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RESEARCH ARTICLE

A Comprehensive Real Time Investigation on the Influence of Plant Species on Antenna Characteristics in Outdoor Wireless Communication

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ABSTRACT Wireless communication in an outdoor environment is influenced by different living and non-living creatures in the earth's atmosphere. These influences are based on the interaction of EM (electromagnetic) waves emitted from antennas in communication systems. This research work focuses on analyzing the role of different plant species on antenna characteristics in outdoor wireless communication. The influence of different plant species on the communication system is analyzed by using the Fieldfox analyzer N9915A and microstrip antenna operating at 2.45 GHz. The variation in return loss of the microstrip antenna when placed nearer to a group of selected 25 plant species is analyzed and the obtained return loss is compared with the return loss of the antenna in free space. The relative change in return loss of antenna when tested with different species in free space is between 2.8 % to 73.68 %. From the analysis, it could be concluded that up to 73.68% loss in antenna characteristics can be brought in by the influence of certain species. The performance of the wireless communication system is dependent on the antenna performance which is influenced by the variation in return loss when coming in contact with different materials in the near field. This experimental investigation analyzed the influence of different plant species on wireless communication and observed that the pigmentation, water content, and mass density have an indirect influence on the antenna characteristics in wireless communication systems.

INDEX TERMS Antenna, electromagnetic (EM), electromagnetic radiation (EMR), outdoor environment, plants, wireless communication.

I. INTRODUCTION

Wireless communication technology plays an inevitable role in communication systems. The physical medium where it communicates is the free space environment through electromagnetic (EM) waves [1]. It can communicate over different distances based on the preferred technologies of operation band using electromagnetic signals. These signals can be categorized based on the frequency of operation [2]. Radio Frequency (RF) communication can be made possible using electromagnetic signals of frequency ranging from 3 KHz to 300 GHz where the microwave frequency exists within this range, ie., from 300 MHz to 300 GHz [3]. These EM signals can penetrate through the objects and communicate over large distances and are possible through antennas that exist in the communication systems [4]. The performance of all communication systems including the RF and microwave, is dependent on the operational frequency, amount of the power transmitted from the antenna at the transmitted end, height, size, and type of the antenna [5], [6], [7]. So, the antennas that exist in the wireless communication system have a significant role in achieving efficient communication [8], [9], [10], [11]. The design and performance of an antenna at a specified

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frequency have a significant role in maintaining the signal strength, transmission and reception quality of EM signal, range of the signals, and directional capability, for reducing the interference in communication [12].

Antennas convert the electrical signals to electromagnetic waves and propagate through the free space considering all the environmental conditions [13]. It helps to amplify and direct the signals to improve the range and the signal strength by minimizing noise, interference, and the distortion of EM signal. Different types of antennas are used in wireless communication systems based on various factors like physical characteristics, frequency of operation, and radiation characteristics [14]. Some of the antenna systems that are commonly used in these wireless communication systems are dipole antenna [15], monopole antenna [16], [17], [18], yagi antenna [19], parabolic antenna [20], horn antenna [21], [22], and microstrip patch antenna [23]. Each of them is categorized, based on the physical properties and characteristics at the desired frequency range. Dipole antennas are a simple designs with omnidirectional characteristics with signals radiating in all direction [24]. Monopole antennas are commonly used in mobile phones, and routers due to their compact size and omni-directional properties whereas the planar patch antennas provide directional characteristics for short range communication commonly used in WiFi, bluetooth devices, and mobile phone with miniaturized configuration [25], [26], [27], [28].

In wireless communication systems, electromagnetic waves are transmitted from an antenna in the free space environment and propagate in all direction as a spherical wavefront [29], [30]. The electric field 'E' and magnetic field 'H' in the wavefront are perpendicular to each other and also to the direction of propagation. The intensity of propagation decreases with the increase in distance from the antenna [31], [32]. The EM wave that propagates from the antenna in free space is affected by various factors such as frequency of operation, antenna properties, and characteristics of the propagation path as the signal is more susceptible to attenuation due to atmospheric absorption, reflection, and scattering [33], [34]. In addition to these, weather conditions such as rainfall, snow, and fog also influence the propagation of EM waves. So, each of these parameters has a significant role in maintaining the efficiency of wireless communication in an open environment. Each of these specific environmental factors requires different approaches for analyzing the quality of communication to achieve better signal characteristics [35]. The distortion of the EM signals can also occur due to the absorption of EM waves by different plant species. The amount of absorption can be dependent on the frequency of EM waves, mineral and water content in plants, and the location of plants with respect to the transmitter/receiver antenna [36]. The studies related to the influence of different plant species on wireless communications are limited. Efficient communication can only be achieved by incorporating these factors in wireless communication systems, as the major part of the transmitted signal from the antennas is absorbed by the plant species within the locality. These plant species within an area are dependent on various geographical properties like climate, soil composition, water quality and availability, topography and elevation, light intensity and duration, biotic interactions, and historic parameters [37]. So indirectly the land cover of an area has a significant role in finding out the availability of plant species within a geographical area, as part of these signals are absorbed by these plant species. Only by considering these parameters, the influence of plant species in wireless communication can be identified. Moreover, a degradation in signal strength was observed in the newly installed cellular towers after a short period in areas nearer to more vegetation. Similar studies have to be repeated in other 5G/6G frequency bands using standard reference antennas based on the operating frequency before setting up a wireless communication network. So, these types of studies have more relevance in the upcoming era beyond 5G and 6G.

In this research work, a detailed experimental analysis is given on the significance of electromagnetic radiation absorption at 2.45 GHz by different plant species from wireless communication in an outdoor environment. This is based on analyzing the variation in antenna characteristics observed when tested in the outdoor environment. Antenna parameters like gain, reflection coefficient/ return loss, polarization, bandwidth, directivity, efficiency, etc. can be varied due to the absorption of EM waves on vegetation. So, this study provides evidence for the absorption of EM waves by plant communities. This is based on analyzing the variation in return loss of antenna in an outdoor environmental condition. This article is organized as follows. Section II describes the materials and methods for carrying out the real-time experimentation including the specification of the test plant species. Section III describes the results and analysis of the experimental testing. Section IV describes the discussion of the results, followed by the conclusion.

II. MATERIAL AND METHODS

To establish wireless communication in an outdoor environment, antennas are used to transmit and receive EM waves. The performance of the communication is analyzed by the reception of the transmitted signal with minimum signal distortion. It is affected by various factors such as interference, reflection, absorption, and scattering of EM signal. A schematic representation demonstrating the influence of these factors in EM propagation is shown in Figure. 1. Interference occurs when the EM signals interfere with different types of signals. This can lead to distortion of the original transmitted signal. It occurs due to the existence of different EM sources in the test environment. Reflection occurs when the EM waves from different surfaces get reflected. Absorption depends on various factors such as the frequency of the EM wave, characteristics of the biotic components, and penetration of the EM wave. Absorption of EM signal can reduce the quality of waves that are being received. Scattering occurs because of the existence

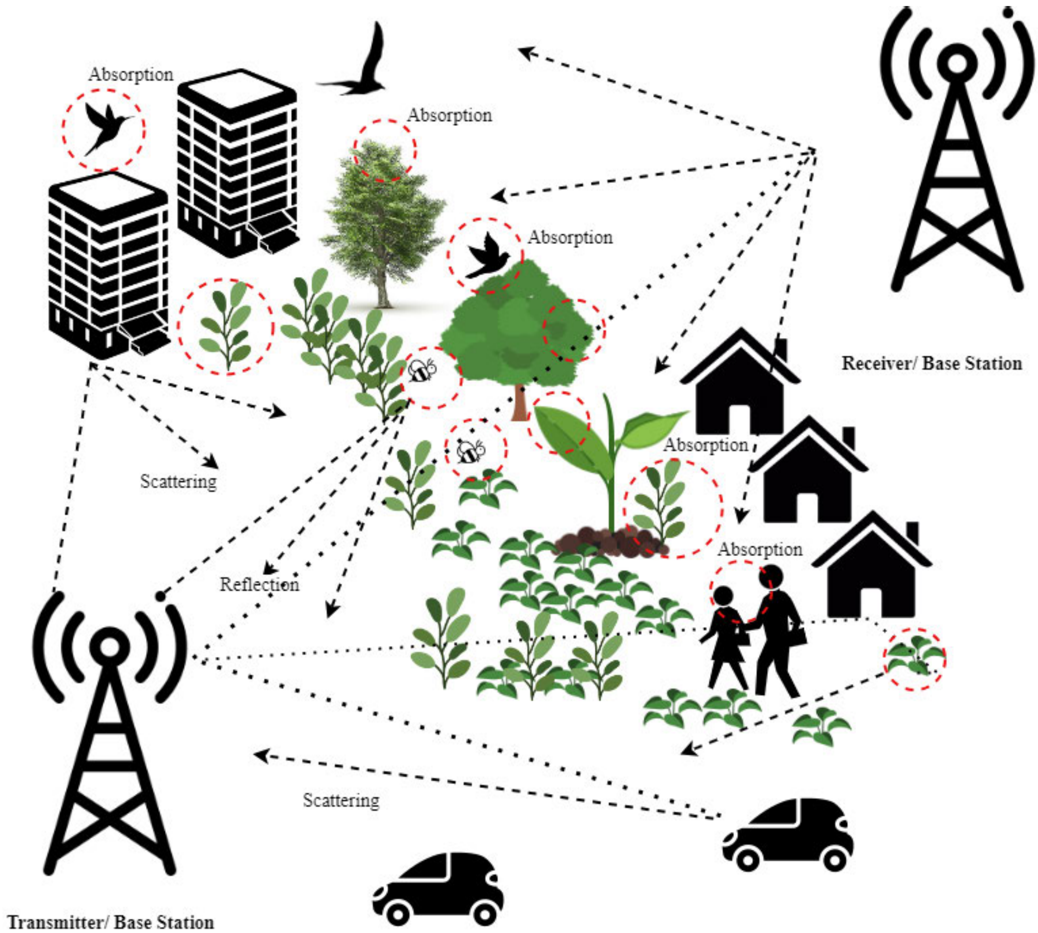


FIGURE 1. Schematic of electromagnetic wave propagation, reflection, scattering and absorption based on the components on atmosphere.

of particles in the environment and it causes the signal to scatter in multiple directions. It results in signal distortion. These are influenced by the existence of physical objects such as buildings, vehicles, plants, trees, and different biotic and abiotic components that exist in the environment.

Detailed experimentation is performed to identify the significance of different plant species on electromagnetic propagation in outdoor wireless communication. The following subsections discuss the explanation of the experimental procedure, test equipment, test antenna, specifications of test plant species, and real time experimentation on the test plant species for validating its significance.

A. EXPERIMENTAL PROCEDURE

The experiment is carried out to analyze the absorption of EM waves by different plant species, by analyzing the return loss of the antenna in the outdoor test environment. Testing an antenna in realistic operating conditions in an outdoor environment is an important procedure for validating its performance. Different factors like antenna mounting position, ground plane, signal interference, weather conditions, and calibration of measuring equipment are also considered for real time experimentation. So, the experiment is performed by considering all these factors and validating the antenna characteristics. The environmental conditions are monitored throughout the experiment where the temperature is 31°C and humidity of 70%. An enclosed microstrip planar antenna operating at 2.45 GHz is connected to the Fieldfox analyzer (N9915A) and is placed in the free space environment where the experiment is carried out. Since the antenna is placed inside an enclosure, the effect of the ground plane when comes in contact with the component under test will be nullified. The analyzer is calibrated in the environment where the experimentation is carried out. This helps in minimizing the noise and interference that could affect the measurement. By energizing the microstrip antenna using the Fieldfox analyzer, the EM wave emitted is propagated through the atmosphere and is affected by various factors like reflection by nearby objects, absorption on the biotic components, scattering by particles in the atmosphere, attenuation/distortion due to the interference and the modification in the polarization of EM waves. Each of these variation can be nullified by calibrating the test setup. The experiment is carried out in an environment where different plant species are present as represented in Figure 2. Based on the experimentation, the variation in the antenna characteristics can be analyzed. For conducting the experiment, 25 different plant species were identified and studied absorption characteristics based on the variation in the measured value of antenna characteristics. Each of the species has its own physical and morphological characteristics. The characteristic variation of each species have their significance in real time experimentation. So, the test antenna is placed nearer to the different plant species and identifies the variation in the return loss of the antenna. The detailed analysis of all the components in real time experimentation is explained in the next sections and subsections.

1) TEST EQUIPMENT

The equipment used for antenna measurement in the environment where the plant species are present is the Keysight N9915A Fieldfox analyzer shown in Figure 3. It is a handheld analyzer used to perform experimental analysis in the outdoor environment. This equipment is capable of measuring the frequency up to 9 GHz. The measurement can be performed by calibrating the equipment by nullifying the loss of the coaxial cables using a high end calibration kit compatible with the test equipment.

2) TEST ANTENNA

The antenna is considered as the major component in the wireless communication system as a transceiver. The antenna that is considered here for the experimentation is a standard rectangular microstrip patch antenna which is shown in Figure 4. This standard antenna is purchased from Keysight Technologies for validating the basic designs. This antenna structure is selected from all the antenna configurations that exist in different communication systems. All these configurations are the modification of the simple patch antenna. So, based on the applications and frequency of the operation, structural modifications are incorporated into the existing antenna designs for generating the new designs. Also, modifications to these patch antennas are being used in the directional transmitting antenna systems within the cell towers/cellular base stations. This reason has led to the selection of a patch antenna as the test antenna for conducting experimentation in identifying the influence of different plant species in wireless communication systems.

The design of the proposed antenna basically depends on the material of the substrate and the frequency of operation. The configuration of the microstrip antenna consists of the ground plane, which is completely covered with metalization. The top of the antenna has a substrate with a radiating microstrip rectangular patch. This antenna system is designed on the substrate with a dielectric constant 3.2 and, height h of 0.762 mm using standard design equations making it operational at 2.45 GHz. The design equations of the rectangular patch antenna are given by equations 1 to 3 [39].

The width 'W' of the patch antenna is given by,

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

TABLE 1. Antenna characteristics.

Sl.No	Antenna Parameter	Specification
1	Operating Frequency	2.45 GHz
2	Return Loss	22.08
3	VSWR	1.18
4	Bandwidth	20 MHz
5	Gain	6 dBi
6	Radiation Pattern	Directional
7	Side Lobe Level (SLL)	-20 dB
8	Polarization	Linear

The length 'L' of the patch antenna is given by,

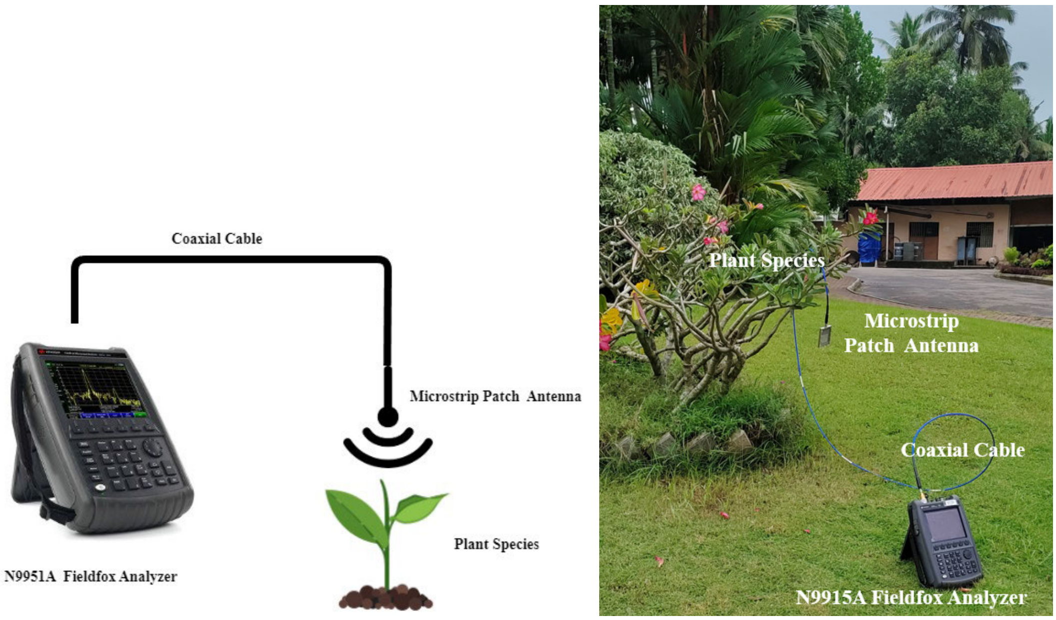
$$L = \frac{1}{2f_r\sqrt{\epsilon_{eff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \tag{2}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\frac{h}{W}}}\right) \tag{3}$$

where, f_r is the resonance frequency, μ_0 is the permeability of the free space, ϵ_0 is the permittivity of the free space and ϵ_{eff} is the effective dielectric constant. The physical dimensions like the feed mechanism and its position, length, and width of the rectangular patch in the antenna prototypes are optimized using standard design equations of the microstrip antenna [39]. The performance of the antenna prototype is experimentally validated within the anechoic chamber using the Keysight N5227b PNA Network Analyser. The experimentation performed within the anechoic chamber for validating the antenna characteristics like return loss and VSWR are represented in Figure 5. From the experimental validation, the antenna operates at 2.45 GHz with a return loss of 22.08 dB, narrow bandwidth of 20 MHz, and VSWR of 1.18. The antenna has a directional radiation pattern with a gain of 6 dBi and a side lobe level (SLL) of -20 dB. The specification of the test antenna is represented in Table. 1.

3) SPECIFICATION OF TEST PLANT SPECIES

Plants are complex biological systems that interact with the EM spectrum in different ways when wireless communication is established in an outdoor environment. Interaction of EM waves depends on different parameters including plant species that are present in the environment. These existing plant species have their unique characteristics. Trees, shrubs, grass, succulents, aquatic plants, etc. are some of the different plant species. This classification is based on the variation in its physical and morphological characteristics. Some among them are leaf shape, flower structure, stem structure, photosynthesis pathway, growth habitat, fruit types, and root system. The leaf shapes are categorized based on the shape of individual leaflets and stem characteristics based on the thickness, colour, texture, and existence of hair and thrones. Leaf colour is influenced by the presence of pigments such as chlorophyll, catatonics, and anthocyanins. Leaf texture can be smooth, glossy, thin, or thick, and existence of wax on its surface. Leaf shape varies from simple to complex structure and its size varies based on environmental factors



(a) (b)

FIGURE 2. Experimental setup (a) Schematic diagram (b) Real time scenario.

FIGURE 3. N9915A fieldfox analyzer [38].

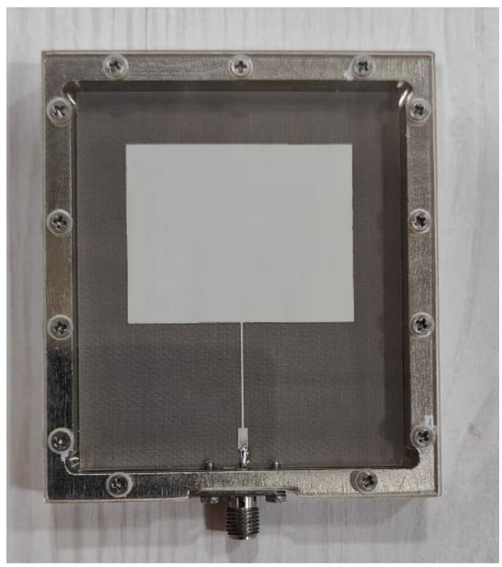


FIGURE 4. Rectangular microstrip patch antenna [38].

such as temperature, light, and water availability. Flowers can be categorized by shape, size, colour, and the arrangements of their petals, stamen, and pistils. These are influenced by genetic factors and all other environmental conditions.

Experiments have been carried out on different species of plants. This variation in its properties determines its influence on electromagnetic wave propagation in the outdoor environment. The selected species and the specification of each species are listed below:

- **Tabernaemontana divaricata - Green, Variegated White Plant**: This species is commonly known as crape jasmine. It belongs to the small shrub category of plant species with large glossy leaf structure with green and variegated white pigmentation. Stem of these species is smooth [40].
- **Perennial ryegrass**: It is a category in grass family where highly green coloured and back of its leaf are shiny. It contains 0.57% of calcium and 0.27% of potassium [41].
- **Adonidia palm**: This palm species which is an ornamental plant, have a single trunk. The palm is grey in colour with leaf having scar rings and base is swollen. It is of the smooth and slender form [42].
- **Adonidia palm - Dry Leaf**: Dry leaf of the above mentioned 'Adonidia palm' is chosen, where there is less water content within the leaf.

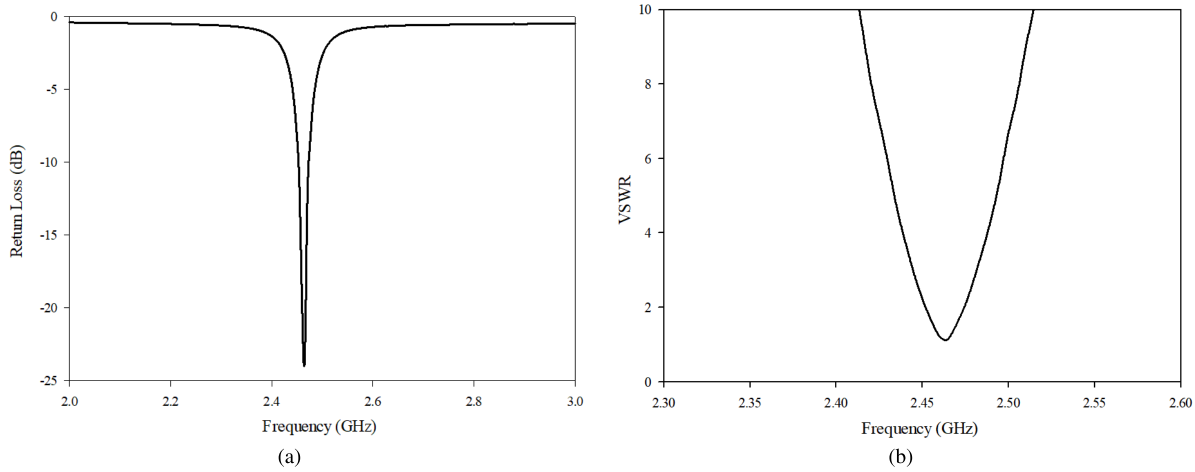


FIGURE 5. Experimental results (a) Return loss (b) VSWR.

- **Neomarica gracilis**: This species lacks stem and have soft and flexible green leaves. The water content is high with shrubs like property [43].
- **Caesalpinia pulcherrim - pink, orange, Seed**: This species mainly exists in different colours. For the study, pink and yellow flower groups are considered. The analysis is performed by considering its flower with bowl shaped petals with elongated red stamens. The seed for this species is green in colour with a hard texture [44].
- **Petra croton - Yellowish Green Leaf, Red Leaf**: This species exists in different coloured leaves. They are differentiated based on the colour of the leaves. This species has the ability to absorb the pollutants from the atmosphere. The leaf contains water content, and the bark is of hard texture. The properties vary based on the colour composition [45].
- **Cyrtostachys renda: Lipstick palm**: It has a deep green coloured leaf structure with the bright red trunk. The water content in the entire body is high and it shows medium growth [46].
- **Princess caroline napier grass**: Purple coloured lengthy leaf structure with high protein content. This species contains plenty of minerals [47].
- **Pleioblastus fortunei variegata**: It is a species of bamboo family with striking creamy-white and green striped leaves [48].
- **Adenium obesum**: The grey green to variegated branching leaves with very few leaves exist. It has a thick succulent trunk with thin and delicate leaves [49].
- **Ixora - Pink, Yellow, Red**: It has bright coloured bloom with flat topped flower heads, and the flowers are in clustered form [50]. The analysis is performed based on colour of flower.
- **Crinum asiaticum**: This species of the plant have light green coloured stalkless leaves. It is a herberours plant that grows up to 2m tall [51].
- **Heliconia psittacorum**: This species has simple banana like leaves, and the midrib is ivory and pink colour. The tenderness of leaves is very low, and water content is less [52].
- **Mussaenda frondosa**: The flowers of these species are white in colour with a thin planar texture and sparsely hairy on both surfaces [53]. The flower of this species is considered for evaluation.
- **Bismarckia nobilis: Bismarck Palm - Leaf, Seed, Palm bark**: It is the category of palm species where the truck is thick, leaves and seeds are hard [54]. The leaf, seed, and bark of the palm is considered for this study.
- **Excoecaria bicolor**: The leaf of the species has papery and slightly fleshy leaf blades [55]. The top portion of the leaves is whitish green with red pigmentation on the bottom side.

B. REAL TIME EXPERIMENTATION IN PLANT SPECIES

Antenna characteristics in the outdoor environment are analyzed to study the influence of different biotic and abiotic components in outdoor wireless communication. The variation in the antenna characteristics is analyzed depending on whether there is absorption or reflection of electromagnetic waves. The only possible way to analyze the absorption of EMR on different plant species is based on the captured return loss of antenna using a Fieldfox analyzer. The real time experimentation with a microstrip antenna operating at 2.45 GHz placed nearer to various plant species is analyzed using a Fieldfox analyzer and is shown in Figure. 6.

Biotic and abiotic components have direct or indirect influences on the performance of the antenna in an outdoor environment. For the experimentation, the biotic components considered for the evaluation are different plant species. The performance of the antenna is influenced by the type of plant, its proximity to the antenna, pigmentation, morphological properties, and frequency of operation. The influence of plants on the outdoor environment of an antenna is complex depending upon multiple factors like propagation over a green environment, reflection, scattering, and absorption which can cause interference and signal distortion, etc. This

FIGURE 6. **Real time experimentation on different plant species (a) Free Space (b) Tabernaemontana divaricata -Green Leaf (c) Pleioblastus fortunei variegata (d) Neomarica gracilis (e) Crinum asiaticum (f) Adenium obesum (g) Caesalpinia pulcherrima - Seed (h) Petra croton - Red (i) Heliconia psittacorum (j) Ixora - Red (k) Tabernaemontana divaricata - Variegated White Plant (l) Caesalpinia pulcherrim - Orange (m) Bismarckia nobilis: Bismarck Palm - Leaf (n) Bismarckia nobilis: Bismarck Palm - Seed (o) Bismarckia nobilis: Bismarck Palm - Bark.**

can be analyzed based on the variation in the antenna parameters such as frequency response, return loss, gain, radiation pattern, efficiency, polarization, etc. Variations in the dielectric properties of different plant species can lead to variations in the frequency response of the antenna. The electromagnetic waves interact with different plant species, resulting in frequency dependent losses, thereby resulting in impedance mismatch leading to reflections and an increase in return loss. This variation is based on size, dielectric properties of plants, and proximity to the antenna. When the electromagnetic waves propagate over the plant environment where the diffraction occurs, it results in variation in gain, radiation pattern, range, and signal strength of the antenna. The absorption, scattering, and reflection of electromagnetic waves by the plants can result in energy losses and decrease in efficiency. The electromagnetic waves can experience

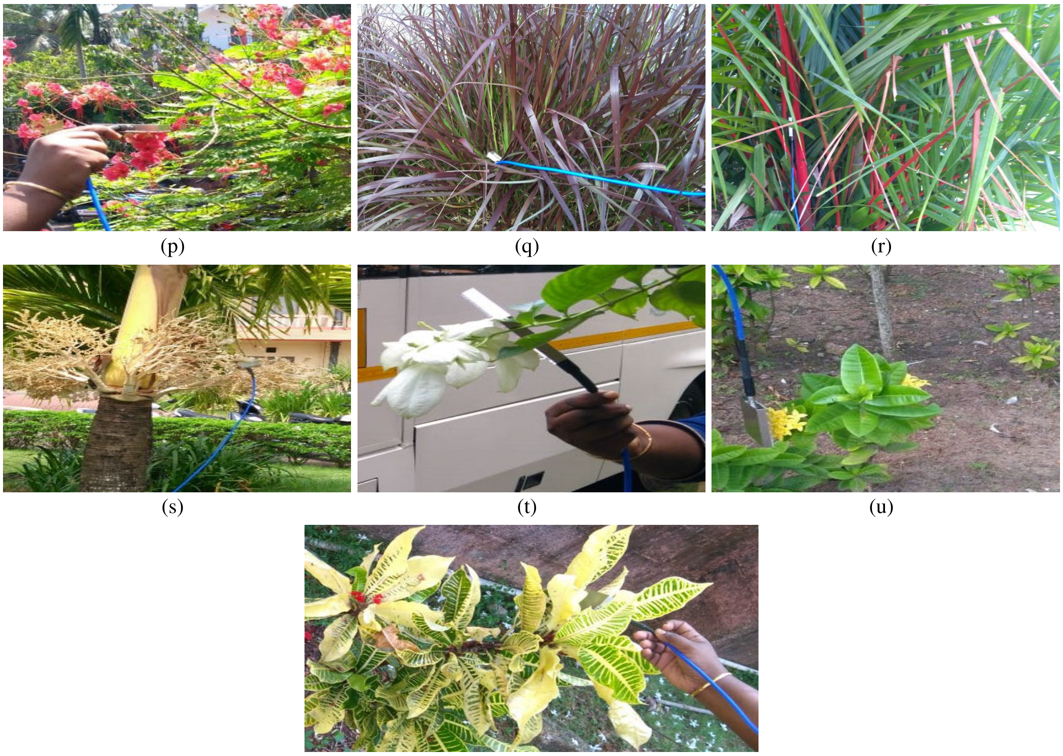


FIGURE 6. ***(Continued.)*** **Real time experimentation on different plant species (p) Caesalpinia pulcherrim - Pink (q) Princess caroline napier grass (r) Cyrtostachys renda: Lipstick palm (s) Adonidia palm (t) Mussaenda frondosa (u) Ixora - Yellow (v) Petra croton - Yellowish Green Leaf.**

changes in their polarization state due to interactions with the plant material, resulting in variations in received polarization at the receiving antenna.

III. RESULTS AND ANALYSIS

This study focuses on identifying the variation in the return loss of antenna and its significance in the absorption of electromagnetic radiation on plant species. The variation in return loss of antenna when placed near to different plant species is represented in Figure. 7. From the experimental analysis, the variation in the return loss of antenna in free space with respect to the existence of antenna nearer to different plant species is identified. The detailed analysis on the return loss of antenna when tested in the outdoor environment by the influence of different plant species is represented in Table. 2. The variation in the return loss are influenced by different plant species. The plant species when present in the near field of the antenna creates an impedance mismatch with the surrounding environment of the antenna leading to the variation in the return loss of the antenna. The impedance mismatch with the components that exist in the test environment results in the variation in the reflection of the EM wave towards the antenna under test. This reflection from the surrounding environment depends on the morphological characteristics of the components that exist nearer to the antenna. When comparing these reflection characteristics of the antenna with and without the presence of a plant helps in identifying the significance of the species and how physical and morphological characteristics influence the antenna characteristics. From Figure. 7, it is identified that the return loss of antenna by the influence of the different species is varied from higher to lower with respect to the antenna without the influence of plant species. Only the species like neomarcia gracilis, the green seed of the caesalpinia pulcherrim, lipstick palm, and bismarck palm leaf shows a 200 MHz frequency shift along with the variation in the return loss. This can occur because of the variation in the dielectric properties of the plant based on physical and morphological characteristics like cell composition, water, and mineral content; when the EM waves from the antenna interact with these, it leads to changes in the effective dielectric constant, and velocity of propagation leads to frequency shift. Other than the absorption of EM waves based on the interaction with each plant species, coupling of EM waves creates the field and the current fluctuations resulting in changes in radiation pattern, and the impedance mismatch leads to the frequency shift of the antenna characteristics. Along with frequency shift, these four species also show variation in return loss, with respect to the return loss of antenna kept in a region with no influence of plants. Other than these, the remaining plant species have shown significant variation in the return loss of antenna operated at 2.45 GHz. This variation is identified based on comparing the antenna performance in the isolated environment in the same test scenario and the antenna placed nearer to these specified plant species.

It is identified that the return loss of the antenna varies with respect to the placement of the antenna in normal free space conditions depending on the variation in the plant species. As a result of the variation in morphological and physical characteristics, impedance mismatch has occurred in the transmission medium of the antenna under test. When the plants exist in the nearby region of antenna, the dielectric properties, water content, pigmentation, surface area, cell structure, etc, create variation in the return loss. This variation is also dependent on the reflection, scattering, and absorption of EM waves by the plant environment. From the experimental analysis, it is identified that the return loss of the antenna in free space is 19.57 dB, where the load impedance is approximated as 61.74 Ω. This return loss and load impedance are considered as the threshold values for conducting other measurements in the outdoor environment by considering the temperature, humidity, and pressure. The influence of different plant species can be identified by analyzing the variation in the return loss of the antenna by placing it nearer to the specified plant species. Table 2 represents the return loss of antenna in the presence of different plant species. From this, it is identified that the antenna return loss varied from higher to lower value with respect to the open environment and in the presence of plant species. Overall, in 25 species of plant, the analysis is performed on different parts of the plant. The characteristics of antenna is varied based on the composition of each plant species. The value of return loss is varied due to various factors like impedance mismatch, reflection, improper feed line connections, grounding of the antenna design, and existence of nearby objects. Impedance mismatch relates to reflection, and it reduces the signal strength. Even though impedance mismatch and reflection are directly related, they are indirectly related to the absorption of EM waves. However, absorption and impedance mismatch directly relates to the property of the different plant species that exist in outdoor environments. The reflection coefficient, Γ, and impedance mismatch are interrelated and is represented in equation 4 [39].

$$\Gamma = \frac{(Z_L - Z_0)}{(Z_L + Z_0)} \tag{4}$$

where Z_L is the impedance of the antenna and Z_0 is the characteristic impedance of the transmission medium where the experimentation is carried out.

Based on Lambert's law of absorption, the radiation absorption losses can be quantified as in equation 5 [56].

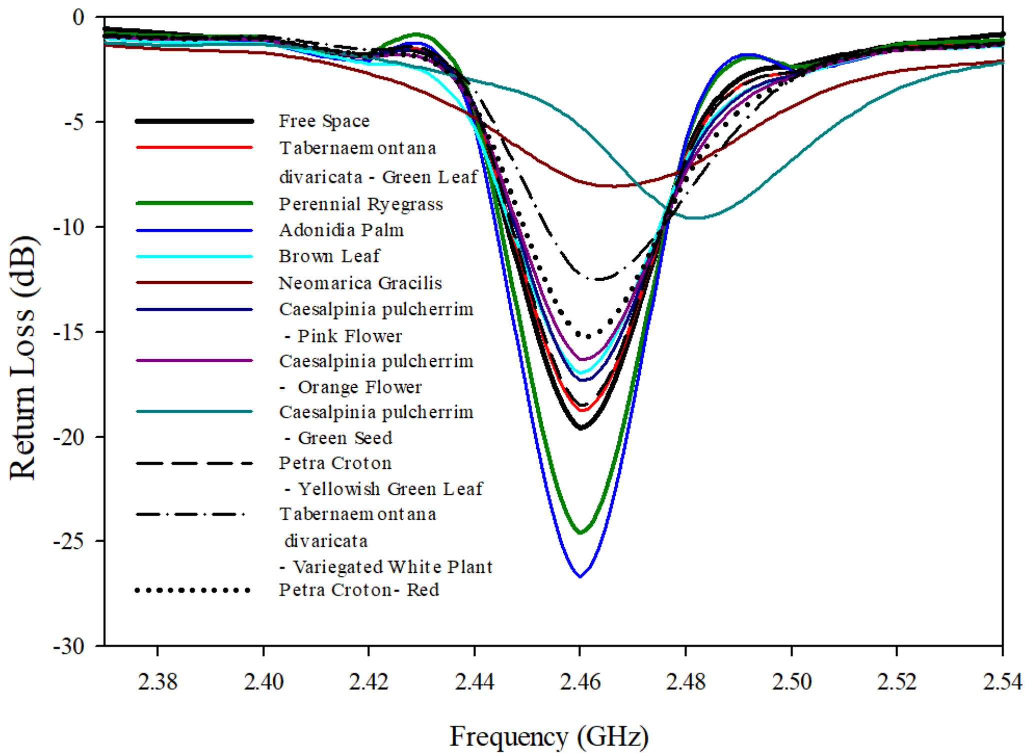
$$P = e^{-\alpha L} \tag{5}$$

where P is the fraction of power absorbed by the object, α is the absorption coefficient of the object, and L is the path length penetrated through the object. The absorption coefficient measures the object's ability to absorb electromagnetic radiation and is a function of its material properties, frequency, and other factors. The path length of penetration depends on the distance between the antenna and the size and shape of the object.

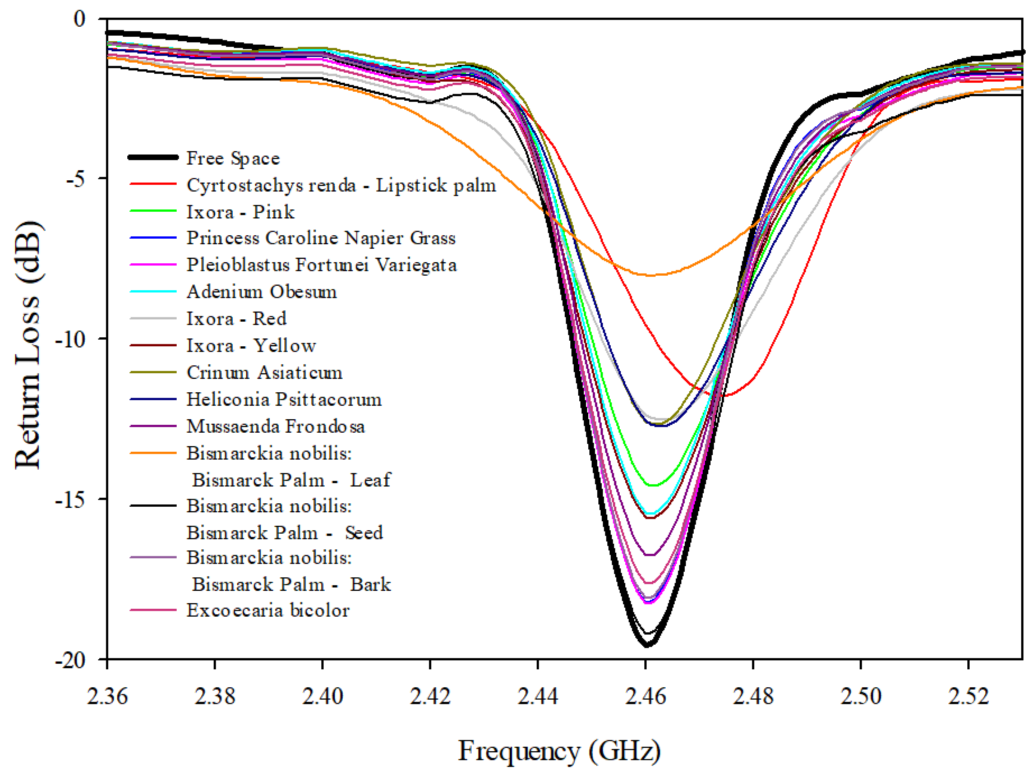
From the measurement carried out, it is identified that adonidia palm and perennial ryegrass have a low return loss compared to the antenna in free space and the variation from 26.55 dB to 24.6 dB. The smooth and slender adonidia palm creates less impedance mismatch. Calcium and potassium rich grass have highly reflective surfaces with less return loss characteristics. The green glossy leaf surface of Tabernaemontana divaricata species, the yellow green leaf of petra croton, the seed of bismarck palm, and bark of the palm have the relative same characteristics as that of the free space. These species have return loss in the range of 18.58 dB, 18.44 dB, 18.51 dB, and 19.02 dB. This variation is the result of dependency on species characteristics. The Caesalpinia pulcherrim seed, lipstick palm leaf, and bismarck palm leaf show very high return loss. High chlorophyll content in lipstick palm with trunk having bright red colour, which is grown in shrub form having leaf of less surface area, Caesalpinia pulcherrim seed, and hard leaves of bismarck palm also creates high reflection, thereby less absorption. The return loss is between 5 dB to 9 dB. Based on its properties other species in effect influences on the return loss of the antenna. The value of return loss varies between high and low values during experimentation conditions. High return loss is the representation of high power reflected to the antenna system. It is because of an impedance mismatch between the antenna and the surrounding environment. Here, it can be because of the influences from the existence or presence of plants. The higher return loss of the antenna indicates the high absorption of EM waves by the specific plant species when considered as a whole plant/ leaf/ bark/ seed/ flower. Low return loss of antenna represents less absorption by plant species due to its lower impedance mismatch. This impedance mismatch can be easily interpreted from the VSWR of the corresponding species. High VSWR results in a high impedance mismatch. So, these species with low absorption have less impact due to EMR emitted from antenna systems. Thus, these species create less impact on the wireless communication propagation system.

IV. DISCUSSION

Living and nonliving creatures that exist in the environment have their own significant role in each and every activity in wireless communication systems. Based on the property of these creatures, the dependency of each property of the EM wave varies and thereby influences the entire wireless communication system. This depends on the frequency of operation of the system, which in turn determines the penetration of the waves into the creatures. The range of the system determines whether the EM wave can interfere with the living/non-living creatures in the communication systems, as antennas are the prime source of EM waves in the wireless communication system. So the characteristics of the antennas are one of the factors which has to be considered



((a)) Variation in return loss of antenna with different plant species



((b)) Variation in return loss of antenna with different plant species

FIGURE 7. Experimental validation of variation in return loss of microstrip antenna in free space when compared with presences on different plant species.

TABLE 2. Antenna parameters in different experimental scenarios.

Sl.No	Scenerio/Plant Species	Return Loss (dB)	Reflection Coefficient	VSWR	Impedance Mismatch(Ω)
-	Anechoic room	22.08	0.07	1.18	50.09
0	Free space	19.57	0.11	1.25	61.74
1	Tabernaemontana divaricata	18.58	0.12	1.27	63.35
2	Perennial ryegrass	24.6	0.06	1.13	56.26
3	Adonidia palm	26.55	0.05	1.11	54.94
4	Adonidia palm - Dry Leaf	17	0.14	1.33	66.45
5	Neomarica gracilis	7.73	0.41	2.39	119.69
6	Caesalpinia pulcherrim - Pink	17.18	0.14	1.33	66.06
7	Caesalpinia pulcherrim - Orange	16.38	0.15	1.35	67.88
8	Caesalpinia pulcherrim - Seed	5.15	0.55	3.44	173.57
9	Petra croton - Yellowish Green Leaf	18.44	0.12	1.27	63.59
10	Tabernaemontana divaricata - Variegated White Plant	12.13	0.25	1.67	82.88
11	Petra croton - Red	15.08	0.18	1.44	71.39
12	Cyrtostachys renda: Lipstick palm	9.04	0.35	2.08	104.6
13	Ixora - Pink	14.29	0.19	1.47	73.91
14	Princess caroline Napier Grass	18	0.13	1.3	64.4
15	Pleioblastus fortunei Variegata	18	0.13	1.3	64.4
16	Adenium obesum	15.44	0.17	1.41	70.34
17	Ixora - Red	12.29	0.24	1.63	82.09
18	Ixora - Yellow	15.36	0.17	1.41	70.57
19	Crinum asiaticum	12.57	0.24	1.63	80.76
20	Heliconia psittacorum	12.53	0.24	1.63	80.94
21	Mussaenda frondosa	16.62	0.15	1.35	67.31
22	Bismarckia nobilis: Bismarck palm - Leaf	8.03	0.4	2.33	115.76
23	Bismarckia nobilis: Bismarck palm -Seed	19.02	0.11	1.25	62.61
24	Bismarckia nobilis: Bismarck palm -Bark	18.51	0.12	1.27	63.47
25	Excoecaria bicolor	17.62	0.13	1.3	65.14

for effective communication in the outdoor environment. Different types of antennas are used in the system, and the selection of these antennas is based on the required application. Based on the antenna and frequency of operation, the EM waves emitted from the antenna create reflection, scattering, diffraction, and absorption based on different components that exist in the outdoor environment. Living creatures like plants, animals, human beings, birds, insects, micro organisms, etc. are present in the outdoor environment. However, the study on the influence of all these components on wireless communication needs to be analyzed separately. This research study focuses on the influence of different plant species - both the ornamental plants and ayurvedic plants on wireless communication in outdoor environments. Experimentation is performed at a temperature of 31°C and humidity of 70% using a microstrip antenna operating at 2.45 GHz and N9915A Fieldfox analyzer. The antenna is connected to the analyzer and is calibrated to nullify the effects of cable and connector using the 85033E 3.5mm calibration kit. The microstrip antenna placed in free space is first analyzed using the Fieldfox analyzer, and antenna characteristics are studied at the same atmosphere condition. This antenna is placed nearer to different plant species that are present in the nearby region for experimentation. The antenna characteristics analyzed here for the experimental validation are its return loss. Return loss is the most significant characteristic of an antenna. It measures the amount of power that is reflected back to the antenna due to impedance mismatch. The antennas in the outdoor environment depend on different factors such as plant species, frequency of operation of antenna, and distance between antenna and test species. The identification and analysis of these parameters is complex. During experimentation, it is observed that the orientation of antenna has no significance on antenna properties. The variation in the return loss of the antenna is identified when located 5 cm horizontal and vertical locations over the circumference of the selected species. There is no significant difference in variation in return loss of antenna when placed 5 cm apart and in close contact with the test species. So, in this research, the analysis is performed based on the variation in the return loss of the antenna where the antenna is placed very close to the specified plant species.

The analysis is performed on 25 different plant species where the leaf, stem, bark, seed, and flower bunch are also considered for experimentation. The influence of plants nearer to the antenna creates an impedance mismatch, thereby leading to high return loss based on the reflection from different plant species. The intensity of reflection depends on the dielectric properties at 2.45 GHz, pigmentation of specified parts of plant, mineral, and water content. The impedance mismatch is due to the standing wave along the medium by which the EM waves transfer energy, thereby causing variation in voltage and current along the antenna. This variation has occurred due to the existence of plant species in the test environment, thereby causing significant effects on the return loss of the antenna. This variation in the impedance mismatch is analyzed by measuring the VSWR. The VSWR and return loss are inversely related. The observed higher and lower return loss in effect relates to the significance of plants on the antenna characteristics. Higher return loss in effect results in higher absorption of EM waves that are emitted from the antenna. This creates a reduction in range, signal strength, and less amount of power transmission. Lower return loss in effect relates to the less absorption of EM waves. The higher and lower return loss occurs as a result of the tenderness of the seed, the high surface area of the leaf, water content, pigmentation of flower bunch, and composition of the bark of species. So the significance of higher and lower return loss relates to the plant species characteristics, frequency of operation, and other environmental factors. The consideration of all the factors in an efficient way is required to optimize the variation in return loss of antenna based on the different plant species.

The possibility of absorption of EMR on the plant community at the specified frequency of 2.45 GHz is considered for optimizing the variation in the antenna return loss by the involvement of different plant species. The impedance mismatch in the outdoor environment by different plant species is influenced by the distribution of the electric field. The distribution of the E field determines the interaction of EM radiation on different plant species. The field distribution relates the conductivity of each species based on its dielectric permittivity. The variation in all these factors creates clear evidence of the EMR absorption on each plant species. The absorption of EMR is measured in terms of Specific Absorption Rate (SAR). It depends on the E field, conductivity, and mass density of tissues. The variation in the return loss relates to the orientation of E field. So, the increase in the E field distribution, conductivity of the plants based on material properties and physical dimension of each species relates to the electromagnetic radiation that is being absorbed by each species under the given frequency of operation. So, the variation in return loss of antenna in outdoor environment is interrelated to the absorption of EMR by the different plant species.

On analysing the experimental results, it could also be observed that the reflection coefficient is dependent on the pigmentation of the sample species, its water content, mass density and conductivity of the sample. On analyzing the samples based on pigmentation, it is observed that the sample species with orange and red pigmentation have more absorption of EM waves than the violet and green species. A similar observation is made when considering the water or fleshy content within the plant species. With the increase in water content or mass density of the sample species, the absorption of EM wave by the plant species is increasing. All the above mentioned results confirm the influence of plant species in wireless communication. If a plant species has more absorption content in a certain geographical area, then the wireless channel communication will certainly be affected, leading to disturbances or losses. In some other cases, depending on the pigmentation, water content, density, or other parameters of the species, the absorption of EM waves by the plant species may increase or decrease, which results in communication fluctuations. So, the land cover of an area also needs to be considered in fixing the wireless channel and propagation parameters.

This research work can prove the dependency of the antenna characteristics on the different plant species in the environment. Based on the studies, it can be clearly understood that the variation in antenna characteristics has happened because of the impedance mismatch and thereby affects the E field distribution and conductivity, and it relates to the absorption of EM radiation. From the studies, it can be observed that the absorption of EM waves by the plant species has mostly resulted in the variation in return loss of the antenna. All these inferences provide clear evidence that the plant species has an influence on the antenna characteristics in wireless communication in outdoor environments. This study could act as a baseline in predicting the variation in antenna characteristics if any plant species having the same morphological characteristics exists in the wireless communication environment. As a future scope, the study needs to be extended to identify the influence of different components in the environment on outdoor wireless communication to ensure better signal strength with reduced latency and noise figure.

V. CONCLUSION

The article provides a detailed study to identify the influence of different plant species on antenna characteristics in the outdoor environment. For the experiments, the antenna is placed nearer to the selected 25 different plant species and has analyzed the variation in the return loss with respect to free space without the influence of plant species. From the experiments conducted, it is identified that the return loss varies from higher to lower as the species differ from one to another. The pigmentation, water content, and mass density of the plant species have found influence on the absorption level of EM waves by different the plant species, resulting in more changes in return loss characteristics. Return loss variation is the result of impedance mismatch and the E field orientation based on the dielectric property, morphological and physical characteristics of each species. This creates the impact on the plant species as well as the communication system based on the absorption of EMR as it is identified from the fluctuation in the return loss of antenna. This is a primary investigation that proves the influence of plant species on antenna characteristics in outdoor communication.

Further studies are to be carried out in this area to properly investigate and find out the other underlying parameters of the plant species that influence the antenna parameters in outdoor wireless communication. Also, the influence to the antenna properties like radiation pattern and gain by the different plant species are to be studied.

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DISCLOSURE STATEMENT

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