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Research Article

Dielectric and emissive properties of tree leaves at X- Band microwave frequencies

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ABSTRACT

This study presents the experimental data of the measurements on complex dielectric constant of leaves from two tree species at X- band microwave frequencies (10.5 and 11.5 GHz). Leaves from two different tree species viz., Eucalyptus (Nilgiri) and Teak (Sag), have been used in these measurements. These measurements have been carried out by using Waveguide Cell Method. Initially, dielectric constants of freshly plucked leaves are measured. Then the gravimetric moisture content (wet basis) of the leaf sample was gradually reduced by drying it in a hot air oven at 50^o to 60^{o}C. Our results show that dielectric constant (ε') for the leaves of Eucalyptus lie over a range 1.25 to 6.0 when their gravimetric MC (%) (wet basis) changed from 0 % (oven dry) to around 70 % and for the leaves of Teak (Sag) lie over a range 1.29 to 5.4 when their gravimetric moisture content (wet basis) changed from 0 % to around 50 %. The corresponding values of dielectric loss (ε'') for the leaves of both tree species are also found to increase with increase in their MC. Our results also show a little decrease in the values of complex dielectric constants for the leaves samples of both tree species as the frequency is increased from 10.5GHz to 11.5 GHz. Further, our results show decrease in emissivity with increase in MC /dielectric constant. These results on the dielectric constants and emissivities for tree leaves at microwave frequencies have potential applications in remote sensing and mobile communications.

Keywords: Dielectric constant, dielectric loss, emissivity, tree leaves, microwave frequency.

INTRODUCTION

Researchers have used different techniques for determining the dielectric properties of biomaterials to estimate water content. These studies include transmission line techniques such as waveguide (coaxial and free-space), impedance and cavity methods[1]. Dielectric properties represent a measure of the polarizability of a material when subjected to an electric field[2]. The dielectric constant, ε', describes the material's ability to store energy, while the dielectric loss factor ε'', describes the ability of material to dissipate the electric field energy. The dielectric properties of vegetation samples, which are hygroscopic in general, vary predominantly with moisture content, but also they depend on the frequency of the applied electromagnetic field, the temperature of the materials, and on density and structure of the materials.Further, the dielectric and emissive behavior of vegetation canopy has to be studied before one can predict moisture content in the soil. The vegetation emits radiation at microwave frequencies. The emission depends upon the type of vegetation and the microwave frequency at which the emission is measured. There is a correlation between the type of vegetation and frequency at which emission takes place. Similarly the vegetation canopy scatters the radio waves, which are incident on the canopy.

Experimental studies on the microwave dielectric behavior of vegetation material have been reported by several investigators[3-6]. Their results have shown the strong dependence of attenuation by vegetation on frequency. The dielectric constants of leaves of two tropical crops, as a function of moisture content at X-band frequency were reported[7]. Measurements of dielectric constant of Neem leaves from deserted areas at X-band frequency were carried out[8]. Some of the investigators have developed the models relating to microwave remote sensing of forests[9,10]. However, there is a scarcity of data on the dielectric and emissive properties relating to tropical vegetation / tree canopies[11,12]. In order to provide more experimental data relating to this area, we have measured dielectric properties of leaves of two tree species from tropical region at X- band microwave frequencies. Such results will definitely be useful for better understanding the microwave dielectric behavior of vegetation materials.

Here the measurement of the complex dielectric constant of the vegetation (Eucalyptus and Teak leaves) is done at frequencies in the X-band microwave range and estimation of emissivity using emissivity model for vertical and horizontal polarizations has been presented. These values can be used for designing passive microwave sensors to be used for study of vegetation canopy of trees. Such studies are of great interest and will help in better understanding and accurate modeling of wave propagation behavior through forested environments for mobile communication and remote sensing applications.

MATERIALS AND METHODS

Samples of leaves from two tree species viz., Eucalyptus and Teak, have been used in our experiments. These tree species selected lie within the small area covering about 2 to 3 km^2 in the Dhule city. Dhule district is located in the northern region of Maharashtra state (India). Height of these tree species ranged between 10 to 20 meters and the experiments were performed over the temperature range 25^o - $35\ ^oC$. Initially, the freshly plucked tree leaves are inserted into the solid dielectric cell and their dielectric constant is measured. Then the gravimetric moisture content (wet basis) of the tree leaves sample was gradually reduced by drying it in a hot air oven at 50^o to 60^oC. Moistures of leaves are varied from its natural to oven dry value.

The waveguide cell method is used to determine the dielectric properties of the tree leaves samples. An automated X-band microwave set-up in the TE_{10} mode with Gunn source operating at frequencies 10.5 and 11.5 GHz, PC-based slotted line control and data acquisition system is used for this purpose. It consists of Microcontroller (8051), ADC-12 Bit- MCP (3202) Visual based software. The solid dielectric cell with and without the sample is connected to the opposite end of the source. The signal generated from the microwave source is allowed to incident on the tree leaves sample. The sample reflects part of the incident signal from its front surface. The reflected wave combined with incident wave to give a standing wave pattern. These standing wave patterns are then used in determining the values of shift in minima resulted due to before and after inserting the sample. The dielectric constant ε' and dielectric loss ε'' of the tree leaves are then determined from the following relations:

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

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

Where, a = inner width of rectangular waveguide.

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

g_ε = real part of the admittance

β_ε = imaginary part of the admittance

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

$$e_p(\theta) = 1 - r_p(\theta) = 1 - |R_p(\theta)| \qquad (3)$$

$$e_p(\theta) = 1 - \frac{\varepsilon'\cos\theta - \sqrt{\varepsilon' - \sin^2\theta}}{\varepsilon'\cos\theta + \sqrt{\varepsilon' - \sin^2\theta}} \qquad (4)$$

and the emissivity $e_p(\theta)$ for horizontal polarization can be written as

$$e_p(\theta) = 1 - r_p(\theta) = 1 - |R_p(\theta)| \qquad (5)$$

$$e_p(\theta) = 1 - \frac{\cos\theta - \sqrt{\varepsilon' - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon' - \sin^2\theta}} \qquad (6)$$

Where, θ = Angle of observation.

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

$r_p(\theta)$ = Reflection coefficient.

$R_p(\theta)$ = Fresnel reflection coefficient

Estimations of emissivity values for all tree leaves samples are made by using emissivity model for incident angles varying from 0^o (normal incidence) to 60^o for vertical and horizontal polarizations.

RESULTS AND DISCUSSION

Our results on the variations of dielectric constant (ε') and dielectric loss (ε'') of leaves samples of two different tree species with different gravimetric moisture contents (wet basis) and also the variations of their emissivity for vertical and horizontal Polarizations (VV and HH) at different incident angles are summarized in Figs. 1 to 8. These experiments are performed at microwave frequencies 10.5 and 11.5 GHz and for MC variations from moistures of freshly plucked natural leaves to their oven- dry values.

Fig. 1 and 2 show the variations of dielectric constant and loss for Eucalyptus leaves samples with gravimetric moisture content at microwave frequencies 10.5 and 11.5 GHz respectively. The dielectric constant and loss of the leaves are found to increase with increase in MC (%) over the entire range studied. However, these variations are nonlinear and the trends are almost similar for both the frequencies, except their relative magnitudes. There is little decrease in dielectric constant and loss with increase in frequency. **Fig. 3 and 4** show the variations of dielectric constant and loss for Teak leaves samples with gravimetric moisture content at microwave frequencies 10.5 and 11.5 GHz respectively. These results have almost similar trends as that of the results for Eucalyptus leaves **(Figs. 1 and 2),** except the relative magnitudes of complex dielectric constant, which are comparatively lower for teak leaves. This may be due to less initial MC (wet basis) in freshly plucked natural teak leaves (around 50%) than Eucalyptus leaves (around 70%).

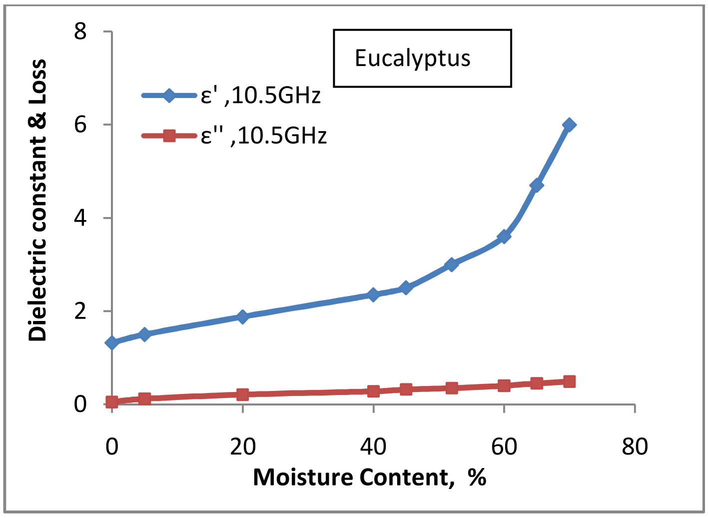

Fig. 1: Variation of dielectric constant and loss of Eucalyptus leaves with gravimetric moisture content (wet basis) at 10.5 GHz.

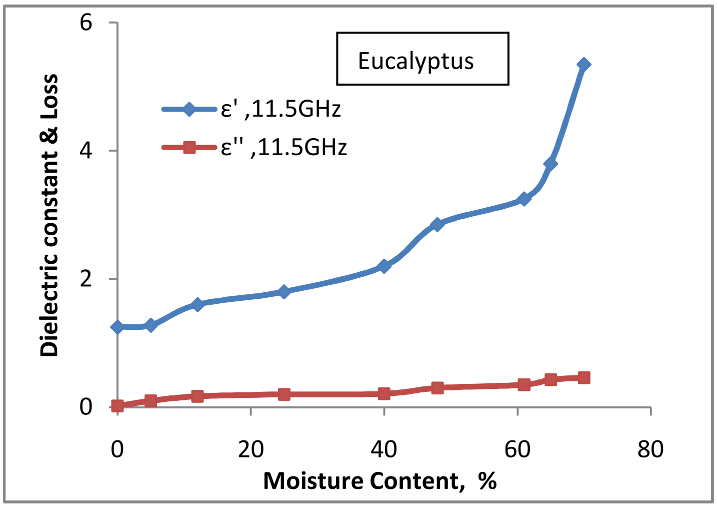

Fig. 2: Variation of dielectric constant and loss of Eucalyptus leaves with gravimetric moisture content (wet basis) at 11.5 GHz.

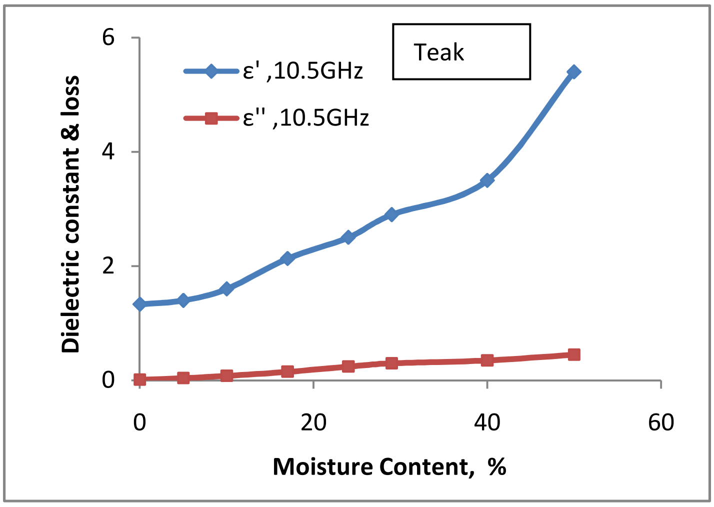

Fig. 3: Variation of dielectric constant and loss of Teak leaves with gravimetric moisture content (wet basis) at 10.5 GHz.

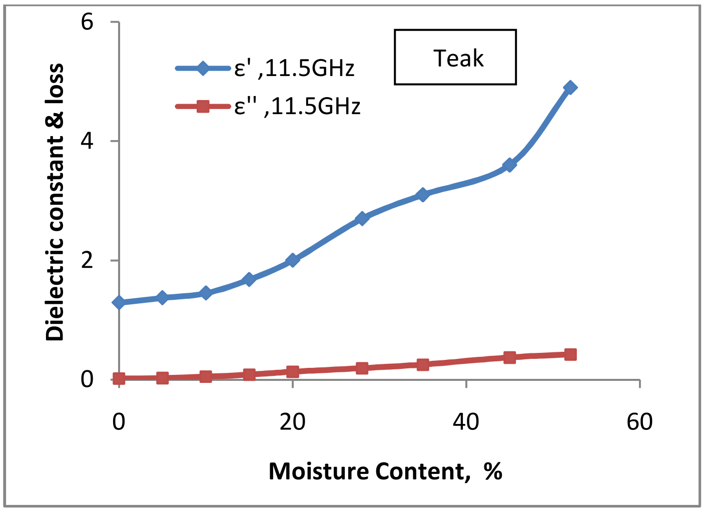

Fig. 4: Variation of dielectric constant and loss of Teak leaves with gravimetric moisture content (wet basis) at 11.5 GHz.

Figs. 5 and 6 show the variations of emissivity with different gravimetric MC (wet basis) and at incident angles varied from 0^o to 60^o for Eucalyptus leaves samples at microwave frequencies 10.5 and 11.5 GHz respectively. These results on variations of emissivity for leaves with MC (wet basis) for both vertical and horizontal polarizations show opposite trends as that of the results for dielectric constant ε' variations in Fig.1 and 2. This is expected because of the inverse relation between the dielectric constant and emissivity. However, the emissivity curve for vertical polarization at higher incidence angle (60^0), shows small initial increase with MC. Further, as expected, the curves for vertical and horizontal polarizations overlap each other at 0^o incident angle. Further, the emissivity of leaves increases for vertical polarization as the angle of incidence is increased whereas for horizontal polarization, its value decreases with increase in angle of incidence.

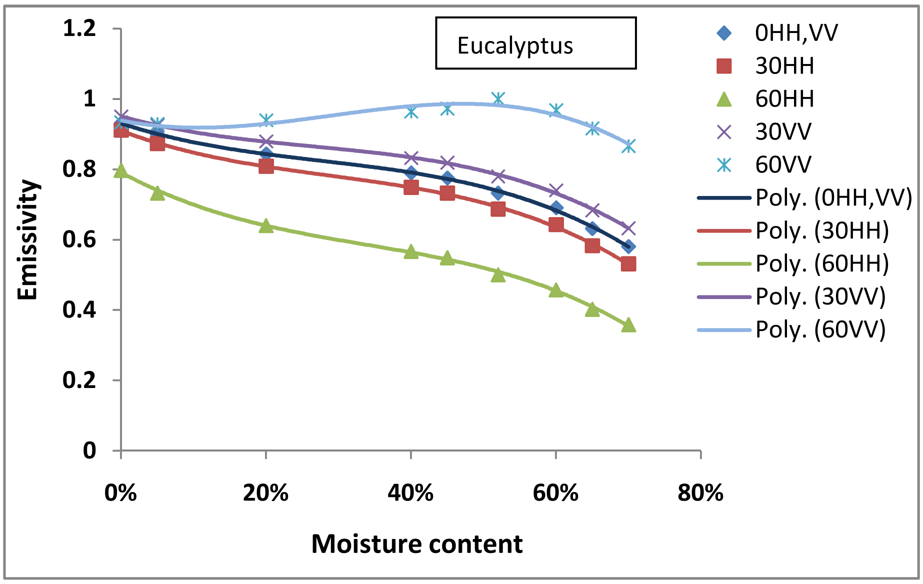

Fig. 5: Variation of emissivity (Vertical and Horizontal Polarizations) for different incident angles in degrees with gravimetric moisture content (wet basis) of Eucalyptus leaves at 10.5 GHz.

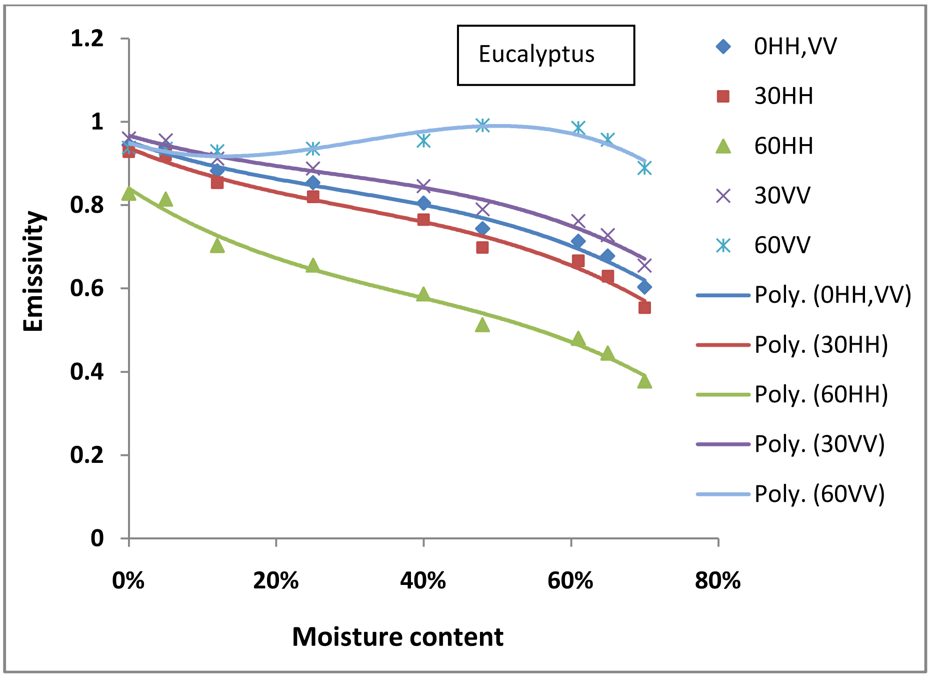

Fig. 6: Variation of emissivity (Vertical and Horizontal Polarizations) for different incident angles in degrees with gravimetric moisture content (wet basis) of Eucalyptus leaves at 11.5 GHz.

Figs. 7 and 8 show the variations of emissivity with different gravimetric MC (wet basis) and at incident angles varied from 0^o to 60^o for Teak leaves samples at microwave frequencies 10.5 and 11.5 GHz respectively. These results have almost similar trends as that of the results for Eucalyptus leaves (Figs. 5 and 6), except the relative magnitudes of emissivity, which are comparatively higher for teak leaves. This may also be due to less initial MC (wet basis) in freshly plucked natural teak leaves than Eucalyptus leaves.

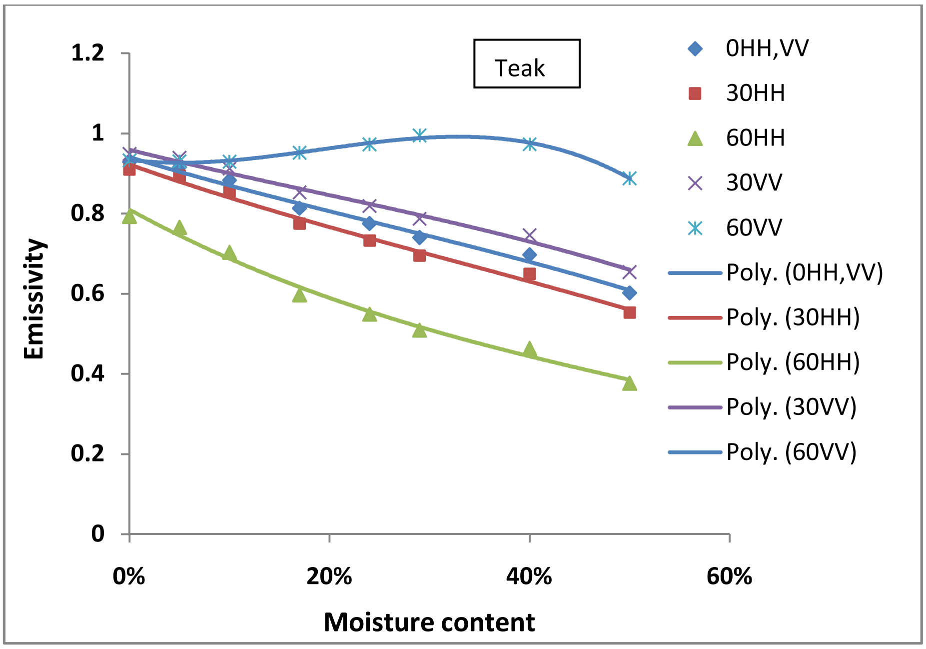

Fig. 7: Variation of emissivity (Vertical and Horizontal Polarizations) for different incident angles in degrees with gravimetric moisture content (wet basis) of Teak leaves at 10.5 GHz.

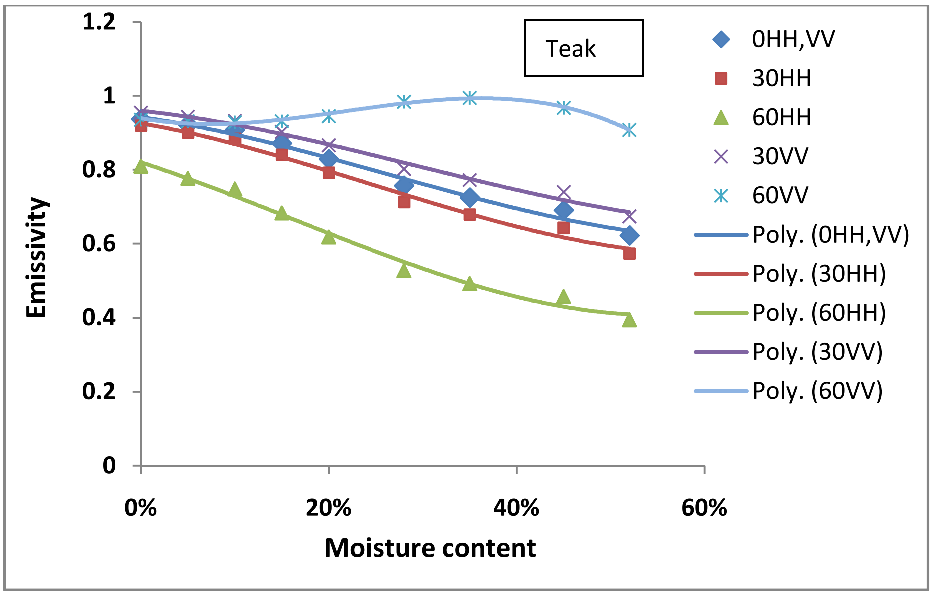

Fig. 8: Variation of emissivity (Vertical and Horizontal Polarizations) for different incident angles in degrees with gravimetric moisture content (wet basis) of Teak leaves at 11.5 GHz.

These results on dielectric constant and emissivity at different MC are useful in designing passive microwave sensors for tree leaves at microwave frequencies. Such sensors may have many uses in remote sensing applications. Such studies may also be helpful for predicting the forest areas, type/classification, and density of tree species and seasonal status of leaves.

Further, trees and large bushes can also have some reducing effects, on the propagated radio signal. In the case of attenuation by trees and bushes the incident electromagnetic field is mainly interacting with the leaves and the branches. The trunk does of course may also have some influence on the attenuation but since the volume occupied by the trunk is much smaller than the total volume of a tree, these effects can be considered as negligible. In the case of wave propagation between antennas that are located at higher altitudes, it will in principal only be the upper part of the tree crown that affects the attenuation.

Research of this kind is thus not only useful for remote sensing applications of forests but also in assigning transmitter power in Mobile communication systems. Such study is important to understand electromagnetic behavior of vegetation canopy. Thus, these results on the complex dielectric constants and emissivities for tree leaves at microwave frequencies have potential applications in remote sensing and mobile communications.

CONCLUSIONS

1. The dielectric constant and loss are found to increase with increase in gravimetric MC (wet basis) for leaves of both the tree species at microwave frequencies. However, these variations are nonlinear and the trends are almost similar for leaves of both the tree species studied, except their relative magnitudes.
2. The dielectric constant and loss show little decrease with increase in microwave frequencies at constant gravimetric MC (wet basis) for leaves of both the tree species.
3. Emissivity of tree leaves decreases with increasing MC / dielectric constants for both vertical and horizontal polarizations.
4. For same values of MC (%), the emissivity for leaves of both the tree species at microwave frequencies increases for vertical polarization as the angle of incidence is increased whereas for horizontal polarization, its value decreases with increase in angle of incidence.

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