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# A Simple Optical Sensor-based System for Monitoring Plant Health Status

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## *Abstract*
*Plant nutrition is the basic need for plant growth and productivity. Nutrient monitoring of plants is the key factor for farmers and agriculturalists. Nitrogen is a necessary element for plant growth and development and it is a major component of chlorophyll in plant leaves. Chlorophyll content of a plant is one of the most important natural indicators of plants nutritional stress and the overall health status of plants. Several sensors have been developed that measure and monitor plant health status, however most of this methods are destructive or they involve expensive instruments. Therefore, it is important to develop a device that is able to detect nutrient stress at an early stage, allowing for early remedial deed to be taken. The proposed sensor system therefore aims to develop an optical sensor system based on imaging and spectroscopic techniques governing leaf properties such as transmittance, absorption/reflectance for early and non-destructive detection/monitoring of plant health status. The proposed sensor is based on measuring the diffused reflectance/transmittance of tulsi (Ocimum tenuiflorum) leaves, using very simple visible and infrared LEDs and photo-detectors. And based on these transmittance/reflection measurements obtained from the Tulsi (Ocimum tenuiflorum) leaves at their various growth stages, the spectral characteristics are obtained. These spectral signatures are then statistically analyzed to correlate them with the plant health status. The proposed methodology is expected to provide non-destructive, convenient, reliable and cost-effective solution for the agri-tech industry.*

***Keywords:*** *Plant health, spectroscopy, optical sensor, chlorophyll, plant nutrients*

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## INTRODUCTION
Nutrient management is a major concern for farmers and agriculturalists. Besides water and sunlight, plant growth and survival is very dependent on available nutrients. Once the plant is exposed to severe nutrient deficiency, it is very difficult for the plant to fully recover [1]. Therefore, it is important to integrate a device that is able to detect nutrient stress early, allowing for early corrective action. In addition to water and sunlight, plants require adequate nutrients for proper productivity and growth. Basically, macronutrients are acquired in greater amount as compared to micronutrients as they are part of the fundamental substances in plant cell and tissue development [1]. A shortage of nutrients, particularly nitrogen, potassium and phosphorus can result in different stress responses such as stunted growth, early defoliation of leaves and decreased biomass yield as described in many studies. Therefore, plant nutrient requirement plays a vital role to ensure availability in the surrounding environment. Spectral reflectance data is closely related to leaf chlorophyll level and relies on the interaction that occurs when light penetrates plant tissue, where it will be transmitted, reflected and absorbed from the surface of the leaf [2]. Therefore, plants tend to absorb red and blue light while, reflecting infrared and green light, making it appear green to human eyes [2]. However, spectral features are useful in detecting plant stress only if one single factor is involved. This approach may be challenging when different stress factors affecting a plant at the same time. So, we

  

understand that nutrients, particularly nitrogen play a very important role in assessing the plant health status. So, we intended to propose an optical sensor system for detection and monitoring of factor(s) related to plant health based on the optical properties such as fluorescence, reflectance and transmittance.

This review mainly focuses on different optical sensing methods for monitoring plant health and early detection of plant status.

This study [3] describes two approaches taken to detect plant diseases. The first approach involves the application of spectroscopic and imaging techniques for disease detection, whereas the second approach describes the application of volatile organic metabolites as possible biomarkers for disease detection. These two approaches were selected as they could be easily integrated with an agricultural vehicle for a fast, reliable, and real-time plant disease monitoring for disease control and management.

In the study [1], an experimental monitoring was introduced for measuring the spectra of leaves, using reflectance spectroscopy. It consists of a light source, a spectrometer, a bifurcated cable with a probe and a laptop for data analysis. It is able to detect the nutrient stress early. Secondly, to analyze iron deficiency it is observed from young leaves, nitrogen deficiency has same symptoms as that of iron deficiency i.e. yellowing of leaves, but for nitrogen it appears in old leaves and for phosphorus deficiency it appears in a dark greenish purple leaves. The nutrient stress analyzer also has potential to detect other nutrient stress. It could also provide a cheaper and reliable source in nutrient management.

This study [4] proposed a device, i.e., leaf colour chart which is used to measure the nitrogen deficiency in plants by using a reflection type of optical sensor. The leaf colour chart consists of four or six colour shades, each colour shades representing a degree of greenness of the leaf. In manual method, the colour of the leaf is compared with the colour chart according to the stage of plant growth. If the leaf shows value below the critical value of the colour chart, then the plant has nitrogen deficiency. The manual method may lead to some drawbacks due to inaccurate results, so automatic nitrogen deficiency detector is developed.

This study [5] review applications of chlorophyll fluorescence mostly the detection of plant stress factors, with main aim of providing comfort conditions for the plants and also increasing production rates. It can be useful in areas of industry, agriculture, food, research and global climate change. A chronological summary of optical sensing methods employed in past 20 years is presented in Table 1.

## METHODOLOGY

The steps involve are:

1. Illuminate the sample with an appropriate light source such that it corresponds to the chlorophyll content of leaf.
2. Measure the transmittance/reflectance/ absorption.
3. Obtain spectral transmittance/reflectance/ absorption curves.
4. Analysis of the obtained spectral signatures.
5. Development of algorithm based on the unique spectral signatures obtained.

### Materials and Methods

#### *Canopy Method*

Samples, i.e., tulsi *(Ocimum tenuiflorum)* plants were planted and after they grown a certain stage with the change in physiological stage measurement were employed. Reflectance was measured from the proposed sensor system. The experiment was carried in a dark room at room temperature. Plant canopies were taken with height of 10 cm, and measurements were taken at 2 cm above the plant canopy. Active optical sensors emit a light pulse which is projected onto the target surface, the plant canopy. Separate source was used consisting of Blue (475 nm), Green (510 nm), Red (650 nm) and IR (930 nm) sensor during the experiment. The light reflected back from the canopy is detected by the optical detector. The response was noted every 1 minute. The output of the optical detector was connected to the multi-meter for correlating different response corresponding to different source.

### *Single Leaf Method*

Healthy leaves were collected from four different plants. Both transmittance and reflectance measurement were performed. The reflectance data obtained here appeared to be the same as that of canopy method, which validates the performance of both the proposed models. Several experiments were carried out and the transmittance readings were obtained for all four species. The experiment was carried in a dark room at room temperature. So, for both reflectance and transmittance response it was also converted into a simple ratio vegetative index and statistical analysis was carried out.

### *Spectrophotometer Method*

Healthy leaves were collected from four different species and separate sample solutions were prepared. The absorbance and transmittance values were obtained using a spectrophotometer.

### *Design of the System*

The system consists of the sensing part which has following four sources—Blue, green, red and IR and a detector along with the sample to be investigated. It also has a control unit for monitoring and estimating the amount of chlorophyll content. Display unit where in the final result will get displayed. Figure 1 shows the block diagram of the sensor system.

For model-1 (Figure 2), it was utilized for diffuse reflectance. Model-2 (Figure 3) both diffuses reflectance and transmittance was employed.

***Table 1:*** *Optical Sensing Methods and Monitored Parameters.*

| Methods | Energy Output | Visualized Parameters | Year/Citation |
|---|---|---|---|
| Green Fluorescent Protein(GFP) | 395 nm or 480 nm | Green Fluorescent | 1998[6] |
| Thermography | - | Tobacco Mosaic Virus(TMV) | 1999[7] |
| • Passive Thermography | • Long-wave IR radiation loss 8-14$\mu m$ | • Transpiration | 2000[8] |
| Vegetation water content using reflectance | • Visible to shortwave IR(400-2500nm) | • Chlorophyll content, leaf area index | 2001[9] |
| Spectral reflectance | NIR and red reflectance | Green crop area index(GCAI) and Canopy chlorophyll | 2002[10] |
| Nutrient stress analyser | • Young, old, dark greenish purple leaves | • Iron, nitrogen, Phosphorus deficiency | 2003[1] |
| Compact Fiber-optic fluoro sensor | Light-green, fully-green, and yellow leaves | Chlorophyll fluorescence | 2004[11] |
| Nitrogen management | Red and NIR bands | Fertilizer requirements | 2005[12] |
| • Nutrient stress analyser | • Reflectance spectroscopy(680-750nm) | • Nutrient stress | 2006[2] |
| Delayed fluorescence(DF) | - | Plant photosynthesis | 2007[13] |
| Light-weight UAV (Unmanned aerial vehicles) | Visible and NIR wavebands | Special reflectance | 2008[3] |
| Vivo fluorescence imaging | - | Chlorophyll fluorescence | 2009[14] |
| Imaging Methods spectroscopic methods | • 598, 715nm(550, 605, 623, 660, 697 and 733 nm)<br>• 540 and 680 nm | • Scab (Fusarium head blight)<br>• Phytoplasmas causing yellowing disease | 2010[15] |
| RGB colour sensor parallax TCS3200 | - | plant stress | 2011[16] |
| Chlorophyll fluorescence | red and far-red light | plant stress such as drought, frost damage, ceone, nutritional and nitrogen | 2012[17] |
| Spectro radiometers | Red(640 nm) and an infrared light (940 nm) | nitrogen status | 2013[18] |
| • Green seeler | • Reflectance of red(660nm) and NIR(770 nm) | • NDVI | 2014[19] |
| • SPAD-502 | • Absorbance of red (650nm) and NIR(940nm) | • Chlorophyll content | |
| • Atleaf+ | • Absorbance of red (660nm) and NIR(940nm) | • Chlorophyll content | |
| Near-infrared spectroscopy and hyper spectral imaging | - | Seed quality | 2015[20] |
| Leaf colour chart | NIR and red reflectance | Nitrogen deficiency | 2016[2] |
| • Non-imaging and imaging | • Blue-green and red spectra | • Nutrient deficiency detection | 2017[21] |

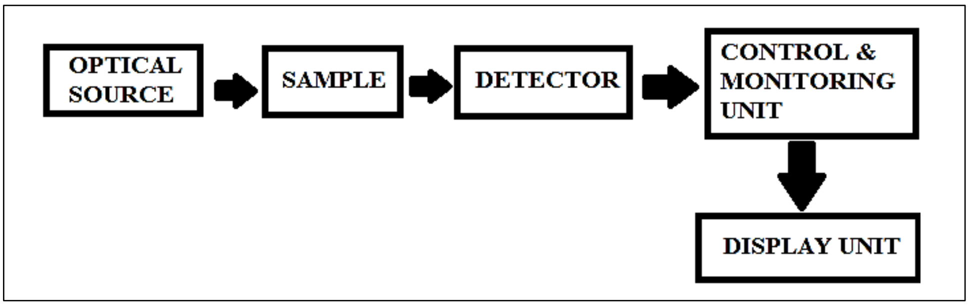


***Fig. 1:*** *Block diagram of the sensor system.*

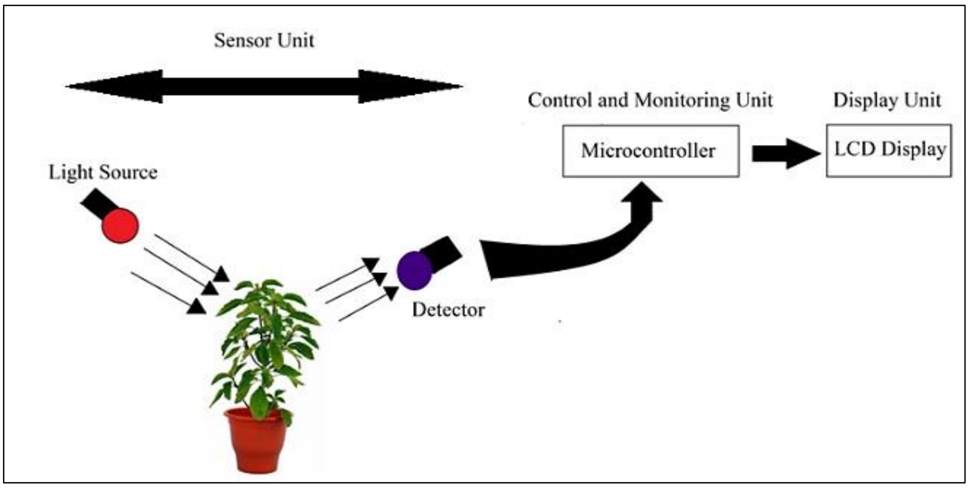


***Fig. 2:*** *Schematic diagram illustrating the proposed sensor Model-1 (Canopy Method).*

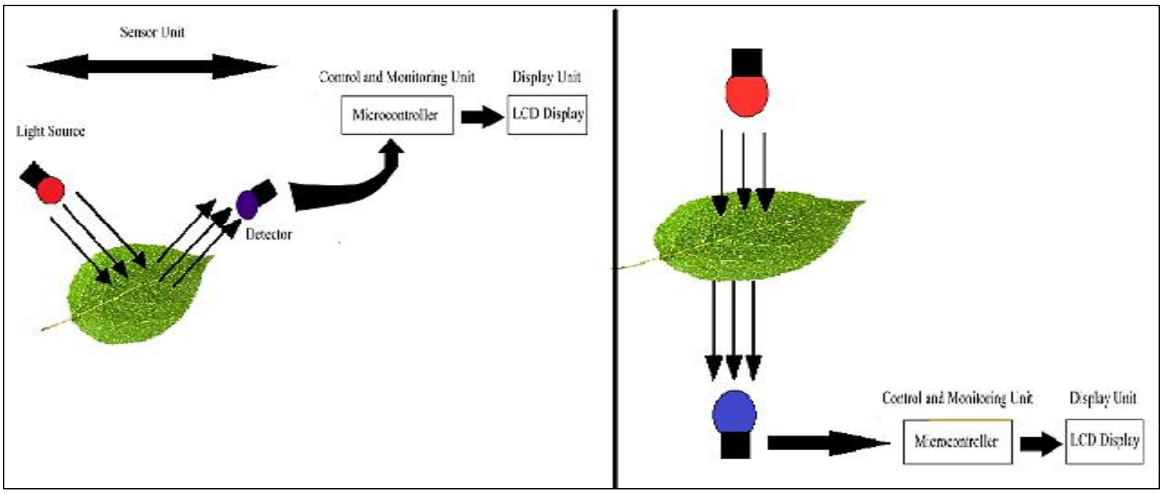


***Fig. 3:*** *Schematic diagram illustrating the proposed sensor Model-2 (Single leaf method); (a) for transmittance measurement; (b) reflectance measurement.*

## RESULTS AND DISCUSSION

In Figure 4, we observe that from cycle 1 to 3, the reflectance decreases from blue to IR source. It has also more reflectance in the visible region as compared to IR region. From cycle 4, 5, 6 there is more absorbance in the green region with high reflectance in the red region. We also observed that for all the six cycles, the red has more reflectance as compared to IR.

In Figure 5, total 30 experiments were performed for six samples each. The sensor system shows stable relationship when tested with six different types of tulsi (*Ocimum tenuiflorum*) Plant.

In Figure 6, total 3 cycles of experiments were performed with each cycle consisting of 10 days. We observe that blue and green sources did not exhibit much change in response with the physiological changes in plants, however red and infrared wavelengths exhibited major change in response. Thus it was understood that red and infrared wavelengths provided important cues related to the chlorophyll content of the plant. So, several experiments were further carried out to analyze the relation of red and infrared wavelengths to the chlorophyll content. To study this, we considered an important parameter known as **Simple Ratio Vegetation Index (SRVI)** which measures the greenness of leaf.

Simple Ratio Vegetation Index (SRVI) is a simple indicator employed to check the greenness of a target area. It is given by:

$$\text{SRVI} = \frac{\text{Transmitted or reflected light from the leaf in IR region}}{\text{Transmitted or reflected light from the leaf in Red region}}$$

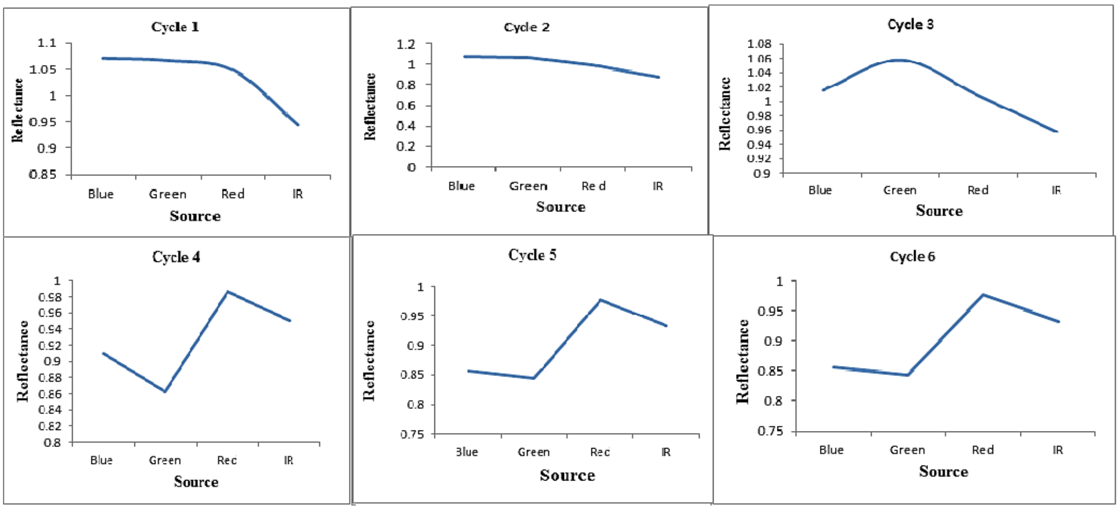


***Fig. 4:** Spectral characteristics of Tulsi (Ocimum tenuiflorum) Plant for different growth stages.*

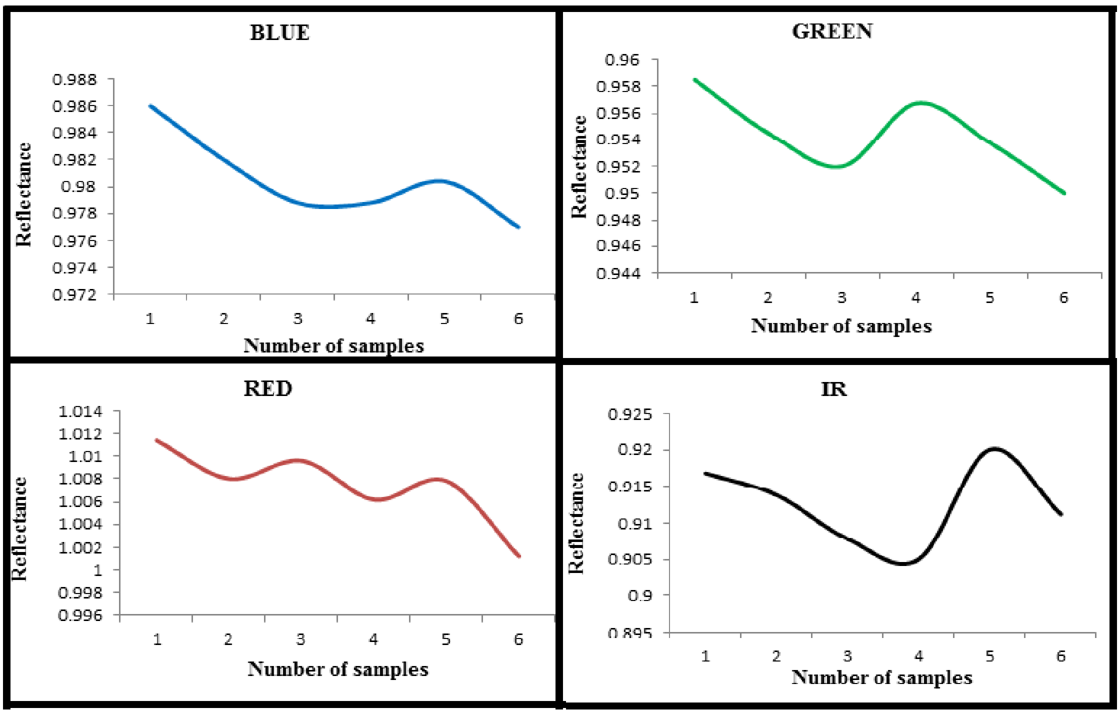


***Fig. 5:** Stability of RGB and IR sensors for six Tulsi (Ocimum tenuiflorum) plants.*

 

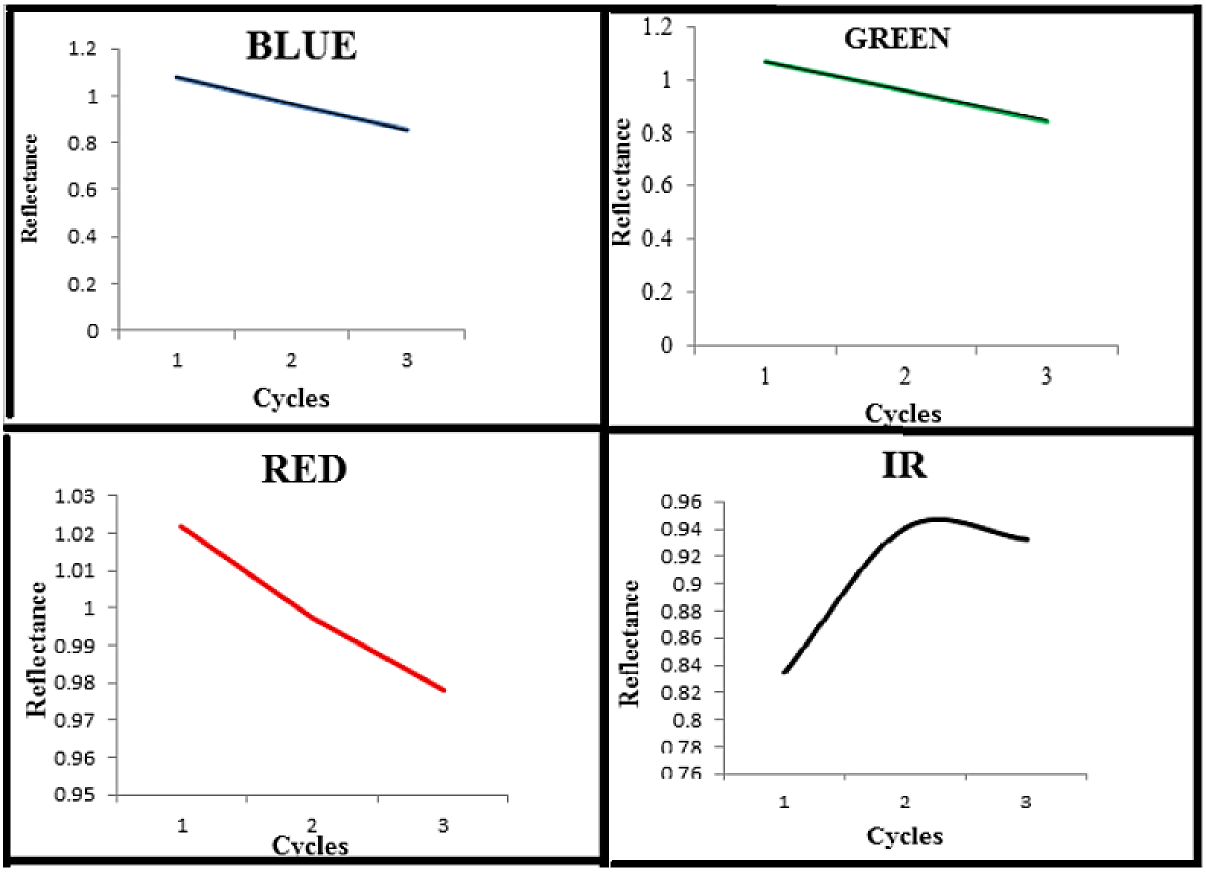


***Fig. 6:*** *Spectral characteristics of RGB and IR sensors for different growth stages.*

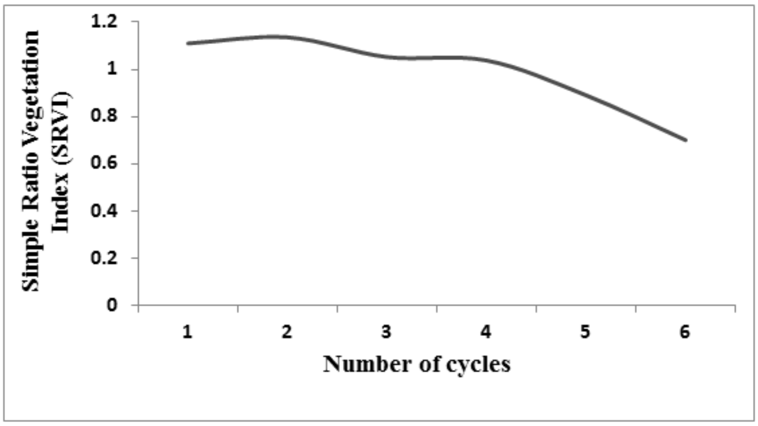


***Fig. 7:*** *Simple Ratio Vegetation Index (SRVI) for different growth stages*

We obtained the SRVI for the Tulsi (*Ocimum tenuiflorum*) leaves for 6 cycles (each cycle is taken as 5 days) which is shown in Figure 7. We observe that as the growth stage varies depending to physical condition the SRVI values decreases.

Here, Figure 8 is a bar graph showing the comparison of Simple Ratio Vegetation Index (SRVI) for proposed sensor system and standard spectrophotometric method for four different healthy leaf samples. It was calculated using the SRVI which is the first true vegetation index.

In Figure 9, it shows the SRVI based on transmittance measurement for different methods performed. It was observed that SRVI for Single leaf method was much better as compared to Canopy method. To validate the results of the proposed system, analysis were further performed from spectrophotometric method. Since it has some certain drawbacks, it showed better and accurate results, and higher SRVI was obtained compared to the other two methods.

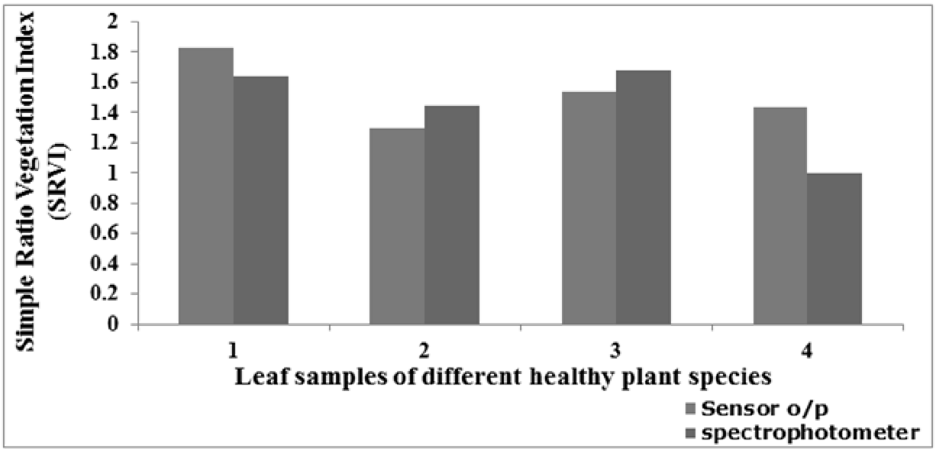


***Fig. 8:*** *SRVI for proposed sensor system 2 and spectrophotometer.*

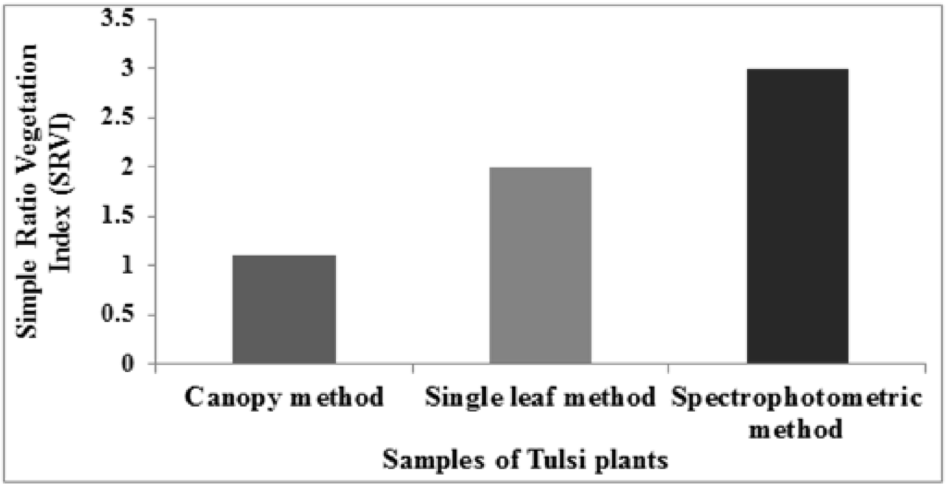


***Fig. 9:*** *Comparison of SRVI for model-1, 2 with spectrophotometer.*

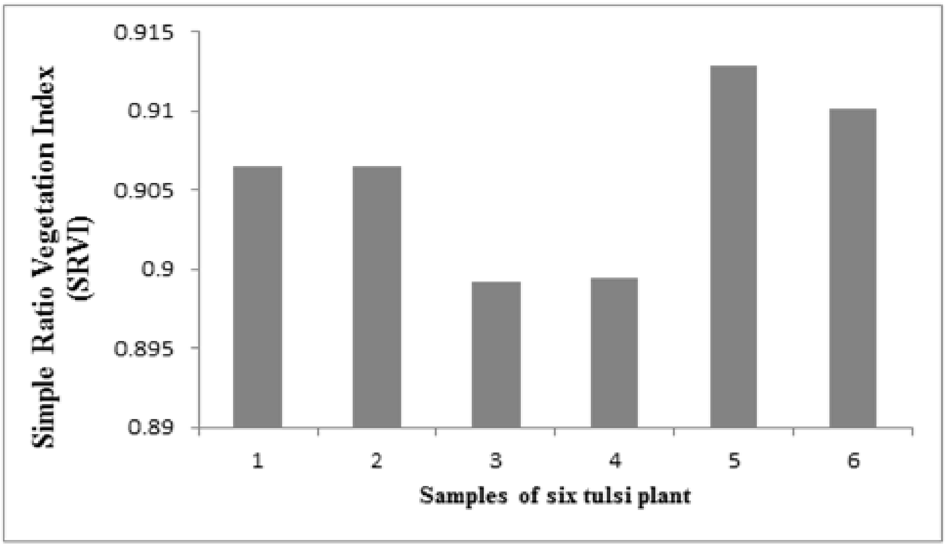


***Fig. 10:*** *SRVI for canopy method of six Tulsi (Ocimum tenuiflorum) plant.*

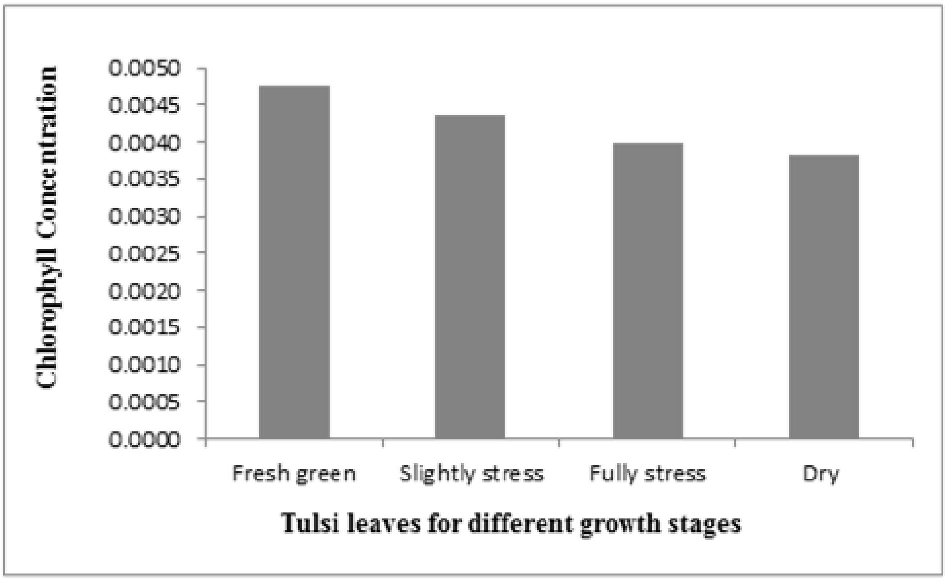


***Fig. 11:*** *Chlorophyll concentration for different growth stages of Tulsi (Ocimum tenuiflorum) leaves using standard Spectrophotometric method.*

In Figure 10, we observe that six samples planted together vary depending on physical conditions. We also observe that sample 5 contain the highest SRVI value and sample 3 contain the lowest SRVI value.

In Figure 11, different growth stages of Tulsi (*Ocimum tenuiflorum*) leaves were taken. It shows highest chlorophyll content in fresh green leaf and lowest chlorophyll content in dry leaf.

## CONCLUSION

The potential of simple VIS-NIR sensor to measure the chlorophyll content was studied. Detailed review of existing literature on the topic has been presented. Simple frameworks, one based on reflectance measurements from Tulsi *(Ocimum tenuiflorum)* canopy and the second one based on transmittance measurements from single leaf have been employed. Several experiments were carried out and accordingly certain features unique to chlorophyll were obtained, based on the statistical analysis of the reflectance/transmittance spectrum. It was observed that mainly the red and infrared sensor output can be well correlated to the chlorophyll content of leaves. Also, SRVI, which is a very important indicator of greenness of leaves, was calculated and it was found that for a healthy leaf, the SRVI is greater than 1 whereas for a stressed or dull yellow leaf the SRVI value decreases to much below 1. SRVI for model-2 was much better as compared to model-1.

We also measured the SRVI of the same leaves based on the absorbance/ transmittance data obtained from a spectrophotometer. This was done to validate the performance of the proposed models. The proposed system showed satisfactory results in comparison to the standard spectrophotometric method. Chlorophyll concentration of Tulsi *(Ocimum tenuiflorum)* leaf and four different leaf species were also performed using spectrophotometric method. The highest chlorophyll content obtained was in fresh green leaf and lowest in dry leaf. The $R^2$ value obtained was 0.923 and the RMSE was found to be 0.164. Thus in future, further experiments will be carried out to obtain a standard threshold for the SRVI, such that the stress in plants can be detected at a very early stage so that effective remedial measures can be taken.

The proposed framework is expected to have a great potential in detecting nutrient stress despite some shortcomings. The potential of the proposed sensor system could be extended to the other nutrient elements as well and if this proves successful it could greatly help by providing a cost-effective and reliable source into nutrient management.

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