The Chlorophyll Paradox, the Colour of Vegetation and Use of Image J to Analyse Ramans Physiology of Vision

Mitali Konwar and G.D.Baruah

***Abstract*— The green colour of vegetation has been termed as a paradox and it has explained in terms of the characteristics of the atmospheric absorption against the background of solar irradiance and solar blackbody radiation distribution profile. It is noted that the molecule chlorophyll, which is primarily responsible for a most familiar environment phenomenon, that is, the green colour of vegetation, absorbs strongly at violet, blue and red sector of the spectrum but is absorbs very poorly in the green, yellow and orange sector of the spectrum. But the sun shines by far the brightest in the green yellow sector. We term it a paradox and attempt to explain it as one of the absorption holes in the atmosphere which is analogous to spatial holes in laser theory. We also describe here a method involving the use of a software (Image –J to test Ramans observation on the green colour of vegetation, at successive stages of growth.**

***Index Terms*— green colour of vegetation, Ramans observation, molecule chlorophyll.**

I. INTRODUCTION

In 1871 Lord Rayleigh [1] used the method of dimensional analysis to derive a formula for the intensity of scattered radiation by particles that are small compared to the wavelength of the incident light. The formula is given by

$$I = Io\frac{8\pi^4\alpha^2 N}{\lambda^4 R^2}(1+Cos^2\theta)$$

where I is the intensity, α is the polarizability, λ is the wavelength, N is the number of scattering molecules and R is the universal gas constant. This formula explains the most familiar environmental phenomenon like the blue colour of the sky, red of the sun set etc. Rayleigh's formula was subsequently improved by physicists like King, Pendorf and Chandrasekhar, but the main form has remained the same and is still used today [2]. An alternate to Rayleigh's theory was developed by Einstein [3] in 1910 in his work related to critical Opalescence, based on the work of Smoluchowski. Critical opalescence is the strong scattering that takes place in a system where the liquid and gas phase have the same density and liquid drops of the same size as the wavelength of the visible light is formed. Einstein expanded on this to derive an equation for scattering without directly assuming that matter in the atmosphere is discretely distributed. Instead he considered the matter to be continuous, but characterized by a refractive index that is a function of the position. The equation worked out by Einstein for a homogenous ideal gas is given by

$$\frac{Jo}{J} = \frac{RTo}{N}\frac{(\notin -1)^2}{P}\frac{(2\pi)^4}{\lambda}\frac{\theta}{(4\pi D)^2}Cos^2\varphi \quad (1)$$

which also shows the $1/\lambda^4$ wavelength dependency.

A more general scattering theory is the Mie Webye or Mie scattering of electromagnetic radiation. It was published by Gustav Mie [4] in 1908 and describes the scattering of electromagnetic radiation by spherical or homogeneous particles. Rayleigh scattering is in fact a limiting case of Mie theory for particles much smaller than the wavelength.

Like the blue of the sky and ocean, the green of the vegetation is another prominent environmental phenomenon of the earth. Similarly the blue colour of the hills covered with vegetation another prominent environmental phenomenon. We do not have a Rayleigh type formula to explain these phenomenon in this article. It is generally understood that the green of the vegetation from tiny grass to lofty trees is due to chlorophyll. Blue of the sky which is completely explained by the scattering theories. the green of the vegetation needs a suitable theory to account for it. There are presumably few theories and notably that by Sir C.V.Raman [5]. In the present work we give an attempt to explain few **unexplained** features associated with the green of vegetation. Specifically we describe a method, involving the use of a software to test Ramans observation [5] on the green colour of vegetation at successive stages of growth.

II. The Paradox of Chlorophyll:

Chlorophyll absorbs strongly at blue-violet and red sector of the spectrum but it absorbs very poorly in the green-yellow and orange sector of the spectrum. On the other hand the sun shines strongly in the green-yellow sector of the spectrum. This is a mystery of nature. We term it as paradox for the first time and try to resolve it as least partially without being influenced by the beliefs and ideas taken from the existing earlier works. Let us first consider the molecular structures of chlorophyll a and b as shown in Fig 1 (a) (b). The corresponding absorption spectra of chlorophyll a and b are shown in Fig 1c.

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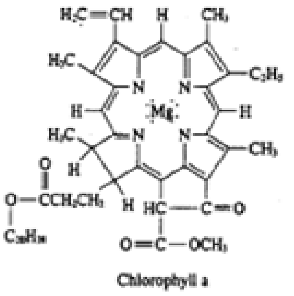
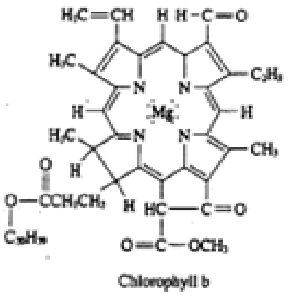
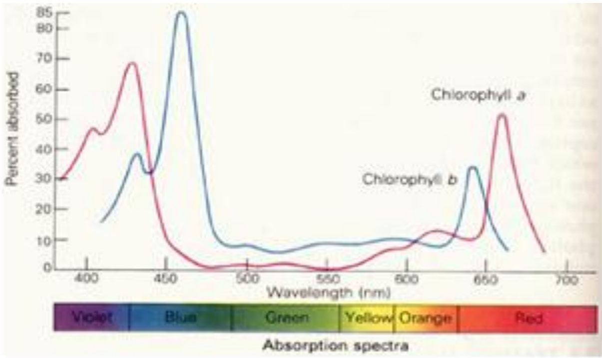


(a) Chlorophyll -a



(b) Chlorophyll -b



(c)

Fig 1 (a)-(b) Structures of chlorophyll (c) Absorption spectra of chlorophylls a & b.

Chlorophyll functions by absorbing light which excites the electrons within the molecule and the process is analogous to the operation of a solar cell. This produces a series of complex reactions. We observe from Fig 1 that chlorophyll is a very poor absorber in the green yellow region, which presumably accounts for the green color of the vegetation. It is worthwhile to note that the sun emits electromagnetic radiation over a wide range of wavelengths. The distribution of intensity as a function of the wavelength is given by the Planks equation for a black body, that is, by

$$I(\lambda)d\lambda = \frac{2\pi hc\ \Delta\lambda}{\lambda\ ({}_e hc/\lambda\alpha t_{-1})} ---(3)$$

where I (λ) Δ λ is the emitted energy per unit area of black body per unit time within a wavelength interval Δ λ, measured at temperature T, and ∝ is the Boltzmann's constant. We also observe here that if we take 5800^0 K as the surface temperature of the sun the peak wavelength of the black body distribution curve of the sun is 500 nm. This is the blue-green sector of the spectrum which is the range of the human eye. Thus it is essential to understand the basic facts related to human vision to explain the blue of the sky or the green of the vegetation. In fact this matter was raised Sir C.V.Raman[5] several decades ago. Let us consider again the absorption characteristics of the molecules of chlorophyll as illustrated in Fig 1, in the visible region and compare the characteristics features with the absorption characteristics of the atmosphereric species in the entire region of wavelength from 200 to 3000 nm as shown in Fig 2. In this curve the energy distribution curve for sun (taken as a black body) at 6000^0 k, Solar irradiance curve outside the atmosphere and solar irradiance curve at sea level are shown.

It is interesting to note that the selective absorption processes due to the species 0_3, H_2O and others take place beyond visible region in an oscillating manner. It is reasonable to infer that the absorption characteristics of chlorophyll in the visible are also a part the oscillating pattern as shown in Fig 2. Thus the so called chlorophyll paradox is not a paradox at all if we examine the shape of the entire absorption characteristics of the atmosphere against the background of solar irradiance in the wavelength range 200 – 3000 nm. There are six distinct absorption holes as indicated in the following table, Table 1. We would like to indicate here that these holes are analogous to the spatial holes which are burned by the laser field in the population difference at regular intervals inside a laser cavity [6-8]. Both the formulas and calculations which show spatial holes are outside the scope of the present article. But we give below the formula which is used to work out the spatial holes in the laser cavity.

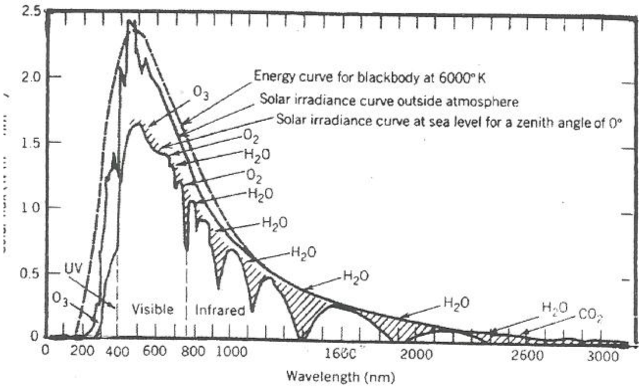


Fig. 2 Solar radiation incident at the top of the atmosphere, outside the atmosphere and at sea level. Energy distribution curve for blackbody at 6000^0 k is also shown.

$$\frac{Paa - Pbb}{N(z,t)} = \frac{1}{1 + In\sin^2\frac{2\pi}{\lambda}z} \quad \text{.... ..... (4)}$$

The LHS represents the normalized population difference. In the L.H.S. the parameter I_n is referred to as dimensionless intensity and Z is the direction of the laser axis.

Table 1

Absorption characteristics of the atmosphere in the range 200 – 3000nm. Absorption holes are produced at regular intervals.

Range (nm)	Species
450 – 700	0_3 chlorophyll
700 – 1000	H_2O O_2
1000 – 1300	H_2O
1300 – 1600	H_2O
1600 – 2200	H_2O
2200 -- 2700	H_2O

III. COLOR PERCEPTION AND GREEN OF VEGETATION:

In this section we consider the phenomenon of color perception by the human eye. Whether it is the scattered blue radiation accounting for the blue of the sky or the transmitted green radiation, accounting for the green of the vegetation it is the regime of wavelengths the human eye can see. Thus it is essential to have an idea about the visual response curves of the human eye, as exhibited in Fig 3. Human eye has three types of light receptors located in the retina [9]. They are known as cones which operate only during the period with enough illumination. There are also present in the retina receptors known as rods which are sensitive only during low levels of illumination. Each cone is sensitive to a broad range in the visible sector of the spectrum. The peak sensitivity of the cones are found at 580 (Red), 540 (Green) and 450 nm (Blue). The color as perceived by the eye depends on how many photons of particular wavelengths fall within the response curves. As may be seen in Fig 3 the sensitivities overlap which means that if light of any color is intense enough it will be visualised as white, because of the fact that all the cones will be fully activated. In this case the principle of superposition of color is important. The principle of superposition of color indicates that there are many ways to produce a unique combination of wavelengths e.g. to create the green. When looking at the green of the vegetation, the red cones respond primarily to the small amounts of red light transmitted and less to the orange. The green cones have their strongest response at the scattered or transmitted green. The colours near the strongly scattered blue wavelengths primarily stimulate the blue receptors. From this it can be concluded that the sky lights stimulates the red and green cones almost equally stimulating the blue cones more strongly. From the blue curve it can be inferred that the sensivity for the blue light is much higher than that for the violet. This shows that even thought there are more scattered violet wavelengths than there are blue wavelengths, the blue is perceived better which results in human perceiving the sky to be blue. What about the green of the vegetation? By using the same argument we can explain the green of the vegetation. From the absorption curves of chlorophyll (Fig 1c) and the sensitivity curve of the human eye (Fig 3) it can be concluded that the green colour is transmitted and it is perceived better. Again, what is the role of the solar blackbody radiation curve which has also the maximum intensity at the green yellow sector of the spectrum. This fact needs to be included in explaining the green colour of vegetation. Colour presumably depends on intensity. We have an occasion here to use this fact in explaining the green of the vegetation. The familiar examples are the green colour of the widely spread tea gardens or the green coloured rice fields. To illustrate the idea we consider an experiment where the green colour of the tea garden spread over a distance of 1 kilometer is viewed with the help of a pocket spectroscope fitted with a wavelength scale and the intensity of the green colour is visually estimated. The pocket spectroscope is enclosed in a rigid enclosure fitted with the help of a solid stand for convenience in observation. A sensitive photodiode is connected with a multimode optical fiber to estimate the green sector of the spectrum quantitatively. The observation is made from a height of about 4 meter in a room which is made dark for convenience of observation. It is very instructive to make observations at different times during day from morning to afternoon. Visual observation clearly indicates that in a clear sunny day the intensity of the green colour is at its maximum at noon and at other occasions the intensities vary, Table 2 includes the results of observations made visually and with the help of a photodiode using the experimental arrangement as described above. As can be seen from Table 2 that the intensities are maximum at around midday and they are insignificant in the morning and afternoon.

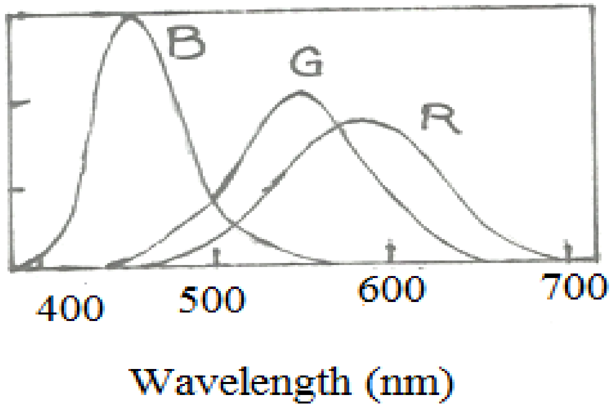


Fig 3 Sensitivity curves of the human eye.
B denotes blue, G green and R red

Table 2
Intensities of the green color of tea garden at successive stages of the day.

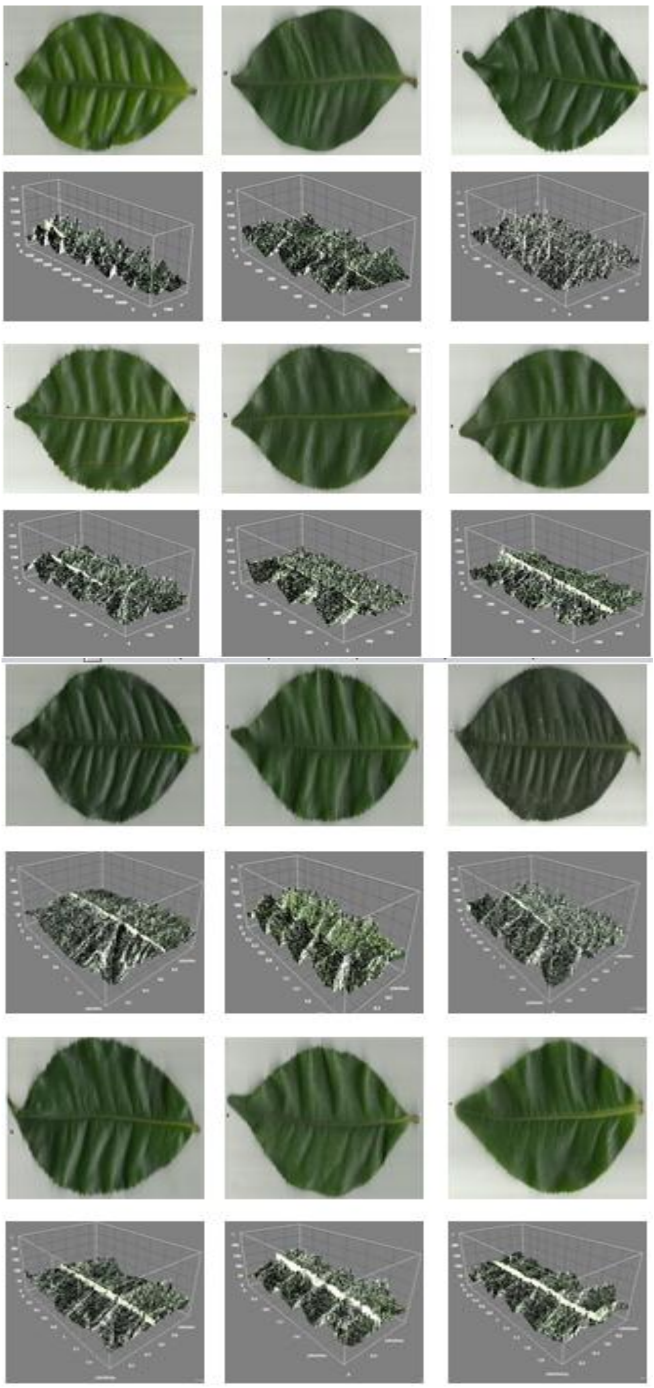
Time (in hrs)	Intensity	
	Visual	Photodiode
6	vw	.000
7	vw	.000
8	vw	.001
9	w	.009
10	ms	.009
11	s	.510
12	vs	.520
13	vs	.400
14	s	.080
15	w	.009
16	w	.005
17	vw	.000
18	vw	.001
19	vw	.000
20	vvw	.000

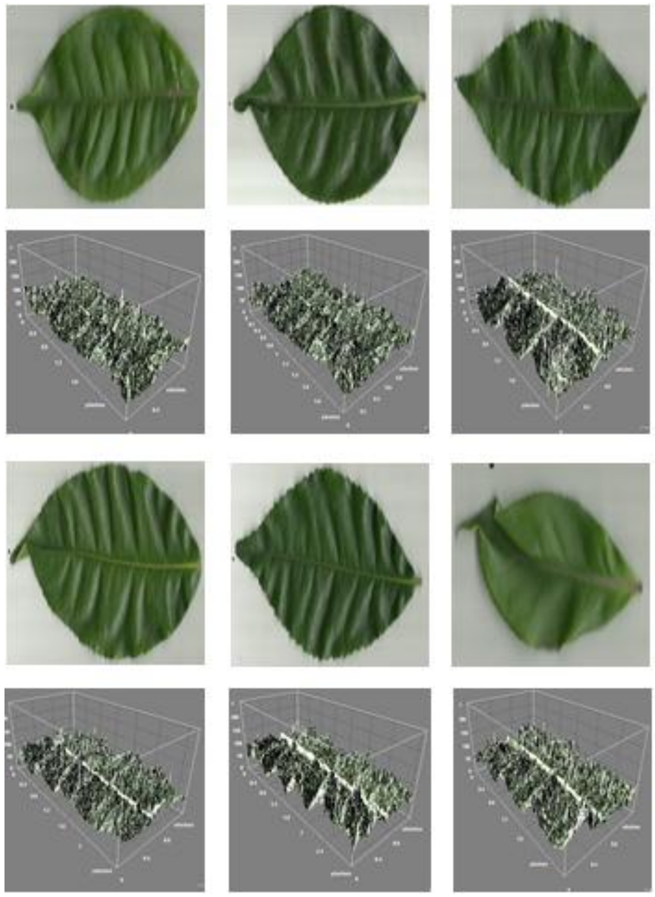
W=weak, vw=very weak, vvw=very very weak, s=strong, ms=medium strong, vs= very strong

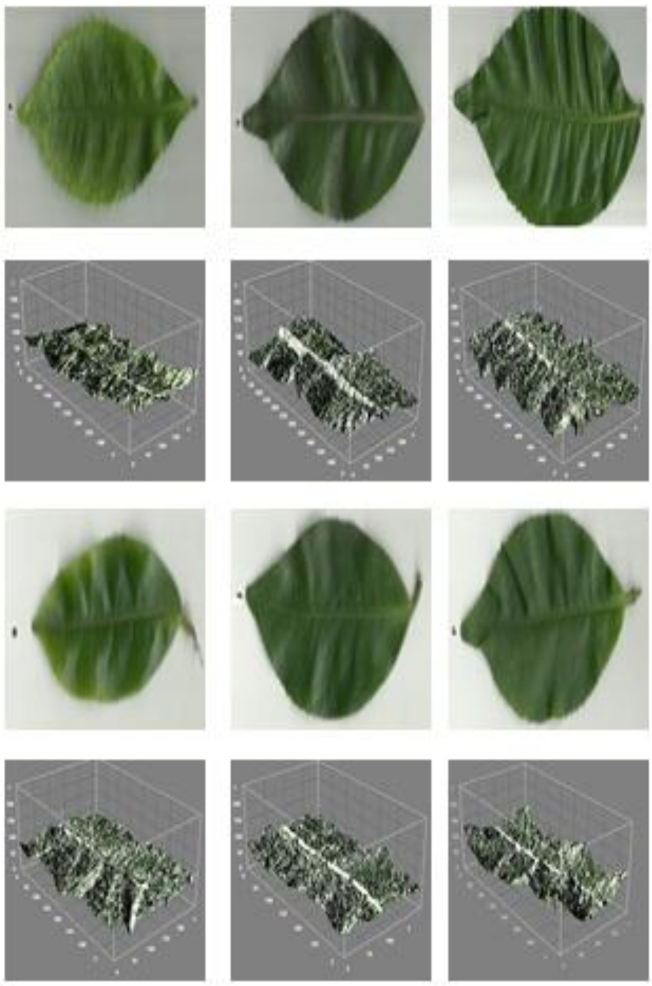
The photodiode readings and visual estimates are identical. In this connection we would like to indicate one of the interesting environmental features which is the so called blue of the hills. If we look at a hill covered with vegetation from a distance of more than two kilometers, the hill appears blue. The green of the tea gardens located quite close to an observer and the blue of the hills further away is a familiar scene. The explanation was given in a paper by Saikia and coworkers [10]. We do not discuss the salient features associated with the phenomenon of the blue of the hills but emphasize the fact that like the other phenomena it is also concerned with the physiology of vision.

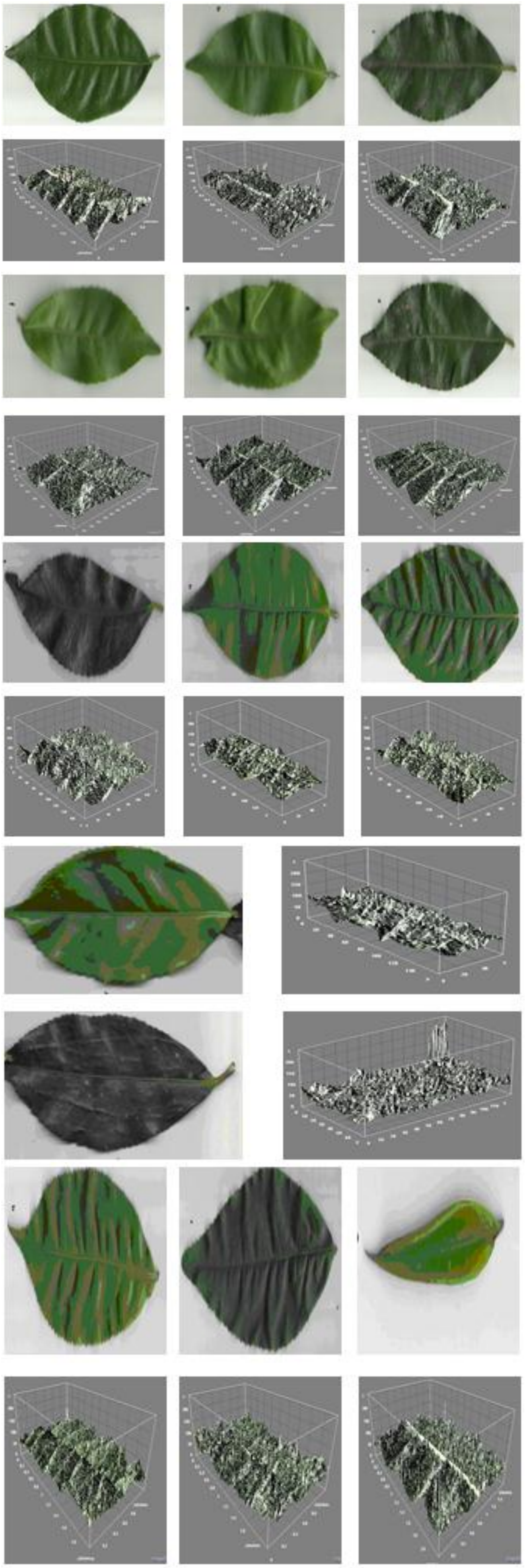
IV. RAMANS PHYSIOLOGY OF VISION:

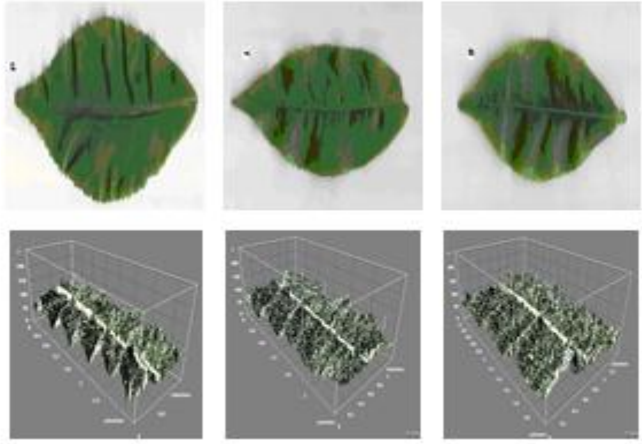
In this section we proceed to discuss the observations made by sir C.V.Raman in his work related to the physiology of vision and the green of vegetation [5]. He has noted few interesting results from a comparative study of the leaves in different stages of growth from the same tree. The comparisions are best made by viewing the surface of each such leaf under similar conditions of illumination through a pocket spectroscope. It is then noticed that despite the enormous differences in colour of the leaf in various cases, the spectral range covered the light emerging from the leaf remains the same. The brightness of the spectrum shows a progressive diminution as one passes from stage to stage in the development of the leaf. We now consider our work related to the measurement of intensities worked out with the help of a software (Image – J) on thirty different leaves of tea at different stages of development.











The three dimensional photographs of measurements corresponding to thirty samples are exhibited in Fig. 4 along with the photographs of the leaves at different stages of growth. We would like to comment here that the peaks as observed in the three dimensional patterns correspond to the intensities of light which actually pass through the leaves during scanning. The peaks are different at different stages. The maximum peaks are observed in the tender leaves.

V. SUMMARY AND CONCLUSIONS

From the discussions above it is essential to make a conclusion and summary of the work. The green colour of vegetation has been termed as a paradox. It has been explained in terms of the atmospheric absorption against the background of solar irradiance and blackbody radiation profile. Analogy of spatial holes has been drawn with the absorption hole in the green sector of the spectrum. Green colour of vegetation is related to the physiology of vision. Intensity measurements on the leaves of tea have been carried out using software which indicates differences at successive stages of growth of the leaves, as observed earlier by Raman using a pocket spectroscope.

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