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Light use index: a biophysical index to predict plant growth parameters

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ABSTRACT

Canopy reflectance based spectral indices to predict plant biophysical status are extensive in literature. An index called Light Use Index is proposed in the present study, which captures the peak and valley of the classical plant canopy absorption spectrum. The index is linearly fitted to several parameters like nitrogen doze, total plant nitrogen, dry matter as well as the Leaf Area Index at different stages of a wheat crop. The results were encouraging and it is thought that it could effectively be utilized to quantify the plant status in simulation models.

Keywords: Absorption spectra, light use index, nitrogen status, dry matter, leaf area index.

Among plant nutrients, nitrogen is the most important and essential element. Nitrogen is an integral part of chlorophyll, which is the primary absorber of light energy needed for photosynthesis. There are lots of studies, which use indices, which are constructed from the reflected electromagnetic radiation from the canopy and their utility to predict plant status (Jordan, 1969; Rouse, 1973). There is hardly any index, which is constructed from the absorbed electromagnetic radiation. Our interest was to develop an index called as Light Use Index (LUI) which pertains to the absorption peaks rather than taking into consideration the whole visible region of the electromagnetic spectrum and test our hypothesis to use LUI as a prospective biophysical index to characterize plant growth and nutrient status.

MATERIALS AND METHODS

A maize crop (in Summer) was grown without any fertilizer, followed by flooding the fields (twice) to leach residual nitrogen. A wheat crop was taken up in the following winter with varying levels of nitrogen fertilization with 12 treatments *viz.* 0, 15, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120 kg ha^{-1} of Nitrogen along with the usual doses of P (40 kg ha^{-1}) and K (20 kg ha^{-1}). All plant protection measures and irrigation and other cultural practices were followed as recommended.

Spectral observations

The spectral reflectance observations of the crop canopy and soil were taken by LICOR LI-1800 Portable Spectroradiometer, which scans continuously from 330nm to 1100nm at 5nm intervals. The incident solar radiation measurements were taken by holding the sensor horizontally while focusing it skywards. While taking the observation care was taken not to cast shadows over the area being scanned.

Spectral absorbance

The photosynthetically Active radiation lies between 400-700nm. Because of this reason, we used only this interval from the spectral data collected to compute the spectral absorbance by the canopy in different treatments. The spectral absorbance was calculated as the ratio of the difference between the incoming solar radiation and the reflected radiation by the plant canopy to the incoming solar radiation.

Light use index

Initially, the absorption spectra were split into three regions corresponding to the 'peaks' and 'valley' viz. 'B' (400-500nm), 'G' (500-600 nm), and 'R' (600-700nm) The LUI is defined as the ratio of the fraction of electromagnetic energy in blue and red region in the absorption spectra (f_{canopy}) to the fraction of the blue and red region in the solar radiation (f_{sun}). Although f_{sun} is not highly variable, a keen observation reveals that it is also variable with the time of the day as well as local conditions. To normalize the numerator, it is better to divide f_{canopy} with f_{sun}.

$$LUI = \frac{f_{canopy}}{f_{sun}} \quad (1)$$

$$f = \frac{R+B}{R+B+G} \quad (2)$$

Here we emphasize the relative contribution of the energy absorbed in the two peaks of the absorption spectra from a plant canopy.

Plant observations

Leaf area index (LAI) was determined during different stages of the growth. The leaf samples taken for the LAI determination were used to determine the dry matter production at different stages of the crop for different treatments. Plant Samples from each treatment obtained for the estimation of leaf area index and dry mass was used for the estimation of plant nitrogen using N-autoanalyser (Technicon Monograph I). For the present study, we express the nitrogen content per unit area. Nitrogen in the plant sample collected (g m^{-2}) = % Nitrogen x Dry weight of the sample collected from 1 m^2 area.

RESULTS AND DISCUSSION

Total plant nitrogen

The total plant nitrogen in percentage showed a decreasing trend in

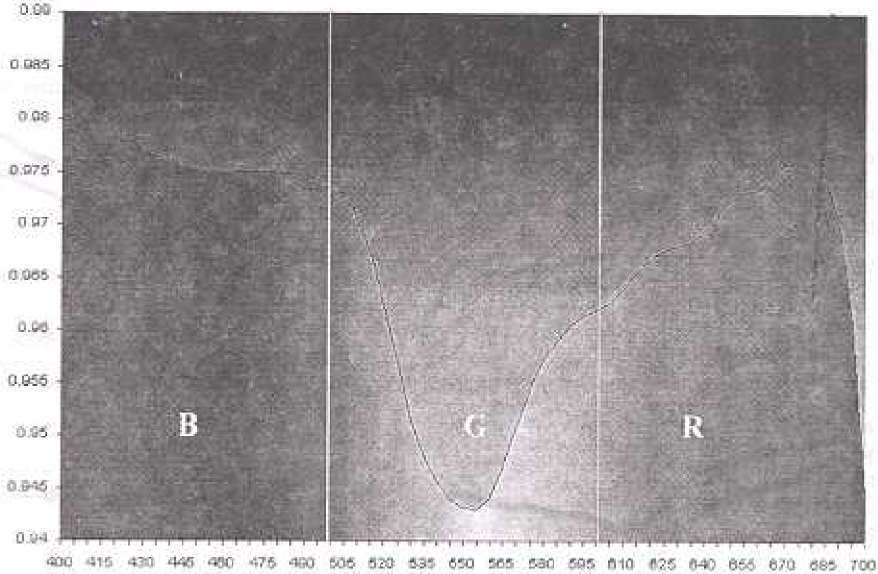

Fig. 1: Three regions of the absorption spectrum of a healthy canopy

all the treatments with time, but this trend was reversed when the total nitrogen was expressed as uptake of nitrogen in $1m^2$ area, which a better form of expression and can be related with other parameters. The highest plant total nitrogen was observed in 120 kg N ha^{-1} treatment at about 100-118 DAS (48.68 gm^{-2}), and similarly for 0 kg N $^{-1}$ha (13.58gm^{-2}). Initially, the plant nitrogen was higher in 0 kg N ha^{-1} upto 67DAS the sudden increase in total plant nitrogen was observed in late jointing to maximum vegetation stage.

Spectral absorbance

In general, the spectral absorbance data in the visible region corresponding to the Photosynthetically Active Radiation showed a peak in the blue region (400-500nm) and in the Red Region (600-700nm). There is a 'valley' in the green region (500-600nm) because of the lower absorption in that region. This pattern varied with the stage of the crop as well as the nitrogen fertilization (Fig. 2). In the initial stage of the crop, all the treatments and stages showed a higher absorbance in the blue region almost with the same magnitude. As the crop progressed, the absorbance in the blue band did not vary much but still there was a small decrease with time as well as nitrogen status. In the final stage of the crop, corresponding to the senescence, the absorbance in this band by nitrogen-limited plots was less.

The green band had the least absorbance in the visible region. In the initial stage, there was a weak absorbance in this

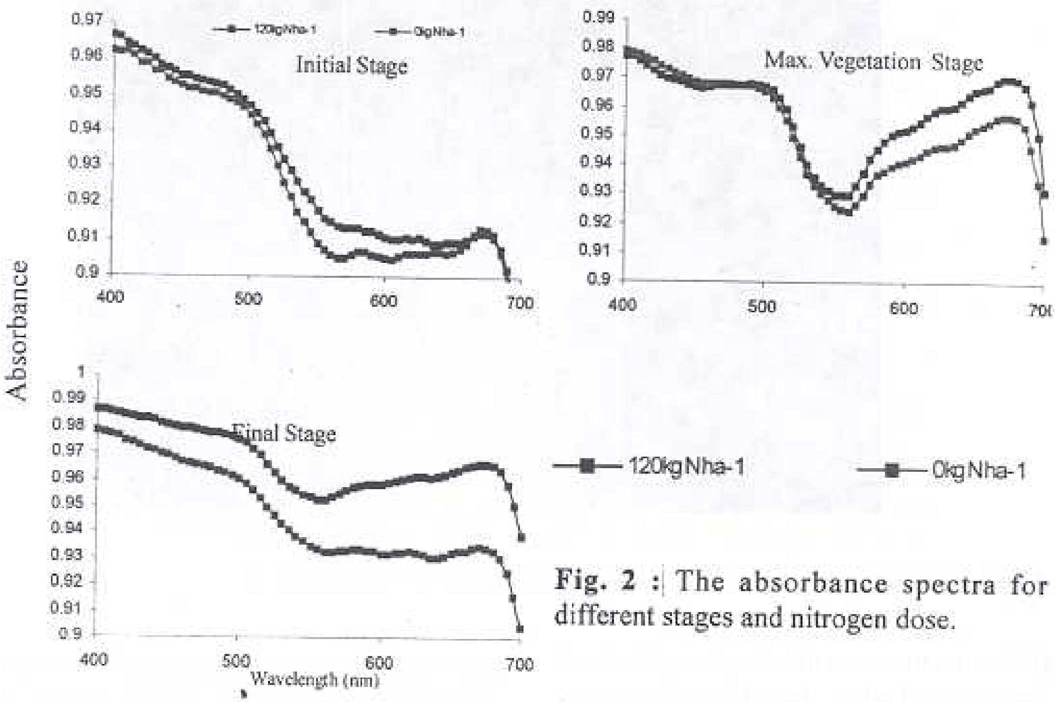

Fig. 2 : The absorbance spectra for different stages and nitrogen dose.

band for all the nitrogen treatments. However, this may be because of the soil background effect, which had a higher absorbance in the red region. The nitrogen level had a negative effect for the absorption in the green region in the sense that plants with low nitrogen status showed a lower absorption than plants with higher levels of nitrogen in the green band probably due to the fact that it is not the green band which makes the crop which look more greener but a relative higher absorption of the red band which makes it relatively more greener. This difference was diminished as the crop reached the maximum vegetation stage and again increased substantially in the senescence. The absorbance trends in the red band had a very large variability both due to the crop stages as well as the nitrogen levels. The absorbance was very low in the initial stage of the crop in all the treatments. It increased substantially at the maximum vegetation stage with a large difference accounting to the nitrogen fertilization in this region. In the final stage the absorption in this band decreased but not to the magnitude as the blue band.

Relationship between LUI and plant growth

We used the spectral and plant parameters at three stages of the crop viz. Initial (54 DAS), Maximum Vegetation Stage (94 DAS), and Final stage (127DAS).

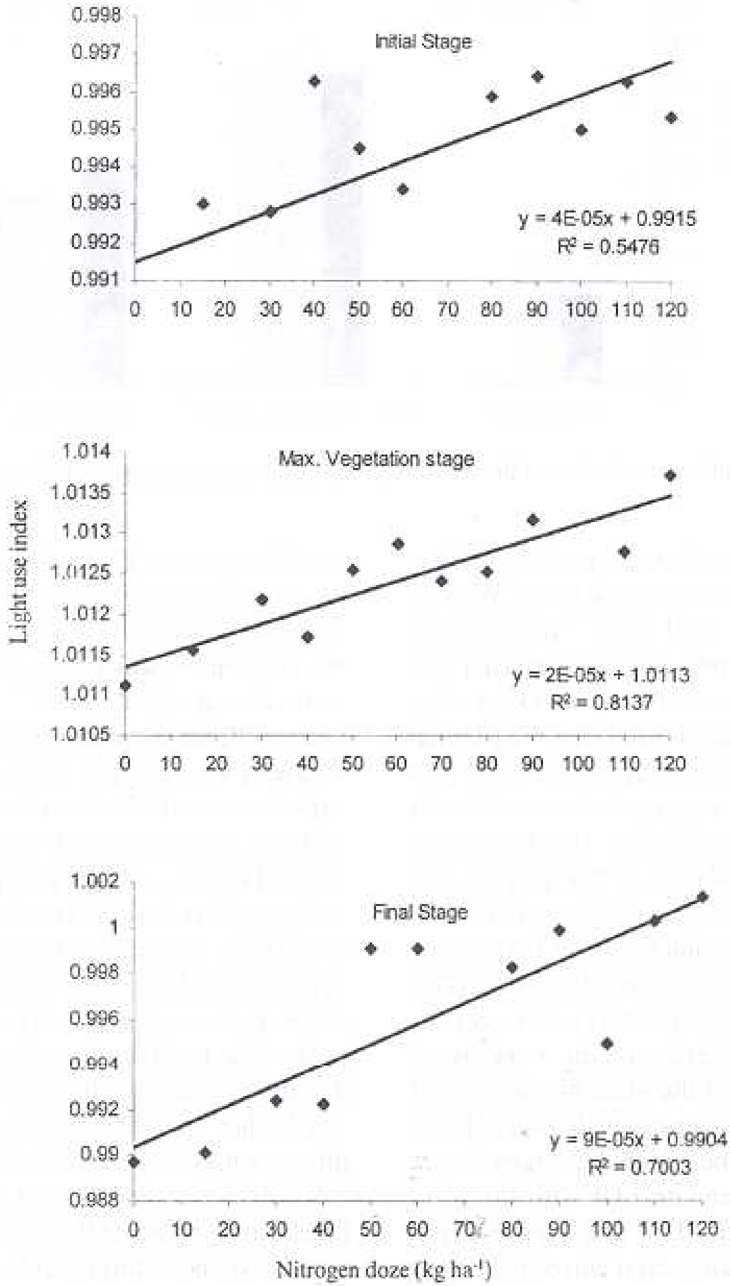

Fig.3 : Relationship between LUI and nitrogen doze at different stages of wheat

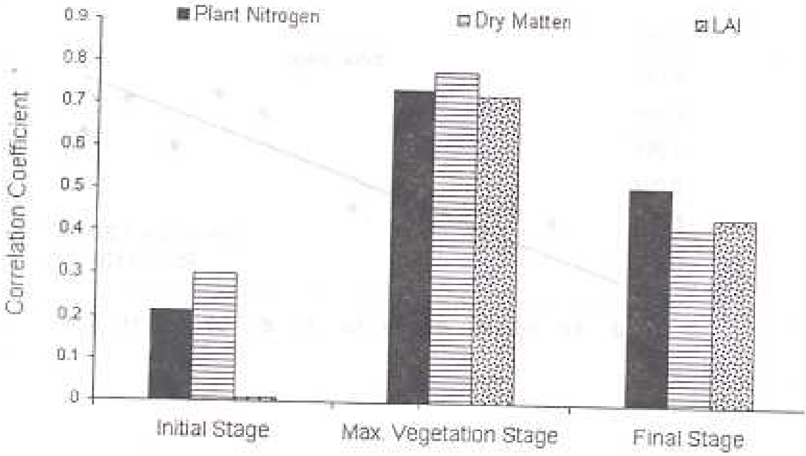

Fig.4 : Correlation coefficients between LUI and plant parameters at different stages

In general, LUI showed a positive relation with most of the plant parameters. We tried to relate the LUI with the different parameters like nitrogen dozes plant nitrogen content, Leaf area Index, and Dry matter. In general, trend showed that the LUI has a lower correlation at the initial and the final stages, higher correlations with the parameters studied at the maximum vegetation stage.(Fig.3) The LUI showed a good correlation as high as 0.8137 at maximum vegetation stage with the nitrogen doze and a modest relation at initial (0.5476) and the final stages (0.7003). However, the nitrogen doze may not be very much representative of the plant nitrogen status due to the heterogeneity which occur in the field due to some residual nitrogen, hence we tried to correlate LUI with the plant nitrogen content. LUI and plant nitrogen content showed a good relation (0.7377) at the maximum vegetation stage. When we tried to correlate LUI with plant nitrogen content, the relation was not significant in the initial stage (0.2177) and in the final stage the correlation was lowered to 0.515.But an r^2 value as high as 0.7377 was observed. Our results are supported by the theoretical studies (Sinclair and Hoire, 1989) and experiments which showed a curvililinear increase, increase in LUE with an increase in areal leaf N content. In the case of dry matter and Leaf Area Index also, the highest correlation was attained at the maximum vegetation stage. The leaf area Index showed a low value initially and reached a peak value and then decreased, while the dry matter increased in a sigmoid manner. The higher correlation of LUI with plant nitrogen may be related to the increased LAI, which is responsible for intercepting a higher amount of PAR. Our results agree with previous findings that the main effect of N fertilization is an increase in canopy

LAI and intercepted light (Gulmon and Chu, 1981; DeJong *et al.*, 1989; Walters and Reich, 1989) and also it has been observed experimentally in various species that the profile of leaf-nitrogen in the canopy follows an exponential function with LAI counted from the top of the canopy (e.g. Field, 1983; Hirose and Werger, 1987.

CONCLUSIONS

The proposed index has good prospects to quantify the plant growth parameters similar to LUE and can be easily incorporated into ecosystem or crop simulation models through remote sensing data, which simulates processes like carbon sequestration of terrestrial biomes where plant nitrogen is also a major player. Unlike LUE which is calculated by indirect means, this index can be easily calculated by inverting the spectral signatures obtained from remote sensing platforms, which is temporally and spatially having a higher resolution and can be directly fed to simulation models.

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