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"Dielectric Dependence Characteristic Study Of Sugarcane Vegetation At C-Band MW Frequency And Comparison With Debye-Cole Dual Dispersion Model"

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ABSTRACT

The fundamental interaction of microwave radiation with the earth's component like soil, water and vegetation gives crucial information for the development of microwave remote sensing (MWRS) technique and its applications. This interrelation is highly influenced by complex dielectric properties which act as a bridge between MW responses and physical characteristics of parts of the crop vegetation (such as sugarcane, grass etc.,). This paper investigates the laboratory measurements of complex dielectric constant E′and dielectric lossE″ of sugarcane leaves sample at room temperature (300 K) by using C - band MW frequency and then analyses the difference in the complex dielectric constant with respect to gravimetric moisture content. The calculation is performed by using Von – Hippel method. The data obtained is then compared with different dielectric vegetation model. Here, we have compared the experimental data with Carlson Formulaand Debye Dual dispersion model to check the accuracy of these models with experimental responses of dielectric values for sugarcane leaves sample. Moving further, Fresnel equation is used to theoretically evaluate the emissivity and brightness temperature from the obtained values of dielectric constant at different angles for dry and moist sugarcane leaves. All the parameters mentioned in this paper have been playing a vital role for the development of MW remote sensing of sugarcane vegetation. It is found that with increase in the content of moisture, the value of dielectric constant and dielectric loss also increases simultaneously. It has been also observe that Debye Cole dual model is more suitable to study the dielectric properties for sugarcane sampled leaves than Carlson formulation.

Keywords:complex dielectric constant, dielectric loss, sugarcane, microwave, emissivity, remote sensors, gravimetric moisture content.

1. Introduction:

The dielectric properties of vegetation canopy play a prominent role in the microwave remote sensing (MWRS) interpretation and applications. It determines the interaction of vegetation canopy with electromagnetic (EM) waves, affecting the microwave (MW) emission and scattering. The complex dielectric property of a substance is the ability of a material to absorb, reflects and transmits the electromagnetic radiations incident on it and is a measure of electric conductivity. Here the material is polarized under the influence of electric field. The complex dielectric property consists of real dielectric constant and imaginary dielectric loss and both are related by following Equation as

$$\mathrm{E}^* = \mathrm{E}' - j\mathrm{E}'' \tag{1}$$

Where, E' is dielectric constant (real part) and $\mathrm{E}''$is dielectric constant (imaginary part).

The dielectric properties of vegetation depend upon temperature, salinity and dominantly on water content [1]. The complex dielectric property of vegetation is combined effect of vegetation constituents i.e. leaves, branch, stem, and fruits although,most of the covered part of canopy is leaf. In this paper, we investigate the laboratory measurement of the complex dielectric properties, conducted for sugarcane leaves at C–Band (5 GHz) frequency, at room temperature 300k (27°C)[1-2].

Sugarcane (saccharum officinarum) is a cash crop and mainly used for manufacture of jaggery and sugar. A leaf of sugarcane is long and consists of sheath and blade, separated by a blade joint. Sugarcane is C4 plant which undergoes most efficient photosynthesis in plants kingdom[2]. The leaf is heterogeneous medium consists of water, bulk organic matter, and air spaces. But water in fresh leaf is major (80- 90%) constituent and also important for overall growth of the plant[3].Therefore, the dielectric properties of the leaves are mainly driven by water content. These facts motivate to conduct the dielectric measurements of sugarcane leaves as a function of moisture present in it.

In this paper dielectric measurements were performed experimentally for freshly cut Sugarcaneof different moisture content (due to natural evaporation over time) which were later oven dried(including drying up to 0% moisture). The measured data of dielectric constant and dielectric loss is compared using Debye-Cole Dual dispersion model constructedby Ulaby and El-Rayes, (1987) [3-4]. The laboratory validation of dielectric properties is crucial for data pertaining to MWRS [5]. Further radiometric emissivity and brightness temperature are estimated from measured dielectric properties at a different angle of incidence for the moist and dry sugarcane leaves by using Fresnel's equations. The data obtain is very useful for passive remote sensing of vegetation.

Organization such as Indian Space Research Organization (ISRO) gave a much clear view to this study by launching MWRS Satellite at C-Band frequency for precise experimentations. Dielectric properties of the soil, sea water and vegetation like Algae-Aquatic Vegetation [6-8] were studied and reported by MW group and its laboratory by using the same method and the same C-Band microwave bench set up provided by Indian Space Research Organization (ISRO) under a research project to the PI, [5] and is used for present work as well.

2. MATERIALS AND METHOD:

2.1.Fabrication of sample cell for vegetation leaves:

For the compaction of sugarcane leaves, a soliddielectric cell with a movable reflector was fabricated. The cell consists of a movable rectangular reflector that is fitted on the bottom side of the waveguide cell. Inner dimension of the waveguide is greater than the dimension of the reflector to make it slide easily inside the wave guide cell [7-8]. A long screw is attached to the bottom side of the solid reflector and is externally connected to a micrometer screw gauge. The thickness of sample inside the cell is measured by rotating the micrometer screw gauge.By giving appropriate rotations to the screw gauge, the sample is fitted between the reflector and a mica sheet to measure the homogeneity and constant compactness of each sample inside the cell[7-9]. The modification was carried out at a workshop of the government Industrial Training Institute, Aurangabad (MS), India.The modified sample cell is shown below in Fig.1. [9].

Fig. 1: Sample cell fabricated for vegetation material

2.2. Sampling:

The fresh sugarcane leaves were cut from the sugarcane farm from various crops having different height of 1.0 to 2.0 m. Data are measured on the same day to preserve the physical characteristics of leaves. Since, the freshly cut sugarcane leaf starts shrinking and loses moisture content over a period of time. Leaves can be covered in a polythene or transported to the lab immediately to avoid losing its moisture.

The rectangular shape leaves are cut to fitin the area of cross- section of the waveguide cell. Then, the bunch of these rectangular cut leaves are inserted in to the waveguide cell with a compactness to achieve the homogeneity of the material medium.To maintain equal and constant compactness, the sample of leaves are fit in the cell between reflector (bottom side of the cell) and the mica window (top/front side of the cell). Since, the reflector is movable and can slide inside the cell, the sample is pushed towards the mica window.

The tracing of natural moisture is at variancedue to time consumption in transportation of sampleto laboratory and sampling it. In this paper, the natural moisture mentioned is inclusion of this barrier.The dielectric measurements are done for fresh sugarcane leaves with natural 72.80% and of differentiable moisture 66.95%, 60.01%, 51.47% and 00.00% (Dry). Then the moisture of the leaves is reduced by the natural evaporation over a period of time and finally the sample is oven-dried at 70°C in oven for 24 hours.

A simple formula for gravimetrically measured moisture of the leaves is given by:

$$Moist\ content\ \% = \frac{w_l - w_{dl}}{w_{dl}} \quad (2)$$

Where,

w_l= weight of leaves sample

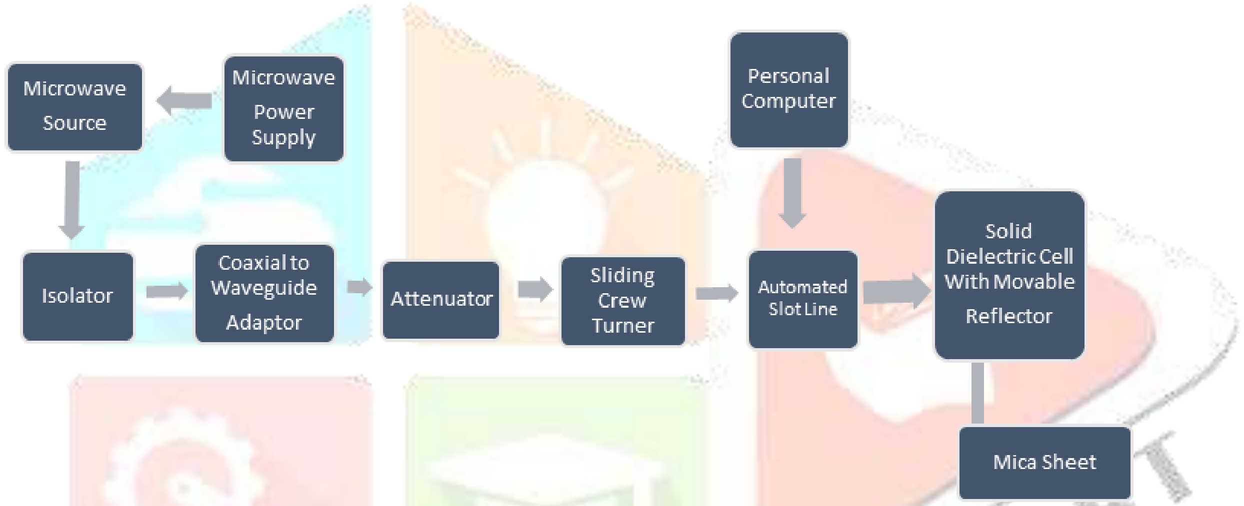
w_{dl}= weight of dry leave sample and

$w_l - w_{dl}$= weight of Moist content.

2.3. Experimental set-up:

Dielectric measurement can be calculated by several method [9], here we have used Von Hipple method to calculate dielectric of sugarcane leaf[10-11]. This method comparatively has good accuracy agreement and is easily accessible. The block diagram of the setup is shown below in Fig. 2.

Fig. 2: The block diagram of automated C-Band Microwave bench set up.



MW generated by the VTO is propagated through passive components of rectangular waveguides into the dielectric cell with a perfect reflector at the closed bottom side.Applying a tuning voltage of 7 volts, we tuned the MW source to give a frequency of 5GHz. By the use of attenuator,the waveguide assembly of the bench is kept at desired power. A slotted section with a tunable probe containing a 1N23 detector with the square law characteristics has been used to measure the current along the slotted line [10].

Then the detector is connected to a micro-ammeter and to the PC for recording the measured value of current. Further, the probe is settled on the slot line in such a way that the tip of the tunable probe is marginally penetrated and can move in forward and backward direction along the slot line sectionto detect the electromagnetic field present in the wave guide. The C-band microwave bench is then tuned to obtain a symmetrical straight (standing) wave pattern along with an empty dielectric cell in the slot line. With the help of precise setting of the probe detector and S.S. tuner, tuning of the bench is done. Therequired sugarcane leave sample is then kept inside the dielectric cell with a fixed compaction. Since the probe is transverse along the slot line at fixed distancesthe current is measured with the help of ammeter for the respective probe positions [10-11]. Through the use of a microcontroller interface system, this data is collected and saved in a file.

The obtained data is then applied on the parameterα_s and β_s.

Where α_s is the attenuation factor and β_s is the phase shift constant for sugarcane leave sample.

The thickness of the sugarcane leaves sample is variable, so the thickness for which the data is measured are 0.7 cm, 1.4 cm and 2.1 cm. The minima of the standing wave pattern give the guided wavelengthλ_{gs}.

$$\beta_s = \frac{2\pi}{\lambda_{gs}} (3)$$

Now, the relation for free space wavelength (λ_ϱ) is given by,

$$\frac{1}{{\lambda_\varrho}^2} = \frac{1}{\lambda_{gs}^2} + \frac{1}{\lambda_b^2} (4)$$

Where, $\lambda_b = 2 \times b = 2 \times 4.73 = 9.46$ cm, and 'b' is the width of the rectangular wave-guide. Given below are the relation to calculate the real and imaginary parts of dielectric constant of the given sample,

$$E' = {\lambda_\varrho}^2 \left(\frac{1}{\lambda_b^2} + \frac{({\alpha_s}^2 - {\beta_s}^2)}{4\pi^2} \right) (5)$$

$$E'' = \frac{{\lambda_\varrho}^2 \alpha_s \beta_s}{2\pi^2} (6)$$

The programming source code made for dielectric constant is used for calculating dielectric constant (E') and dielectric loss (E'')with errors in the measurements as $\Delta E'$and$\Delta E''$ by combining the different sample of leave's thickness to achieve a single data input [12].

Dielectric properties and errors are evaluated using least square fitting technique along with fitting parameter like α_s and β_s.

Estimation of dielectric characteristics is done by programming source code with input value as 'inp.data' which gives more than one (many) solution for the various values of coefficient of propagation constant with respect to differential factor. Here, the differential factor is basically the difference between theoretical and experimental measurements. The final measurements (optimum results) for dielectric constant $E'$and dielectric loss $E''$and for errors $\Delta E'$ and $\Delta E''$will be minima of all the minimum values of the sampled leaves taken from [14].

Gravimetrical Moisture content (%)	Error in Dielectric Constant($\Delta E'$)	Error in Dielectric Loss ($\Delta E''$)
72.8	26.88	6.37 E-02
66.95	22.71	4.70 E-02
60.01	19.40	3.46 E-02
51.47	17.07	2.68 E-02
0	3.92	9.61 E-03

2.4. Carlson Formula for Sugarcane Vegetation:

Using the experimental values of poaceae (grass), taxus baccata, taxus cuspidata and zea mays (maize) leaves on empirical model at 300k and a frequency of 5 GHz, we can derive the Carlson's formula [14-15] for saccharum officinarum as:

$$E = 1.5 + \{[real\, E_w/2] + j[img\ \ E_w/3]\} m_{fm} \quad (7)$$

Where E_w is the water dielectric constant and m_{fm} is the fraction of moisture content in sampled leaves of sugarcane.

Value of dielectric constant for water E_w is given by :

$$E_w = \left[4.9 + \frac{73.5}{1+\frac{jf}{19.7}}\right] \quad (8)$$

Where, f is the frequency in GHz and $j^2 = -1$.

2.5. Debye Cole Dual Dispersion Model (Ulaby& El-Rays, 1987):

This model provides physical basis for experimentation [14-15].The sampled leaf is divided into three parts to measure the complexity of dielectric constant:

(a) Non- dispersive residue component,E_s;
(b) Component of free water$V_w E_{fw}$, where V_w is the volume fraction of water and E_{fw} is the dielectric constant of the free water; and
(c) A combined (bulk) vegetation bound water component $V_c E'_c$, where V_c is the volume fraction of combined (bulk) vegetation bound water component and E'_c is the dielectric constant.

$E' = E'_s + V_w E'_{fw} + V_c E'_c$ (9)

Using Debye equation, the measured value of E'_{fw} is estimated. Putting the values of E_{fw} and E_c in the equation (9);

$$E = E_s + V_w\left[4.9 + \frac{73.5}{1+\frac{jf}{19.7}} - j\frac{18\sigma}{f}\right] + V_c\left[2.9 + \frac{55.0}{\left(1+\frac{jf}{0.18}\right)^{0.5}}\right] (10)$$

$$E_s = 1.7 - 0.74 - M_{gr} + 6.16\, M_{gr}^2 (11)$$

$$V_w = M_{gr}(0.55\, M_{gr} - 0.076) (12)$$

$$V_c = \frac{4.64\, M_{gr}^2}{1+7.36\, M_{gr}^2} (13)$$

$$\sigma = 1.27 \quad (14)$$

Here, value of $j^2 = -1$, f is the frequency in GHz, M_{gr} is the gravimetric moist contentand σ is the ionic conductivity[13].

2.6. Evaluation of emissivity and brightness temperature:

Equation (15) gives the expression to find emissivity($\varepsilon_{S(p)}$)of the sampled leaves [14]

$$\varepsilon_{S(p)} = \left(1 - R_{S(p)}\right) \quad (15)$$

Where $R_{S(p)}$= Smooth - surface reflectivity and (p) represent polarization. Fresnel equation is used to calculated the reflectivity for homogeneous sugarcane leaves sample at vertical and horizontal polarizations, $R_{S(V)}$ and $R_{S(H)}$. Expression for this is given below;

$$R_{S(V)} = \left|\frac{\kappa\cos - \sqrt{\kappa - \sin^2\phi}}{\kappa\cos + \sqrt{\kappa - \sin^2\phi}}\right|^2 \quad (16)$$

$$R_{S(H)} = \left|\frac{\cos - \sqrt{\kappa - \sin^2\phi}}{\cos + \sqrt{\kappa - \sin^2\phi}}\right|^2 \quad (17)$$

Where κ is the value of the dielectric constant and ϕ is the angleof incident for sugarcane leave sample. Both κ and ϕ are the value obtain as the effect of electromagnetic wave on the sampled leaves and is depended on the moisture content % of this sample leaves. The variation in the moisture content for different angles of incident to measure the emissivity of the sugar-cane leaves is given by Fresnel equations [15].

T_b is the electromagnetic spectrum, since Passive microwave remotesensing (MWRS) is formulated by measuring thermal radiation in the centimeter (cm) wave bandof this EM spectrum. The thermal radiations are mainly derived from the physical temperature and emissivity of the radiating surface and then can be estimated (approx.) by equation given below:

$$T_{\beta(p)} \approx \varepsilon_{S(p)} T \qquad (18)$$

Here, $T_{\beta(p)}$ is the temperature of the brightness; p denotes vertical and horizontal polarization whereas, ε_S is the smooth-surface emissivity and emitted layer physical temperature is given by T [15].

3. RESULTS AND DISCUSSION:

The variation in the complex dielectric properties E′ and E″ of sugarcane leaves sample with respect to the gravimetric moisture content (%) are shown in the Figure 3.1 and 3.2. The dependence of E′ and E″ on the moisture content can be seen from graph i.e.; with increase in the content of moisture, the value of dielectric constant and dielectric loss also increases simultaneously. Although for low moisture content sampled leaves, E′and E″increases slowly as compared to high moisture content. This is due to the effect of polarization of electric dipoles for the molecules of water and their binding with the leaf bulk sample. The H_2O molecule is polar in nature, so when electric field is applied at C-band MW frequency its molecule shows orientation polarization with respect to the electric dipole.Higher polarization of dipoles means, increase in value of dielectric constant with respect to moisture content.

Since, in lower moisture content, molecules of water are tightly attached or bonded to the leaf bulk, there will be less polarizability of electric dipoles. Therefore, the change in the values of dielectric properties at lower moisture is quite slow with respect to moisture content. Whereas, the molecules of water are considerably free under the higher moisture content, so here the polarization of dipoles is more resulting in the rapid or sudden change in the dielectric properties

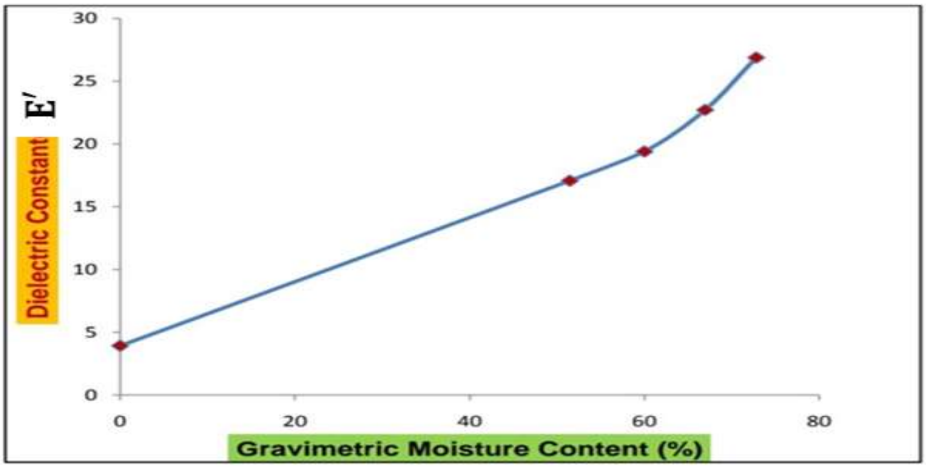


Fig.3.1: Dielectric constant E′ of Sugarcane leaves as function of moisture content (%).

In sugarcane leaves the dielectric constant is increasing with increase in moisture content steadily up to 60.01% moisture. For higher moistures of leaves the increment of dielectric is comparatively rapid. For dielectric loss the rate ofincreasing with respect to the moisture content of the leaves is slow for low moistures, but after 60.01% it is rapidly increasing.

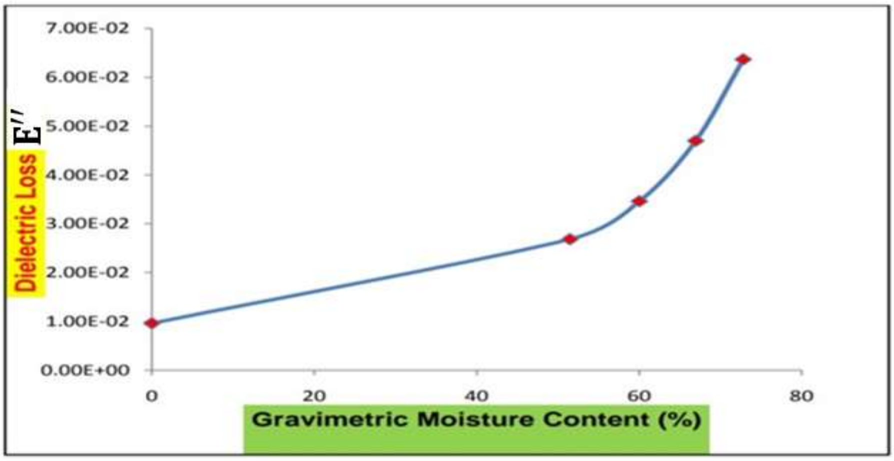


Fig. 3.2: Dielectric loss E′′of Sugarcane leaves as function of moisture content (%).

The experimental values of dielectric constant E′for sugarcane leave sample is closed to the model values. This is because the standard model was constructed using the grass, taxus and other crop vegetation which were similar to sugarcane leaves sample. In the case of dielectric loss, the data obtained for E′′ does not agree with that of the model values. This may occur due to the different technique used for calculating the values or because of the errors present in the dielectric loss measurement. For example, currently slot line technique is used but previously, coaxial probe was used by the actual model. In the slot line technique, measurement of standing wave ratio, variation of maxima and minima at different points on the line also called slope error which occur due to difference in probe depth and probe tuning errors caused by excessive probe penetration to the electromagnetic field in slot line etc., are the well-known source of error which effect the dielectric properties of the sample.

Debye Cole Dual Dispersion Model and Carlson Empirical Model:

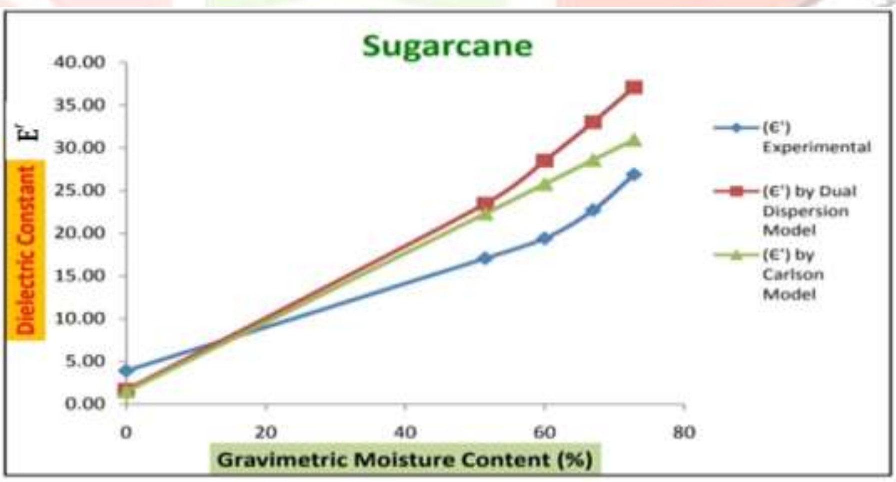


Fig.3.3: Comparison of Measured Dielectric Constant of Sugarcane leaves with Theoretical Model.

Below in Fig. 3.3, we compare the measured value of dielectric constant (real; E′) of sugarcane leaves sample with Dual Dispersion model and Carlson model respectively. The graph clearly shows that the measured dielectric constant value E′ agrees more closely with dual dispersion model than that of the Carlson vegetation model by providing a linear trend between E′ and moisture content of the leaves sample. At C-band frequency almost every model shows quantitively overestimation of E′ for the sugarcane vegetation. It happens when we use model formulation of any other type of vegetation than that of sugarcane.The model usedhere have neglected the freeness of water molecule from the leaf bulk with respect to an increase in moisture, its effect on polarization and hence on the dielectric constant E′. Therefore, the dual dispersionmodel is more effective while explaining the dielectric properties of sugarcane leaves since, the evaluated values and results shows rapid increase with respect to moisture content.

4. Conclusion

In this paper, we have experimentally investigated the complex dielectric properties as the function of gravimetric moisture contentfor sugarcane leaves sample using Carlson and Debye Cole dual dispersion models. Complex Dielectric constant is the most crucial property which act as a bridge to study the interaction between physical basis of vegetation and microwave remote sensing technique and its various application. The experimentation has been performed using C- band microwave frequency at 300k (27ºC or80ºF). The plotted graphs clearly explain the impact of moisture content on the dielectric constant E′ and dielectric loss E′′. Higher the moisture content in the sampled leaves, more will be the polarization of the electric dipoles which rapidly increases the value of dielectric constant and dielectric loss. These results are essential for detection of moisture of the leaves by MW remote sensing techniques. After comparing these dielectric properties with the two models, data obtained is presented and explained graphically. Our observation shows that Debye Cole dual model is more suitable to study the dielectric properties for sugarcane sampled leaves than Carlson formulation. The variation in the different model values indicate towards the errors present during measurement that can be eliminated by working on a model which will be applicable for each type of vegetation.

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Statements and Declarations:

6.1. Compliance with Ethical Standards:

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6.1.2. Research involving Human Participants and/or Animals:

The authors declare that none of the any human participants and or animals was involved during the preparation of this manuscript.

6.1.3. Informed consent:

Since, none of the human participant and or animals was involved *during the preparation of this manuscript.* So, no need to take the consent from authorities.

6.2. Competing Interests:

- *The authors have no relevant financial or non-financial interests to disclose.*
- The authors have no competing interests to declare that are relevant to the content of this article.
- All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.
- The authors have no financial or proprietary interests in any material discussed in this article.

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6.3. Research Data Policy and Data Availability Statements:

- All data generated or analysed during this study are included ine present submitted manuscript.
- Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

6.4. Author Contributions:

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Dr. M. K. Maurya],[Harleen Babara], [Soniya Singh], [Sunil A K Kerketta, [Sunil Kumar Gupta] and [Shyam sunder Tiwari]. The first draft of the manuscript was written by [Soniya Singh], [Harleen Babara] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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