degradation, monitoring was needed . In that paper, the experimentally measured values of the dielectric constant and dielectric loss have been shown for soil with varied salinity levels.

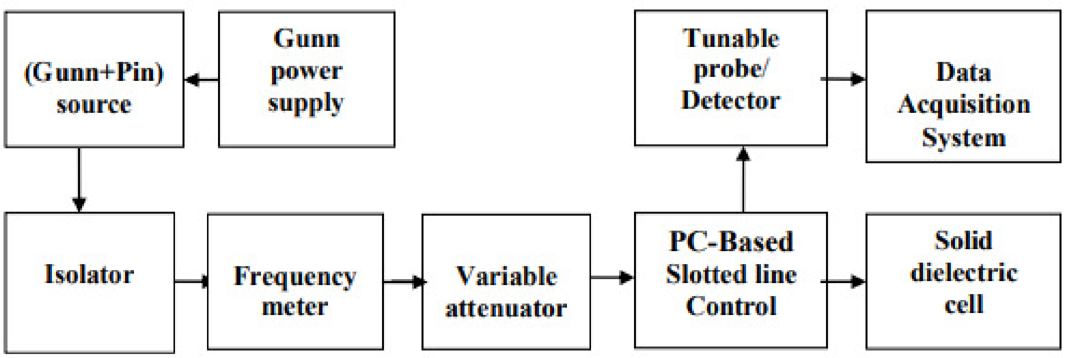


Figure 1: Block diagram of microwave bench setup for measurement of dielectric constant of Soils

The dielectric constant ε', dielectric loss ε" emissivity ep(q) and a.c. conductivity (σ) of these soil samples are then determined from the following relations:

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

and

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

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 emissivity $e_p(\theta)$ for vertical polarization can be written as,

$$e_p(\theta) = 1 - r_p(\theta) = 1 - |R_p(\theta)|$$

$$e_p(\theta) = 1 - \frac{\varepsilon' cos\theta - \sqrt{\varepsilon' - sin^2\theta}}{\epsilon' cos\theta + \sqrt{\varepsilon' - sin^2\theta}}$$

For horizontal polarization,

$$e_p(\theta) = 1 - \frac{\cos\theta - \sqrt{\varepsilon' - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon' - \sin^2\theta}}$$

Where, θ = Angle of observation.

$e_p(\theta)$ = Emissivity of the surface layer.

$r_p(\theta)$ = Reflection coefficient.

$R_p(\theta)$ = Fresnel reflection coefficient

Soils samples of various moisture contents are prepared by adding an exact amount of distilled water to dried soil. The moisture content is percentage by dry weight Wc (%) is calculated using following relation.

Wc (%) = [(weight of wet soil - weight of dry soil) / (weight of dry soil)] x 100

This soil sample was considered as dry or 0 % moisture content soil sample. Then on the basis of volumetric analysis 5%, 10%, 15%, 20%, 25% and 30% moisture content soil samples were prepared and dielectric constant is measured using X band microwave set up.

Result and Discussion:

The study helps in determining the values of different physicochemical parameters and nutrient concentrations of soil from Nasik region.

Physical characterization of soil samples of Niphad Tahsil

Sample No.	Bulk Density (gmcm-1)	Particle Density (gmcm-1)	Water holding capacity (%)	Hydraulic conductivity (cm/hr)	Sand (%)	Silt (%)	Clay (%)	Textural Class
1	1.36	2.22	39	3.53 Moderate	82.12	4.78	13.10	Loamy Sand
2	1.42	2.50	45	2.53 Moderate	62.55	21.97	15.48	Sandy Loam
3	1.16	2.27	62	2.53 Moderate	55.80	30.37	13.83	Sandy Loam
4	1.45	2.13	55	2.82 Moderate	68.12	16.65	15.23	Sandy Loam
5	1.45	2.22	61	3.10 Moderate	64.17	16.83	19.00	Sandy Loam
6	1.33	2.13	56	1.69 Moderate	39.17	30.38	30.45	Clay Loam
7	1.42	1.96	68	2.53 Moderate	60.70	27.10	12.20	Sandy Loam
8	1.25	2.27	55	3.53 Moderate	72.87	19.03	8.10	Loamy Sand
9	1.38	2.13	67	2.12 Moderate	66.15	22.47	11.38	Sandy Loam
10	1.31	2.08	65	3.35 Moderate	64.82	27.10	8.08	Sandy Loam

Table No.1 Physical characterization of soil samples of Niphad Tahsil

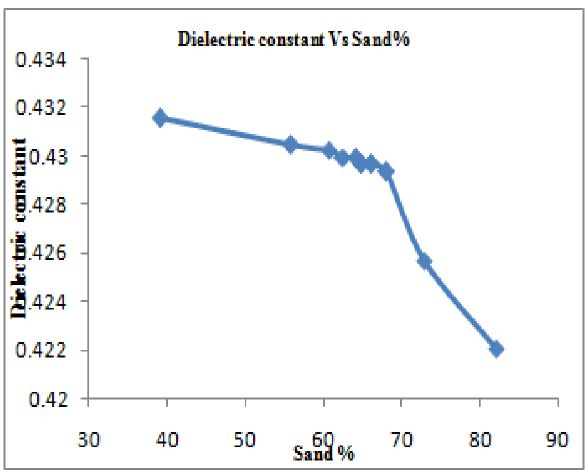
It is observed that the value of dielectric constant increases as moisture content increases. The value of dielectric loss increases as moisture content increases. Our results get confirmed with the result reported for black and red soils by H. C. Chaudhari et.al.(12) and Study of characteristics of the soil of Chhattisgarh at X-band frequency by S. K. Srivastav et.al.(13).

Electrical characterization

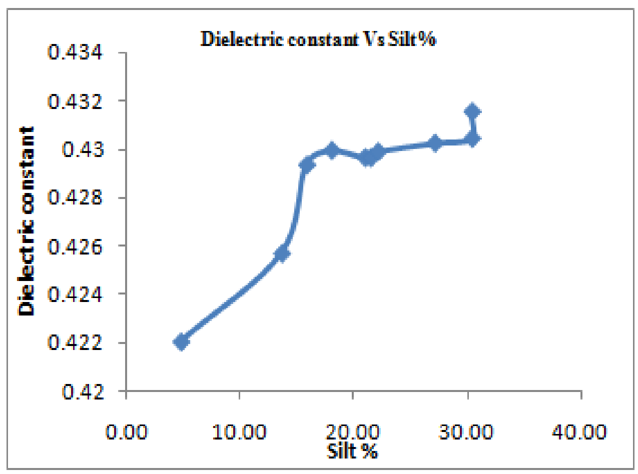
Dielectric constant	Dielectric loss	Tangent loss	Microwave conductivity	Emissivity
0.4803	0.0281	0.0585051	0.013899502	0.967126962
0.43805	0.02675	0.0610661	0.013231732	0.958597702
0.4725	0.02402	0.050836	0.011881354	0.965676877
0.48195	0.03595	0.0745928	0.017782459	0.967426997
0.48555	0.035235	0.0725672	0.017428788	0.968073655
0.4827	0.03254	0.0674125	0.016095722	0.967562615
0.43805	0.02675	0.0610661	0.013231732	0.958597702
0.48355	0.035557	0.0735322	0.017587816	0.967715742
0.48195	0.03595	0.0745928	0.017782459	0.967426997
0.4861	0.03864	0.0794898	0.019113052	0.968171497

Table No.2 Electrical characterization of soil samples of Niphad Tahsil

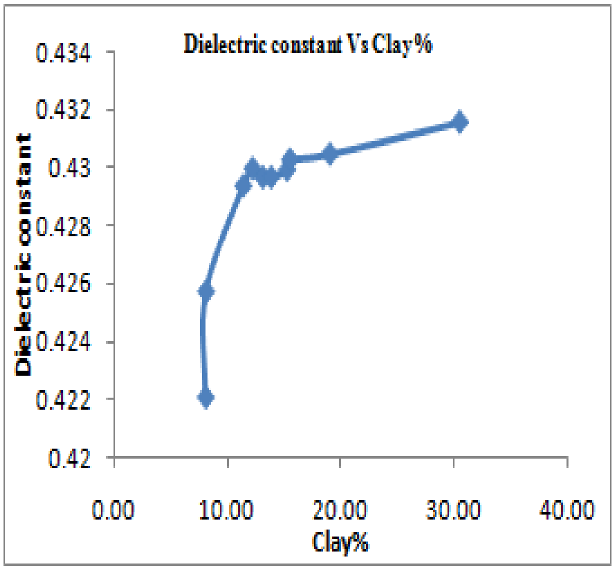
Soil texture can be expressed significantly by its electrical conductivity and dielectric constant. From graph1,2 and 3, it is observed that dielectric constant decreases with increase of sand percentages whereas it increases with the increase in percentage of silt and clay in soil.



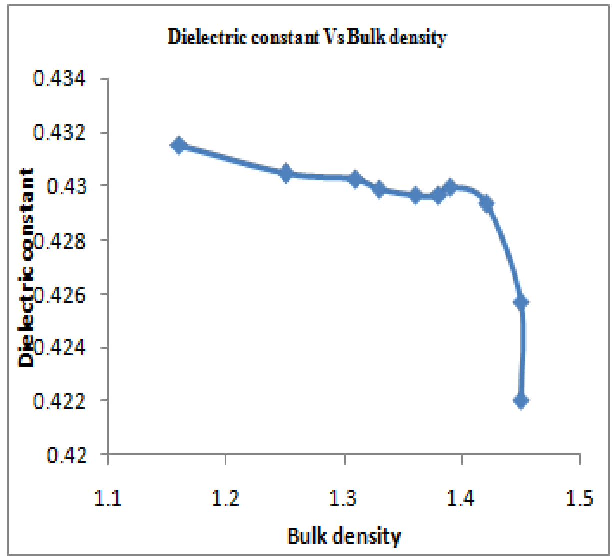
Graph 1:variation of dielectric constant with sand %



Graph 2: variation of dielectric constant with Silt%

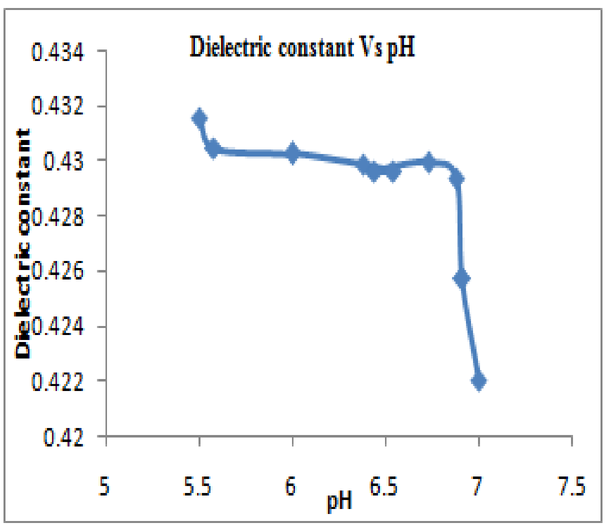


Graph 3:variation of dielectric constant with clay %

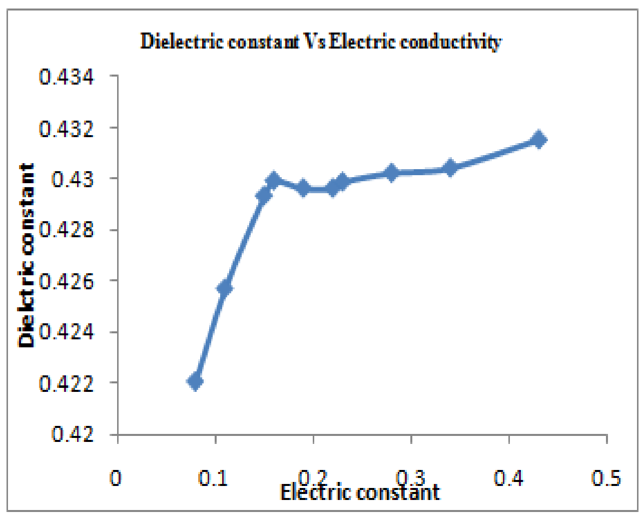


Graph 4:variation of dielectric constant with Bulk density

From graph 4, it is observed that dielectric constant has positive correlation with bulk density. Important physical properties such as soil texture, bulk and particle density and chemical properties such as pH, EC, OC, CaCO3 available macronutrients N, P, K, Ca, Mg, micronutrients Fe, Mn, Zn, Cu, etc. of the soil samples are determined.



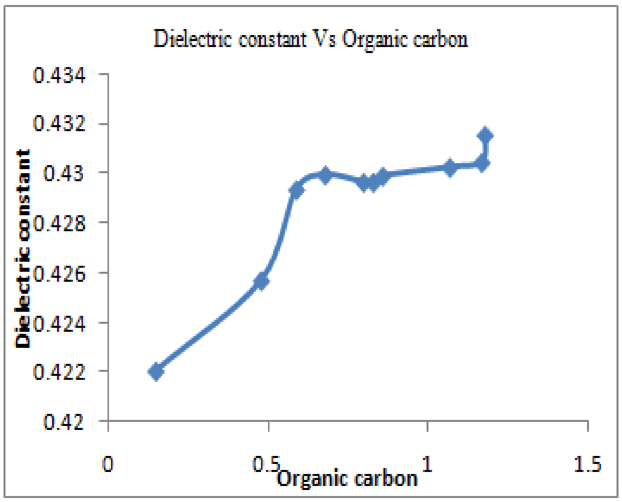
Graph 5: variation of dielectric constant with pH



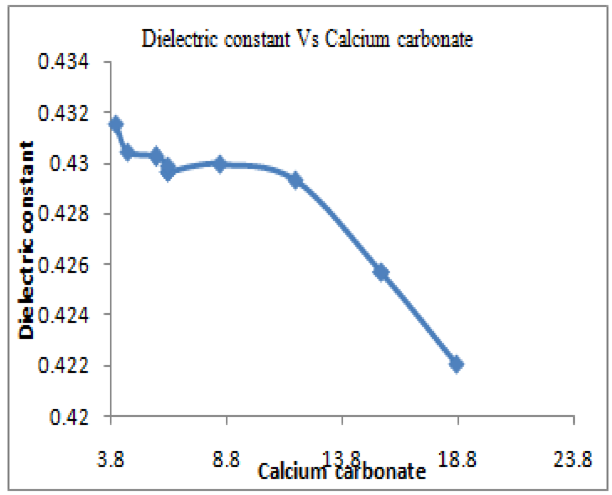
Graph 6: variation of dielectric constant with Electric conductivity

Soil pH is a measure of the acidity and alkalinity in soils. pH levels range from 0 to 14, with 7 being neutral, below 7 acidic and above 7 alkaline. The optimal pH range for most plants is between 5.5 and 7.0. Even if the vineyard has a proper soil pH at the time of planting, it will be necessary to occasionally conduct soil tests to determine if it has changed over time. Soils will gradually acidify over time due to the removal of cations like calcium, potassium, or magnesium either by leaching or uptake by plants, acid rain, or the reaction of certain nitrogen fertilizers in the soil (e.g., urea and ammonium nitrate). We generally recommend that soil samples be collected every four to five years in a particular location, unless the grower is in the process of changing pH or nutrient levels. Soil pH is a routine measure that should be included in any basic soil analysis.

Electrical conductivity (EC) is a measurement of the dissolved material in an aqueous solution, which relates to the ability of the material to conduct electrical current through it. EC is measured in units called Seimens per unit area (e.g. mS/cm, or miliSeimens per centimeter), and the higher the dissolved material in a water or soil sample, the higher the EC will be in that material .From graph 6, it is observed that dielectric constant has positive correlation with electrical conductivity.



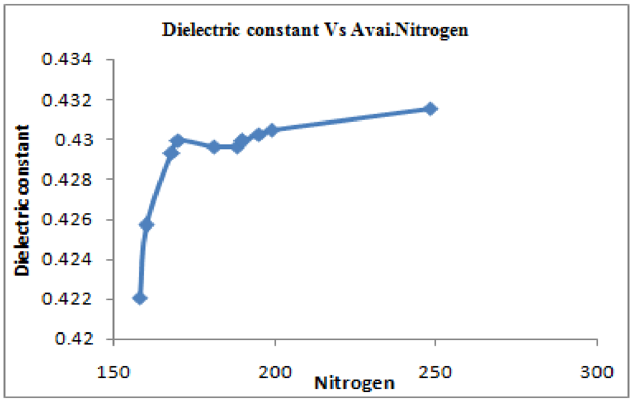
Graph 7: variation of dielectric constant with organic carbon



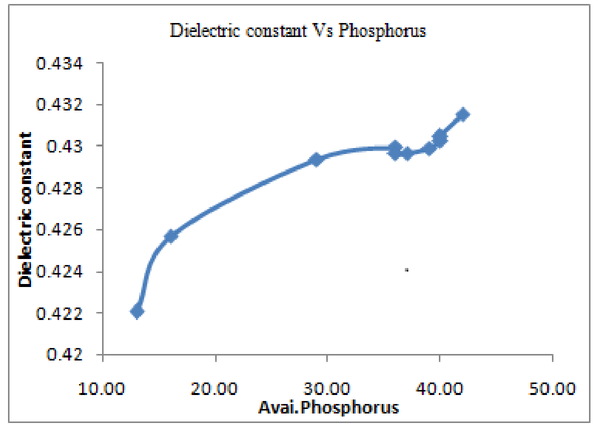
Graph8:variationof dielectric constant with calcium carbonate

Soil organic carbon is the basis of soil fertility. It releases nutrients for plant growth, promotes the structure, biological and physical health of soil, and is a buffer against harmful substances. Increasing the total organic carbon in soil may decrease atmospheric carbon dioxide and increases soil quality. The amount of organic carbon stored in soil is the sum of inputs to soil (plant and animal residues) and losses from soil (decomposition, erosion and off take in plant and animal production).The maximum capacity of soil to store organic carbon is determined by soil type (% clay).Management practices that maximize plant growth and minimize losses of organic carbon from soil will result in greatest organic carbon storage in soil.

Calcium carbonate is one of the cementing agent the participate in the binding of soil particles together through physico-chemical mechanisms and presumably create a stable soil structure. It affects swelling behavior. Clays often more stable when free of CaCo3. It affects dispersion behavior of soil. CaCO3 was found to be very effective against dispersion.CaCO3 changes in the composition of water as they become the soil solution and affect soil permeability. In the presence of CaCO3 excess exchangeable sodium results in high pH of sodic soils.



Graph 9: variation of dielectric constant with nitrogen

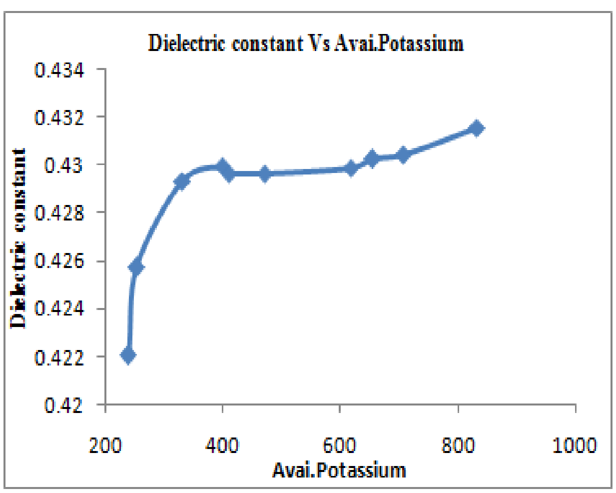


Graph 10: variation of dielectric constant with Phosphorus

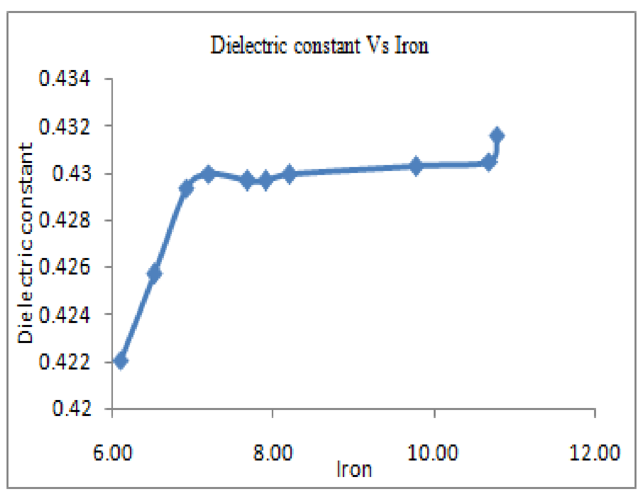
Excess nitrogen fertilizer rates are an environmental hazard. To avoid excess rates, the level of available nitrogen in the soil must be known and considered for assessing the nitrogen fertilizer rate. Numerous sources of N exist and must be considered when evaluating the N budget for any field or region. Nitrogen's mobility factor in the soil must be considered when developing N programs and evaluation environmental effects. Nitrogen loss from the soil system is greatly affected by soil type and climate. Sandy soils may lose N through leaching while on heavy, poorly drained soils it may be lost through denitrification. Because Minnesota has such diverse soils and climate, interpretation of the N cycle should site specific.

Also from graph 9, dielectric constant has positive correlation with nitrogen available in soil.

Phosphorus is a component of the complex nucleic acid structure of plants, which regulates protein synthesis. Phosphorus is, therefore, important in cell division and development of new tissue. Phosphorus is also associated with complex energy transformations in the plant. Adding phosphorus to soil low in available phosphorus promotes root growth and winter hardiness, stimulates tillering, and often hastens maturity. Also from graph 10, dielectric constant has positive correlation with phosphorus available in soil.



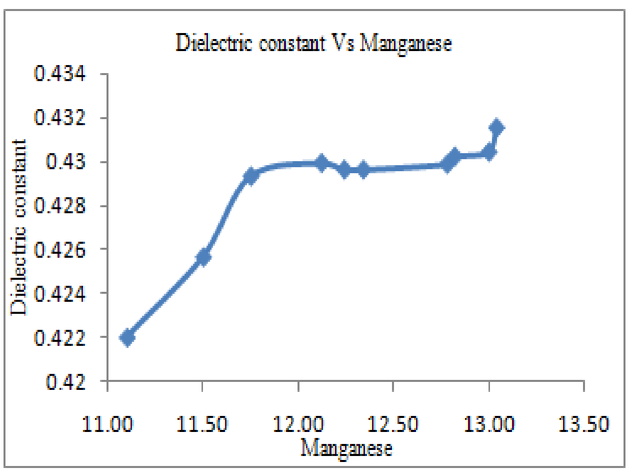
Graph 11: variation of dielectric constant with Potassium



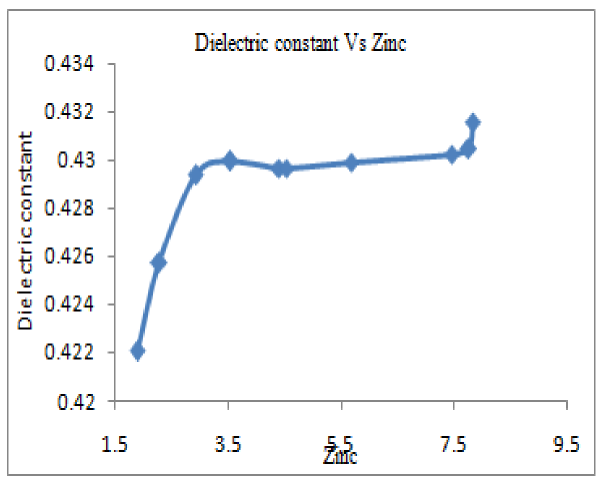
Graph 12: variation of dielectric constant with Iron

The behavior of each plant nutrient in soil is unique. Each nutrient's behavior is a combination of attributes that depends on the parent minerals involved and the solubility and mobility of the nutrient in question. Potassium, unlike nitrogen and phosphorus, is not associated to any great extent with organic matter. Total amounts of potassium in soil will vary from 0.3 to more than 2.5 percent. While total content of potassium is important, it is of little value in determining how well a given soil can supply potassium to growing plants. Potassium is absorbed by plants in larger amounts than either magnesium or calcium; in fact, nitrogen is the only nutrient absorbed in larger amounts than potassium. Potassium is a vital component of numerous plant functions, including nutrient absorption, respiration, transpiration, and enzyme activity. Potassium is unique because it does not become part of plant compounds, but remains in ionic form in the plant. Potassium remaining in plant residues after harvest and in manure are quickly returned to the soil by water leaching through the plant materials and manure.

Iron is the fourth most abundant element found in soil though it is largely present in forms that cannot be taken up by plants. Iron, in small amounts, is essential for healthy plant growth and is classed as a micronutrient. It is important for the development and function of chlorophyll and a range of enzymes and proteins. It also plays a role in respiration, nitrogen fixation, energy transfer and metabolism. As with other nutrients, plants can have too much iron but this primarily affects the uptake of other nutrients rather than producing direct toxicity symptoms. From graph 11,12 dielectric constant has positive correlation with potassium and Iron available in soil.



Graph 13: variation of dielectric constant with Manganese



Graph 14: variation of dielectric constant with Zinc

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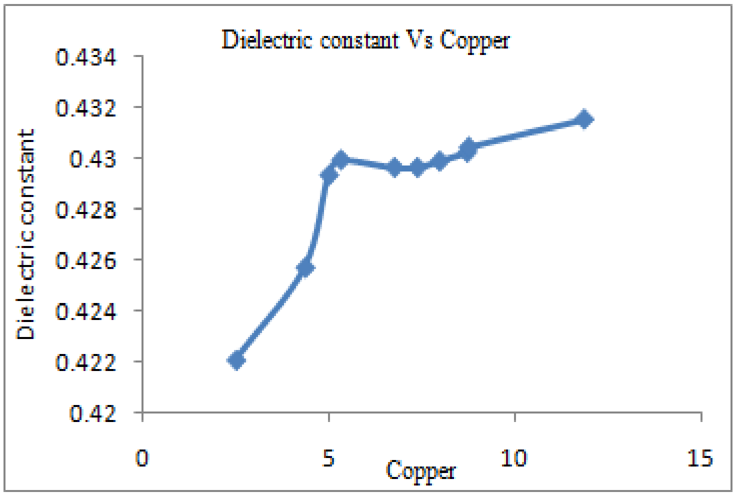
Manganese is a plant micronutrient fulfills a number of roles and is used in photosynthesis (manganese is important for a number of aspects of photosynthesis), synthesis of chlorophyll and nitrogen absorption as well as the synthesis of riboflavin, ascorbic acid and carotene. Symptoms of manganese deficiency include interveinal chlorosis of new leaves, necrotic spots and sometimes, small and/or irregularly shaped leaves. . From graph 13,14 it is observed that dielectric constant has positive correlation with Manganese and Zinc available in soil.



Graph 15: variation of dielectric constant with Copper

Copper is a micronutrient in plants and an important constituent, in small amounts, of the human diet. It is a naturally occurring element in the soil and it can be found as a metal or in a variety of ores. It is a constituent of many manmade alloys and is used in wire and some coins. Copper plays a range of roles in plants. It facilitates respiration and photosynthesis and is important for plant metabolism. It is a component of a variety of enzymes and plant cell walls so it is important for plant strength. Copper also affects the flavor, sugar content and storage life of fruit.

Conclusion:

Analysis of soil pH, physical characteristics, organic matter content is important. A pH of 5.5 to 7.0 is generally recommended for grapes, depending on the variety. Imbalanced soils can be corrected with lime to increase pH or sulfur to reduce pH to the recommended range. Silt loam and clay loam soils will also support healthy growth of grapes as long as they drain well. As the pH of soil samples of Niphad tehsil is between 5.5-7.0, farmers from this region usually grow grapes in their farm.The dielectric constant of Niphad soil varies with the texture of the soil. These variations have been found to be strongly dependent on the texture of soils. Most expert sources suggest sandy loam as the best soil type for growing grapes. This type of soil offers the best blend of characteristics. It drains well but contains a moderate amount of nutritious organic matter and generally lies within the preferred pH range.From our analysis, it is observed that soil sample of this region is sandy loam.So main crop of Niphad tehsil is Grapes.

The dielectric constant of Niphad soil depends on the bulk density and hence porosity. Results show that dielectric constant has positive correlation with bulk density. By knowing the correlation coefficient of various soil properties and nutrients with dielectric constant, it is easy to understand and analyze the satellite data. Results will be helpful for the prediction of soil texture, nutrients type and their concentrations present in the soil.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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