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Determination of optimal narrow bands for vegetation indices to discriminate nitrogen status in wheat crop

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ABSTRACT

Nitrogen stress sensors are based on reflectance measurement controlled by the chlorophyll content. Reflectance of canopy is spectral dependent and more sensitive narrow spectral band can be exploited for reflectance measurement sensors.The experiments for present study were conducted in split plot design on two widely grown wheat (*Triticumaestivum* L.) cultivars (GW 496 and LOK 1) during *rabi* seasons of three consecutive years 2007-08 to 2009-10 at Anand. The two cultivars *viz*; GW 496 and LOK 1 were taken as the main treatments and five nitrogen fertilizer application rates 120, 90, 60, 30 and 0 kg N ha^{-1} as sub-treatments were randomized in four replications. Spectral reflectance measurements were taken over wheat canopy at different crop growth stages with a dual channel spectroradiometer.The ratio based and soil based indices (viz; RVI, DVI, NRI, RDVI, OSAVI,SAVI2,TSAVI and PVI) were used to find optimal wavebands.The optimum wavebands were explored using contours of R^2 values of all possible two band combination for each vegetation index on 2D matrix plots. Except PVI, all indices revealed that red edge inflection point at 733-736 nm was the most sensitive to nitrogen status. The sensitivity of red edge inflection point also explored with first derivatives.

Keywords: Nitrogen stress, vegetation index, red edge, wheat

Non invasive crop status monitoring using remote sensors is the prime requirement of the precision agriculture. High resolution space borne and air borne sensors have potential to use in agricultural for site specific management. Crop monitoring sensors for nitrogen stress are based on reflectance controlled by the chlorophyll content. Nitrogen stress leads to decrease in chlorophyll content, which increases the blue and red reflectance (Carter and Knapp, 2001). The red edge in the spectral signature of the nitrogen stressed crop shifts towards shorter wavelengths with decrease of chlorophyll content and act as useful indicator of stress. (Sahoo *et al.*, 2015; Curran, *et al.*, 1991; Lichtenthaler *et al.*, 1996; Penuelas and Filella, 1998). The vegetation indices developed by using two or more spectral bands combination can be used to determine the reflectance response of the canopy to the stress (Jensen, 2000) and commonly used for the crop status monitoring.In precision agriculture mostly ground based / vehicle mounted field sensors used for crop status monitoring which involves only two sensitive bands (usually red and near infrared) for reflectance/absorbance measurements. So, before implementation of the precision farming programmes for site specific nitrogen management using remote sensing techniques, it requires exploring the potential of different indices using specific wavebands. The study was taken up with objective to determine the sensitive wavebands for vegetation indices and red edge shift as indicators of the wheat nitrogen stress and chlorophyll content.

MATERIALS AND METHODS

Experimental setup and measurements

The field experiments were conducted at Agronomy Farm of Anand Agricultural University, Anand (India) on two widely grown wheat (*Triticumaestivum* L.) cultivars (GW 496 and LOK 1) during *rabi* seasons of three consecutive years 2007-08 to 2009-10. The two cultivars *viz*; GW 496 and LOK 1 were taken as the main treatments and five nitrogen fertilizer application rates 120, 90, 60, 30 and 0 kg N ha^{-1} as sub-treatments were randomized in four replications. The rate of 120 kg N ha^{-1} is optimum recommended dose for the cultivars and other four nitrogen rates were considered to impose different levels of nitrogen stress in the crop. The experiment was laid out insplit plot design consisting 5.00 x 2.70 m^2 sized 20 plots (5 nitrogen levels in 4 replications).

Spectral reflectance measurements were taken over

Table 1: Narrow band vegetation indices

Index	Equation	Reference
Ratio vegetation index (RVI)	$RVI = \frac{R_{\lambda 1}}{R_{\lambda 2}}$	Pearson and Miller,(1972)
Difference Vegetation Index (DVI)	$DVI = \frac{R_{\lambda 1}}{R_{\lambda 2}} - 1$	Gitelson *et al,* (2005)
Normalized ration index (NRI)	$NRI = \frac{R_{\lambda 1} - R_{\lambda 2}}{R_{\lambda 1} + R_{\lambda 2}}$	Sims and Gamon, (2002)
Root Difference Vegetation Index (RDVI)	$RDVI = \sqrt{NRI \times DVI}$	Roujean and Breon, (2001)
Optimal Soil Adjusted Vegetation Index (OSAVI)	$OSAVI = \frac{R_{\lambda 1} - R_{\lambda 2}}{R_{\lambda 1} + R_{\lambda 2} + 0.16} \times (1 + 0.16)$	Rondeax *et al,* (1996)
Second soil adjusted vegetation index (SAVI2)	$SAVI2 = \frac{R_{\lambda 1}}{R_{\lambda 2} + \left(\frac{b}{a}\right)}$	Major *et al.,* (1990)
Transformed soil adjusted vegetationindex (TSAVI)	$TSAVI = \frac{a(R_{\lambda 1} - aR_{\lambda 2} - b)}{aR_{\lambda 1} + R_{\lambda 2} - ab}$	Baret *et al.,* (1989)
Perpendicular vegetation index (PVI)	$PVI = \frac{R_{\lambda 1} - aR_{\lambda 2} - b}{\sqrt{1 + a^2}}$	Richardson and Wiegand, (1977)

*a and b are the waveband combination specific soil line coefficients.

Table 2: Optimal wavelengths combination determined for different indices.

Index	λ_1	λ_2	r	R^2	Optimal combination range	
					λ_1	λ_2
RVI	736	733	-0.79	0.63	752-842	716-729
DVI	736	733	-0.79	0.63	752-842	716-729
NRI	736	733	-0.79	0.63	736-842	713-729
SAVI2	736	733	-0.79	0.63	749-832	716-729
TSAVI	736	733	-0.79	0.63	749-842	716-729
RDVI	736	733	0.79	0.63	752-842	716-729
OSAVI	736	733	-0.78	0.60	746-900	713-726
PVI	763	756	-0.70	0.49	763-769	746-756

wheat canopy at different crop growth stages starting from 25 days after sowing by using a dual channel spectroradiometer (Unispec-DC 2.02; PP System, USA). The spectroradiometeroperates in wavelength range of 310-1100 nm with 3.3 nm spectral resolution. A Spectralon® panel was used as a reference surface. The measurements were recorded under clear and haze free sky condition from all plots in two samples. Out of 310-1100 nm range of reflectance measurements, wavebands below 400 nm and above 900 nm were excluded because of high noise. Thus, the analysis in the present study involved total 80 sets of reflectance spectra (10 treatments (5 nitrogen levels x 2 cultivars) x 4 replications x 2 *rabi* seasons) with 400 nm to 900 nm spectral range measured during 35-45 days after sowing. The results reported by Karande*et al.*, 2014 includes year wise analysis of variance (ANOVA) for yield, straw yield, NDVI (Normalized difference vegetation index), mSR (Modified simple ratio) and NDRE (Normalized difference of red edge) for the data sets of the present study.

Indices

Eight narrowband indices were considered to determine the optimal narrowbands for nitrogen stress (Table 1). Out of eight, four indices were ratio based and other four were soil based. The Ratio vegetation index (RVI), Difference Vegetation Index (DVI),Normalized ration index (NRI) and Root Difference Vegetation Index (RDVI) were ratio based indices chosen for the study. While, soil base indices chosen for the study were Optimal Soil Adjusted Vegetation Index (OSAVI), Second soil adjusted vegetation index (SAVI2),Transformed soil adjusted vegetation index (TSAVI) and Perpendicular vegetation index (PVI).

The SAVI2, TSAVI and PVI required band combination specific soil line parameters 'a' and 'b'. The soil line in the feature space usually considered by relating NIR (near infrared) and red bands. The soil line also found in other waveband combinations (Thenkabail *et al*., 2000). So, the soil line parameters were computed for all possible band combinations from feature space analysis of 54 independent spectral signatures of soil of the field experiment. Regression analysis between index values and nitrogen levels were performed for all waveband combinations for all indices. The optimal narrow-bands were determined by comparison among the coefficient of determination (R^2) of all possible two band combination for each vegetation index. The contours were drawn on 2D matrix plots of coefficient of determination to represent the degree of sensitivity of waveband combinations to the nitrogen levels.

RESULTS AND DISCUSSION

The reflectance spectra of the 4 replication plots treated with equal nitrogen quantity were averaged of both two growth seasons. The ratio of average reflectance spectra to the average spectra of the 120 kgha^{-1} N computed to plot normalized curves (Fig. 1). The normalized curve of the different nitrogen levels clearly reveals the difference in the reflectance variation with each of wavelengths. In visible part of the spectra the normalized factors were found to increase with decrease of the nitrogen level. The differences in red band were more pronounced, followed by green and blue wavebands. Nitrogen level of 90 kgha^{-1}showed factor values less than 1 for visible, indicates the less reflectance by dark and healthy vegetation which was slightly darker than treatment of recommended dose. In near infrared the trend of factors with nitrogen levels was found reversed as reflectance in the NIR increase with weak cellular structure resulted with decrease of nitrogen level.

The linear response of nitrogen levels to wavelength wise reflectance was explored by correlation and simple linear regression. The wavelength specific correlation coefficient (r) and coefficient of determination (R^2) depicted in Fig. 2. The reflectance responses at wavelengths with broken curves in green band and red bands were not found significant at 0.01% level. Maximum linear association between reflectance and nitrogen levels for blue, red and near infrared bands were at 513 nm, 656 nm and 782 nm, respectively. Blue and red wavelengths showed negative association because of higher nitrogen dose leads to more concentration of chlorophyll concentration which leads to high absorption in these bands. These wavelengths can be useful in case of monochrome sensors where only reflectance measured only at single narrow band.

The optimal wavelengths for different levels of nitrogen were determined by computing the coefficient of determination (R^2) for all possible wavelength combinations (150 x 149 = 22350) for each vegetation index. The contours of R^2 values on the 2D matrix plots isgiven in the Fig. 3. The R^2 matrix contours of RVI, DVI, SAVI2 and TSAVI revealed identical contour pattern with NRI (Fig.3a). The RDVI, OSAVI and PVI showed slightly different R^2 contour pattern. The most sensitive wavelength combination (hotspot in figures) was found at red edge (733-736 nm) in all indices except in PVI(756-763). This might be because the PVI calculation based on the perpendicular distance from the soil line in feature space while other indices are computation by similar arithmetic process. Though, maximum values of correlation coefficient (-0.70) and coefficient of determination (0.49) of PVI were comparatively poor than others. The region with nearly maximum sensitivity was also confined to small wavelength range in PVI. While, other indices showed wider optimal range for $\lambda 1$ and $\lambda 2$. The $\lambda 1$ range was more extended compared to $\lambda 2$. Any two wavelength combination from the optimal combination range (Table 2) can be chosen for the practical purposes. The optimal combination wavelength range of OSAVI (746-900nm: 713-726 nm) and PVI (763-769 nm: 746-756 nm) was found distinct while other indices have nearly identical ranges. In general for all indices red edge wavelengths were

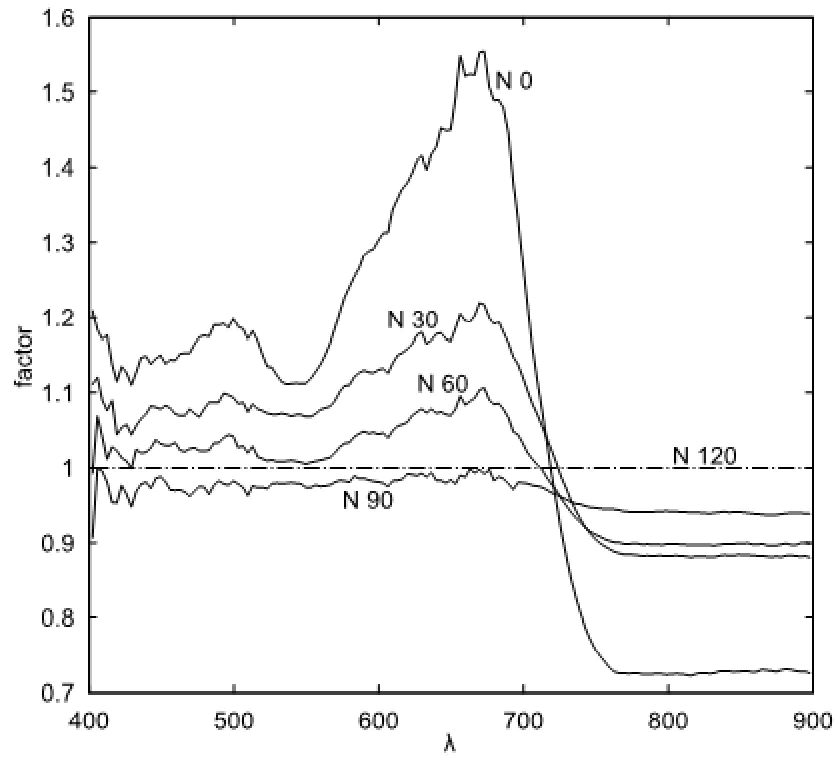

Fig. 1: Normalized spectral signatures

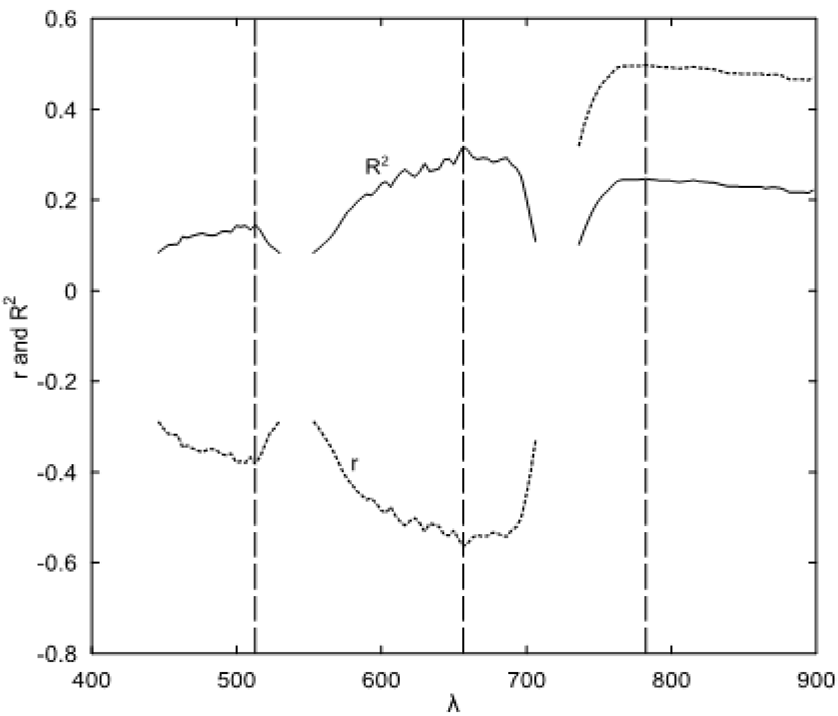

Fig.2: Correlation coefficient (r) and coefficient of determination (R^2) between nitrogen levels and wavelength specific reflectance

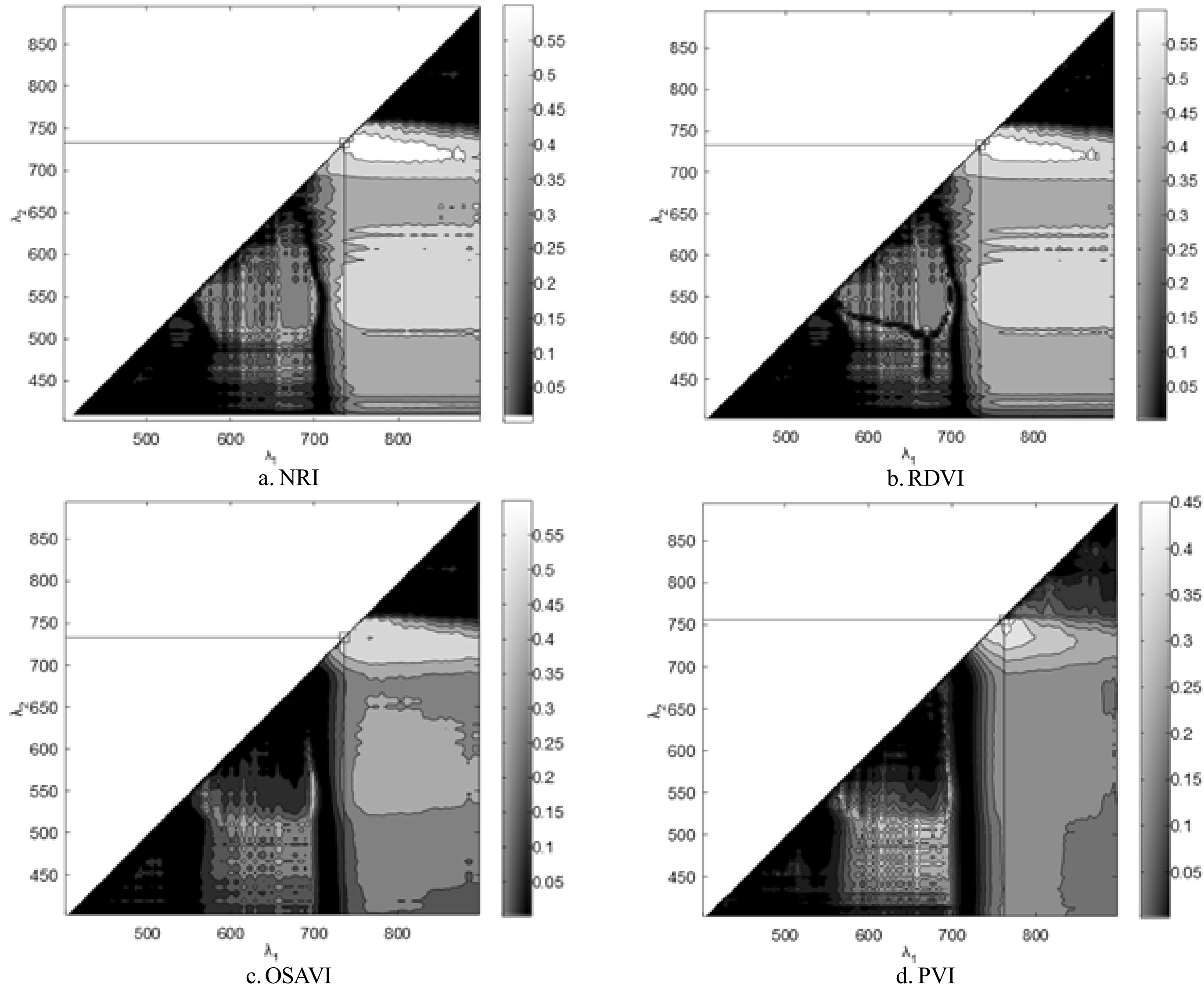

Fig. 3: (a-d) 2D matrix of coefficient of determination (R^2) contours for all possible narrow waveband combinations based vegetation indices.

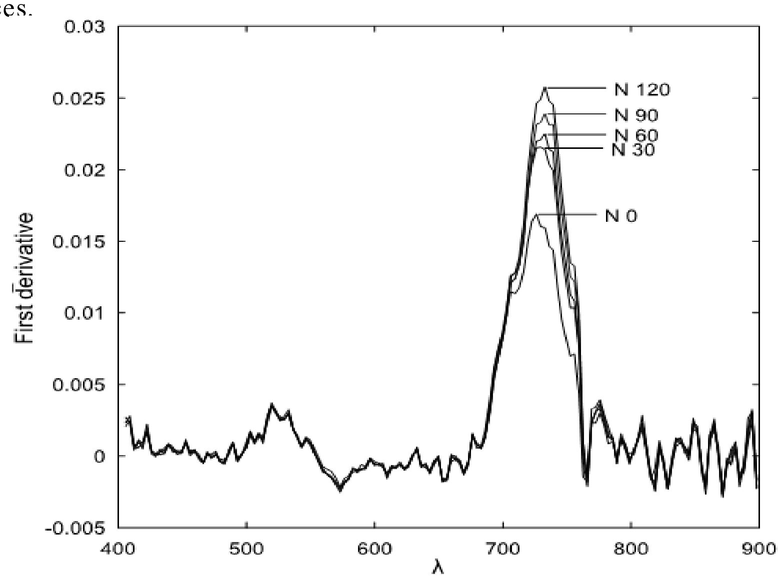

Fig.4: First derivatives of the spectral signatures for nitrogen treatments

more responsive so the red edge position was explored by computing first derivative of the reflectance spectra (Fig. 4). Karande *et al.*, 2014 reported that normalized difference of red edge (NDRE) is more sensitive to nitrogen status in the wheat crop than mSR and NDVI.The red edge inflection point (REIP) in the first derivative curve is the point of maximum peak in the spectra (Dawson and Curran, 1998). The REIP indicated by the first derivative curve were found exactly at the wavelengths of the R^2hotspots in 2D matrix plots for most indices. The red edge peak is considered best indicator of chlorophyll content and which can also be affected by water stress in well-developed crops (Filella and Penuelas, 1994). Thus, spectral wavelengths near REIP can be used in most vegetation indices to approximate the nitrogen status for non-water-stressed wheat crop.

REFERENCES

Baret, F., Guyot, G. and Major, D. J. (1989).TSAVI: A vegetation index which minimizes soil brightness effects on LAI and APARestimation: Geoscience and Remote Sensing Symposium, 1989. IGARSS'89.12th Canadian Symposium on Remote Sensing. 1989 International, p. 1355-1358.

Curran, P.J., Dungan, J.L., Macler, B.A. and Plummer, S.E. (1991).The effect of a red leaf pigment on the relationship between red edge and chlorophyll concentration. *Remote Sens. Environ.,* 35:69-76.

Dawson, T. P. and Curran, P.J.(1998). A new technique for interpolating the reflectance red edge position. *Int. J. Remote Sens.,* 19(11):2133-2139.

Filella, I., and J. Penuelas. (1994). The red edge position and shape as indicators of plant chlorophyll content, biomass, and hydric status. *Int. J. Remote Sens.*,15:1459–1470.

Gitelson, A. A., Vina, A., Ciganda, V., Rundquist, D.C. and Arkebauer, T.J. (2005). Remote estimation of canopy chlorophyll content in crops. *Geophy. Res. Letters, 32* (8) L08403.doi:10.1029/ 2005GL022688.

Jensen, J.R. (2000). Remote sensing of the Environment –An Earth Resource Perspective. Prentice-Hall Inc., Upper Saddle River, NJ, 544 pp.

Karande, B. I., Lunagariya, M. M., Patel, K. I. and Pandey, V. (2014). Model for detecting nitrogen deficiency in wheat crop using spectral indices. *J. Agromet.,* 16 (1):85-93.

Karter, G.A. and Knapp, A.K. (2001). Leaf optical properties in higher plants: Linking spectral characteristics to stress and chlorophyll concentration. *American J. Botany,* 88(4):667-684.

Lichtenthaler, H.K., Gitelson, A. and Lang,M. (1996).Non-destructive determination of chlorophyll content of leaves of a green and an aurea mutant of tobacco by reflectance measurements.*J. Plant Physiol.,* 148:483–493.

Major, D. J., Baret, F. and Guyot, G. (1990).A ratio vegetation index adjusted for soil brightness. *Int. J. Remote Sens.,* 11: 727-740.

Pearson, R. L., and Miller, L. D. (1972). Remote mapping of standing crop biomass for estimation of the productivity of the short-grass Prairie, Pawnee National Grassland, Colorado: 8th International symposium on remote sensing of environment, p. 1357-1381.

Richardson, A. J. and Wiegand, C. L. (1977).Distinguishing vegetation from soil background information: *Photog. Eng. Remote Sens.,* 43:1541-1552.

Sahoo, R. N., Ray, S. S. and Manjunath, K. R. (2015). Hypeerspectral remote sensing of agriculture. *Curr. Sci.,* 108(5): 848-859.

Sims, D.A. and Gamon, J.A. (2002). Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages.*Remote Sens.Environ.,*81: 337–354.

Thenkabail, P. S., R. B. Smith, and E. De Pauw, (2000), Hyperspectral vegetation indices and their relationships with agricultural crop characteristics.*Remote Sens. Environ.,*71: 158-182.

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