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CONTENTS

Net photosynthesis and spectral reflectance over rice crop under different nitrogen treatments in semi-arid region of India

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ABSTRACT: The primary production of an ecosystem is primarily dependent upon net photosynthesis (Pn). Furthermore, rapid and non-destructive techniques for the assessment of Pn are needed to monitor the plant growth and development. Hence, we evaluated the hyperspectral measurements to estimate the Pn under different nitrogen treatments in rice crop. Other variables like photosynthetically active radiation (PAR) and chlorophyll content index (CCI) were also measured simultaneously at three different growth stages of rice. Vegetation index (VI) was calculated using the hyperspectral measurements to develop a model based on VI, PAR, and CCI to estimate Pn. The response of Pn to the normalized difference vegetation index developed at 700nm (NDVI700) was found better in comparison to the other VIs. Furthermore, the model with CCI x NDVI x PAR (R2 = 0.77) was found best among all the models tested to estimate the net photosynthesis.

Key words: Hyperspectral, net photosynthesis, nitrogen treatment rice, vegetation index

Rice production in India, plays an important part in ensuring food security in step with the population growth. India is the second largest rice producer accounting for approximately 22% of the world's rice production. Hence, rice production is an important part of the national economy. In India, today farmers are facing the key challenges of improving productivity and reducing waste to increase their net profits from the limited land holding. In this aspect, agricultural planning plays a key role. The estimates of crop production at regional and national level are required early in the growing season for agricultural planning (Choubey and Choubey, 1999). Continuous growth monitoring during the crop growing season can further improve the yield estimation. Such monitoring becomes more significant in rice crop which covers around 70% of the total arable land in India. Remote sensing has proven successful in assessing vegetation dynamics, monitoring biochemical and biophysical variations of agricultural crops (Shengyan *et al.,* 2002; Kang, 2014; Pascucci *et al.,* 2020), estimating total biomass production and crop yield (Delécolle *et al.,* 1992; Patel *et al.,* 2006; Petersen, 2018; Campos *et al.,* 2019). Spectral reflectance of crops in the visible region of the electromagnetic spectrum is the manifestation of the maximum light absorption by the crop constituents (Choubey and Choubey, 1999). The interaction of the spectral reflectance with the crop canopy is dependent on the canopy structure, nutrition or ultimately on the canopy health. Hence, it is efficient to assess the crop physiological condition under different management practices (Govind *et al.,* 2007). Among nutrients, nitrogen (N) is the most essential element for crop growth and productivity. It is an integral part of chlorophyll, which is the primary absorber of light energy for photosynthesis (Govind *et al.,* 2007; Bassi *et al.,* 2018). The present study considers the efficiency of spectral reflectance to evaluate the variation in chlorophyll content under different nitrogen treatments.

MATERIALS AND METHODS

Study area

The study was carried out over the rice (*Oryza sativa*) crop in the experimental farm of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India. The meteorological conditions in the study site can be referred through Patel *et al.*, 2011.

Field Measurements

Pusa Basmati rice variety was transplanted on 13th July 2010 in a random block design, with three different nitrogen treatments [control (N0), 75% NPK with 10 tonnes/ha FYM (N1) and 100% NPK (N2)] and three replications. Canopy reflectance measurements were obtained under clear sky conditions on 3 days [(17 September (D1), 29 September (D2) and 14 October 2010(D3)] using a portable ASD Field Spec-FR spectro-radiometer. The measurements were collected when solar zenith was at its minimum, between 1100 hrs and 1300 hrs. Spectral measurements were taken at a height of 1m over the canopy.

Net photosynthesis (Pn) was measured using portable CI-340 gas analysis system with a quantum sensor in the measuring cell to measure photosynthetic active radiation (PAR).
Chlorophyll content was measured using a chlorophyll meter (CCM-200, Opti-Sciences). The CCM-200 estimate the chlorophyll content in a leaf and calculate a chlorophyll concentration index (CCI) which is directly proportional to the amount of the chlorophyll in the leaf sample. CCI and Pn was measured from the same leaf.

Vegetation indices

Spectral measurements were further used to evaluate the vegetation indices (VIs). Based on the availability of spectral measurements in the above mentioned measurement days, the following indices were used as the estimators of the CCI (Table 1)

RESULTS AND DISCUSSION

Spectral reflectance of rice

Optical remote sensing of vegetation is dependent on the reflectance from the green vegetation, which is affected by the light absorption through the chlorophyll pigment. The red and blue portion of the electromagnetic spectrum is utilized by the plants for photosynthesis, while the green portion (500 – 600 nm) is reflected. The spectral reflectance of rice in the wavelength of 400-850 nm under different nitrogen treatments is depicted in Fig. 1. In the region of 500 – 570 nm, a peak occurs at 550 nm. A sudden reflectance change occurs at 530 nm, which is known as the ‘green edge’. A distinctive dip occurs at approximately 670 nm, which is ascribed to the absorption through chlorophyll pigments. In the region of 690 – 750 nm, reflectance changes abruptly at approximately 700 nm, which is known as the ‘red-edge’ (Zhang *et al.,* 2019). It is the well-known indicator for the healthy vegetation and is strongly related to the chlorophyll content (Dawson and Curran, 1998; Thenkabail *et al.,* 2000; Mohd Shafr *et al.,* 2006). It also get shifted to the higher wavelength with the increase in chlorophyll content. The red-shift is distinctive between control and the nitrogen treatments, but not conspicuous in between the nitrogen treatments, which indicates that the increase in nitogen levels can promote the rice growth.

The spectral reflectance during different growth stages and under different treatments provides the physiological status of the crop by quantifying the patters in the visible and infrared regions of the electromagnetic spectrum (Govind *et al.,* 2007). In the visible region, insignificant differences were found under different nitrogen levels. In the NIR region, the differences in the nitrogen treatments are attributed to the canopy structural development. In general, the spectral reflectance in the NIR region was higher in N1 in comparison to the N0 and N2 treatment. Furthermore, this difference was higher in the D1 which corresponds to the anthesis stage in the rice crop.

Relationship between PAR and Pn

Figure 3 depicts the relationship between PAR and Pn at different growth stages (tillering, flowering, dough and maturity) in rice crop. The Pearson’s correlation coefficient was higher in the tillering stage (0.76), which further decreased in the subsequent stages. Photosynthetic light response (Pn /PAR) revealed that the rice crop attained the highest quantum yield (0.028) in the tillering stage followed by flowering (0.019), dough (0.013) and maturity (0.011).

Relationship between VIs and CCI

The chlorophyll content in the plant is a primary parameter that influences the amount of PAR absorbed by the photosynthetically active vegetation. Hence, to predict the net photosynthesis on the basis of vegetation indices, we first examined the relationship between the pigment sensitive vegetation indices (Table 1) and the CCI. $NDVI_{700}$ showed highest correlation coefficient with CCI in all the treatments (Fig. 4). Among all the treatments, VIs were highly correlated (0.69 to 0.85) with CCI in N1 treatment. The highest relationship of $NDVI_{700}$ and CCI could be related to the usage of B740 and B700. B740 and B700 are considered as the red-edge bands which are also suitably utilized to derive the vegetation indices from Sentinel 2 dataset (Clevers and Gitelson, 2013). These bands are particularly suitable for the estimation of the crop chlorophyll content, which is a primary parameter for understanding the photosynthetic capacity and vegetation status.

Table 1: Equations used for defining different vegetation indices (VIs)

Estimators	Wavebands (nm)	Equation
RVI_{670}	780,670	B780/B670
$NDVI_{670}$	780,670	(B780-B670)/(B780+B670)
RVI_{700}	740,700	B740/B700
$NDVI_{700}$	740,700	(B740-B700)/(B740+B700)

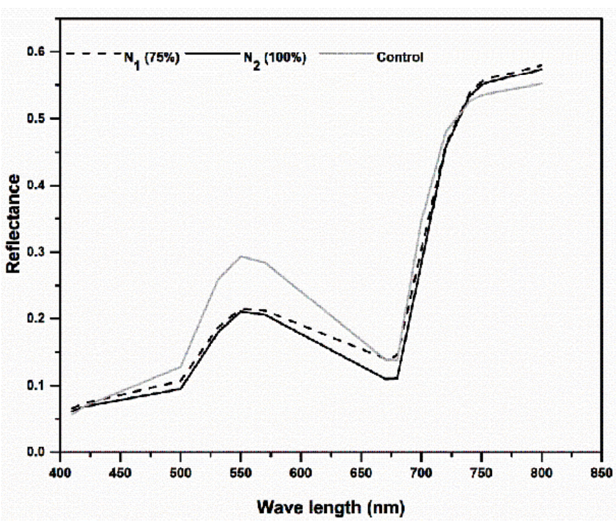

Fig. 1: Spectral reflectance of rice in the wavelength of 400 – 850 nm under different nitrogen treatments.

Relationship between Pn and VI-based models

The temporal behaviours of the photosynthesis is dependent on the phenological and physiological status of the crop, which is closely related to the chlorophyll content and thus to the spectral vegetation indices. The VI alone does not account for the high variation caused by PAR. Hence, to improve the Pn estimation, a product of VI and PAR was considered for the evaluation (Table 2). Among all the combinations of VI x PAR, we found highest coefficient of determination (R^2 = 0.54) with $NDVI_{700}$ and PAR relationship.

We also utilized the VI x VI x PAR combination based on the Monteith's logic (Monteith, 1972), in which VIs depict fAPAR and LUE to estimate the biophysical characteristics of the canopy (Xiao *et al.,* 2003; Gitelson *et al.,* 2006; Wu *et al.,* 2010). We also utilised the CCI in VI x VI based model for Pn estimation (Table 2). The R^2 of the Pn estimation with VI x VI based model was significantly improved in comparison to the single index based model. $NDVI_{670}$ x $NDVI_{700}$ x PAR yielded the R^2 value of 0.71. CCI x $NDVI_{700}$ x PAR combination was highly

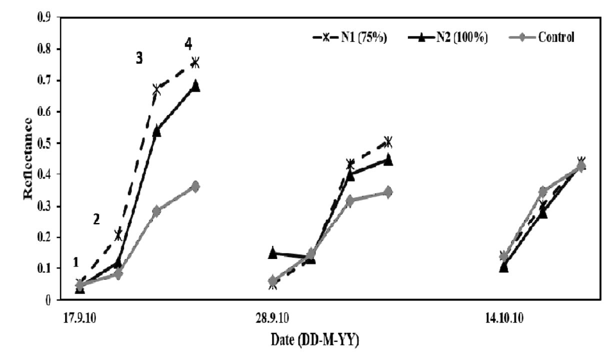

Fig. 2: Spectral reflectance pattern of the crop canopy under different nitrogen levels (N1, N2 and control) at the three different measurement dates. The spectral bands are represented with numerical figures inside the graph, where 1, 2, 3 and 4 represents the reflectance at 670nm, 700nm, 740nm and 780 nm, respectively

Table 2: Linear regression between VI based model and Pn

Model	a	b	R^2
RVI_{670} x PAR	0.0076 ± 0.0038	3.884 ± 1.393	0.32
$NDVI_{670}$ x PAR	0.0018 ± 0.00043	3.755 ± 1.462	0.40
RVI_{700} x PAR	0.0054 ± 0.0023	4.214 ± 1.644	0.53
$NDVI_{700}$ x PAR	0.0058 ± 0.00031	4.549 ± 1.756	0.54
$NDVI_{670}$ x $NDVI_{700}$ x PAR	0.00138 ± 0.00033	4.031 ± 0.989	0.71
CCI x $NDVI_{670}$ x PAR	0.00021 ± 0.000052	4.282 ± 0.939	0.71
CCI x $NDVI_{700}$ x PAR	0.000385 ± 0.00007	4.229 ± 0.811	0.77

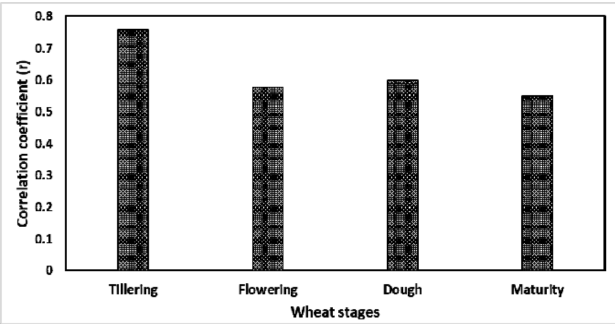

Fig. 3: Pearson's correlation coefficient between PAR and Pn at different growth stages of the rice crop

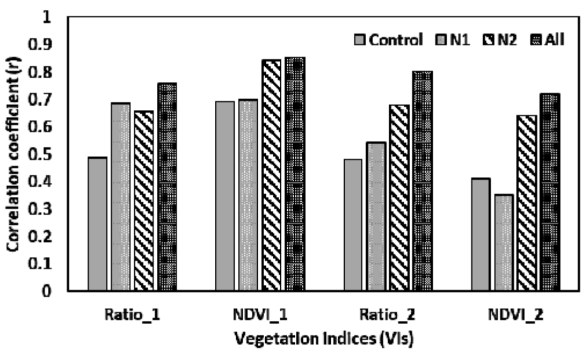

Fig. 4: Pearson's correlation coefficient between VIs and CCI under different nitrogen treatments

efficient in Pn estimation with R^2 value of 0.77. It could be due to higher efficiency of chlorophyll for being a reliable proxy of LUE and at the same time efficiency of VI as a proxy of fAPAR. Hence, from the obtained results it can be concluded that the model based on the Monteith's logic was highly efficient in Pn estimation and the single index is insufficient to address all the components for predicting the photosynthesis of an ecosystem.

CONCLUSION

In the present study, the relationship between the vegetation indices from in-situ hyperspectral measurement and CCI was evaluated over the rice crop under different nitrogen levels in a humid subtropical environment. The spectral reflectance was higher in the D1 with N1 treatment level, which depicted the high performance of the crop during the anthesis stage of crop with the moderate nitrogen level. We evaluated the ratio and the normalized difference based indices to estimating net photosynthesis. After studying different spectral indices, it is obvious that the best index was $NDVI_{700}$ based on B740 and B700. These bands are strongly related to the CCI as a measure of chlorophyll content. Moreover, the performance of the model improved after following the model structure based on the Monteith's logic. The results provided insight in the photosynthesis modelling by using chlorophyll sensitive VIs. In the present study, the impact of different nutrient levels was not considered in the model development due to lower data availability but the inclusion of VIs under different management practices can significantly improve the net photosynthesis prediction. Further extensive studies needed to predict the net photosynthesis under different management practices and different crops with complex canopies. The study can also help to develop the algorithms for coupling the chlorophyll sensitive VIs to the process models to understand the crop-environment interaction in an efficient way.

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