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Model for detecting nitrogen deficiency in wheat crop using spectral indices

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ABSTRACT

An experiment was conducted four years (2007-08 to 20010-11) during *rabi* at Anand, India to study nitrogen stress response of wheat (*Triticum aestivum* L.) on spectral signature using spectroradiometer (Model - UniSpec DC Dual Channel Spectrometer, PP System, USA). The experiment was carried out with two wheat cultivars *viz.,* GW496 and Lok 1 and five levels of nitrogen 120, 90, 60, 30 and 0 kg ha^{-1}. The NDVI (normalized difference vegetation index) which is an indicator of status of crop biomass was found higher at 45 to 65 DAS of the crop age. The same characteristics were also observed in case of NDRE (normalize difference red edge) index at the 45 to 65 DAS of the crop age. Based on the index value of NDVI & NDRE at different growth stages of wheat crop, it was revealed that the crop biomass under the 120 N kg ha^{-1} could be more healthy which resulted in better yield. The variety wise analysis showed that no significant varietal differences were observed for NDVI, mSR and NDRE during different growth stages of wheat crop. The index value of NDVI and NDRE was higher in the highest nitrogen 120 kg ha^{-1} and lowest in treatment without nitrogen application. The NDVI was found more related to biomass production, while the NDRE was found useful to detect nitrogen stress during 45 to 75 DAS of the crop. Moreover the nitrogen stress detected during the initial growth stages 35-45 DAS of the crop are most useful for top dressing dose of nitrogen to overcome the stress. Using stepwise regression approach nitrogen deficiency model was developed, which showed NDRE is the only highly significant ($P<0.01$) index for detecting nitrogen deficiency in wheat crop.

Key word: Nitrogen stress, NDRE, NDVI, spectral signature, stepwise regression model, wheat

Wheat is most important crop of India and largest cultivated cereal crop in world. It is staple food crop of the world. The major constraint for low productivity of wheat is nitrogen stress occurs during different stages of growth. Hence, detection of nitrogen stress during crop growth period is most important to timely and required amount of nitrogen application to the plant. Remote sensing technique can be used to detect nitrogen deficiency in crop by calculating vegetation indices using reflected radiation from crop canopy Walburg *et al.* (1982), Stone *et al.* (1996), Ansari *et al.* (2006), Schepers *et al.*, 1996; Gitelson et al., 2003; Raun *et a*l., 2005. The normalized difference vegetation index (NDVI) is used to detect green biomass (crop cover) from RED and NIR reflected radiation from ground surface (Rouse *et. al.,* 1974). Light reflected by vegetation in the visible region of the spectrum is predominantly influenced by concentration of leaf N (Haboudane *et al*., 2002). Near infrared (NIR) reflectance is influenced by internal leaf cell structure. Non nitrogen stressed healthy spongy mesophyll cells strongly reflect infrared wavelengths (Gates *et al.,* 1965). The spectral region between the red absorption and NIR reflectance, termed the ''red edge'' is correlated with nitrogen deficiency The Normalised Difference Vegetation Index (NDVI) is used as an estimate of percent canopy cover and the Normalised Difference Red Edge (NDRE) index as a measure of nitrogen status of crop (Barnes *et al.,* 2000). Therefore, measurements of reflected energy from crop canopies can be used to estimate N deficiency (Haboudane *et a*l., 2002). The experiments were conducted to develop model a for quantifying nitrogen deficiency in wheat crop.

MATERIALS AND METHODS

Field experiments were conducted at Agronomy Farm, Anand Agricultural University. Anand. Gujarat on wheat (*Triticum aestivum* L.) with two varieties and five nitrogen levels of fertilizer during *rabi* season for four consecutive years 2007-08 to 2010-11. The crops were sown in 5.00 x 2.70 m^2 plots size laid out in split plot design with four replications. The two varieties *viz*, GW 496 (V1) and LOK 1 (V2) as the main treatments and five

Table 1: Grain yield (kg ha^{-1}) of wheat as influenced by different treatments.

Treatments	2007-08	2008-09	2009-10	2010-11	Pooled
Varieties (V)					
V1	4347	3968	3642	5378	4334
V2	4730	3762	4081	5508	4520
SEM ±	75.9	52.9	123.6	73.4	104.0
C D at 5%	341.7	NS	554.1	NS	NS
C. V. %	7.5	6.1	4.5	6.0	6.3
Nitrogen (N)					
N1	5746	4823	4498	6138	5241
N2	5034	4370	4258	5898	4950
N3	4513	3895	4143	5314	4466
N4	4182	3444	3856	5224	4176
N5	3217	2795	2553	4642	3301
SEM ±	104.8	79.9	901.4	122.5	125.5
C D at 5%	305.9	233.4	263.0	357.0	386.9
Interactions					
V x N	NS	NS	NS	NS	NS
Y x T					NS

nitrogen fertilizer application rates 120 (N1), 90 (N2), 60 (N3), 30 (N4) and 0 kg N ha^{-1} (N5) as sub plot-treatments were randomized in spilt plot design. Basal dose of 120 kg P ha^{-1} and 60 kg K ha^{-1} for all treatments were applied. All management practices and irrigations were carried out as per the agronomic practices.

Spectral observations over canopy were taken at 10 days interval starting at 25 days after sowing (DAS) by using Unispec-DC Spectroradiometer version 2.02 (PP System, USA) operated in wavelength of 310-1100 nm covering visible and near infrared portion of the spectrum. Wavelength band width 3.4 nm interval. Data were recorded under clear sky and haze free conditions from all plots under different treatments. Spectral data were used to derive the different vegetation indices. The reflectance was calculated as the ratio between the reflected and incident spectra of the canopy. The spectral reflectance recorded at different phenological stages using narrow band spectroradiometer were converted into Normalized Difference of Vegetation Index (NDVI), Modified Simple Ratio (mSR) and Normalized Difference of Red Edge (NDRE) respectively using the formulae

$$NDVI = (NIR - Red)/(NIR + Red)$$

$$mSR = (R_{750} - R_{445})/(R_{705} + R_{445})$$

$$NDRE = (R_{790} - R_{720})/(R_{790} + R_{720})$$

The vegetative indices *viz.,* NDVI, mSR, and NDRE which are the indicator of crop health during the various phenological stages were used to detect the nitrogen stress condition of wheat crop growing under the treatment of varying nitrogen levels as well as to distinguish the ground cover. Correlations were worked out between spectral indices at different stages with the biomass, LAI and grain yield. Significant correlations obtained were used to develop regression models. Stepwise regression approach was used to develop regression model to detect nitrogen deficiency.

RESULTS AND DISCUSSION

Grain and straw yield as influenced by variety and nitrogen

The grain and straw yields were significantly influenced by nitrogen level (Table 1 and 2). The grain yield observed in N1 (120 kg ha^{-1}) nitrogen level during individual years 2007-08, 2008-09, 2009-10, 2010-11 and in pooled were 5746, 4823, 4498, 6138 and 5241 kg ha^{-1} respectively. The grain yields were significantly higher

Table 2: Straw yield (kg ha^{-1}) of wheat as influenced by different treatments.

Treatments	2007-08	2008-09	2009-10	2010-11	Pooled
Varieties (V)					
V1	12145	8604	7852	12389	10248
V2	11583	8409	8718	12861	10393
SEM ±	160.5	373.5	440.3	272.9	127.3
C D at 5%	NS	NS	1983.3	NS	NS
C. V. %	6.0	5.8	7.5	9.7	11.0
Nitrogen (N)					
N1	14618	9809	9729	13142	11704
N2	13142	9410	9248	12882	11291
N3	11493	8750	8949	12778	10493
N4	10815	7830	8016	11441	9526
N5	9253	6736	5482	10890	8591
SEM ±	196.7	173.6	179.8	205.1	280.1
C D at 5%	574.0	506.6	525.0	630.4	560.5
Interactions					
V x N	NS	NS	NS	NS	NS
Y x T					NS

in N1 as compared to N2, N3, N4 and N5. The straw yield under N1 treatment was also higher in N1 as compared to other N treatments. The interaction effect between treatment combination as well as year × treatment were found non-significant in pooled result as well as in individual year (Table 1 & 2). The grain yields were significantly influenced by varieties during individual year 2007-08 and 2009-10, while it was non-significant during year 2008-09, 2010-11 and in pooled results. The straw yields were significantly influenced by varieties during 2009-10 while it was non-significant during 2007-08, 2008-09, 2010-11 and in pooled results (Table 1 and 2). This indicated that different nitrogen levels produced variations in biomass and grain yield.

Spectral reflectance of wheat crop growing under varying nitrogen level

The characteristics curve of spectral reflectance as influenced by nitrogen level at 45 DAS observed beyond 750 nanometer wave length to 900 nanometer wave length, the percentage value of reflectance in N1 nitrogen level treatment was 12% to 18% higher as compared to N4 and N5 treatment during the year of 2007-08, 2008-09, 2009-10 and 2010-11 (Fig. 1). During the year 2007-08 in NIR (758 to 950 nanometer) region, the reflectance from N1 treatment was highest (0.81 to 0.84). The reflectance percentages observed between 700 to 900 nanometer wave length under N1 nitrogen level during the year of 2008-09, 2009-10 and 2010-11 lies between the range of 0.50 to 0.55 which were 20 to 40% higher than the reflectance observed in N5 nitrogen level treatment. N1 was showing highest reflectance in NIR region because of more green and healthy biomass. The basic reason behind obtaining the higher reflectance values and higher values of vegetative indices in N1 nitrogen level treatment are due to high positive correlation between nitrogen application and canopy reflectance. Similar results were reported by Zhaoa *et al*., 2005, Tilling *et al.,* 2007, Rodriguez *et al.,* 2006. In this study it was found that under higher nitrogen level N1 treatment, the canopy reflectance spectra values were in higher increasing order from 750 to 900 nanometer as compared to lower nitrogen level treatment. Thus, the spectral reflectance data recorded using narrow band spectro radiometer in Red (600 to 700 nanometer) and NIR (750 to 950 nanometer) region in wheat crop growing under varying nitrogen level treatment can be used to

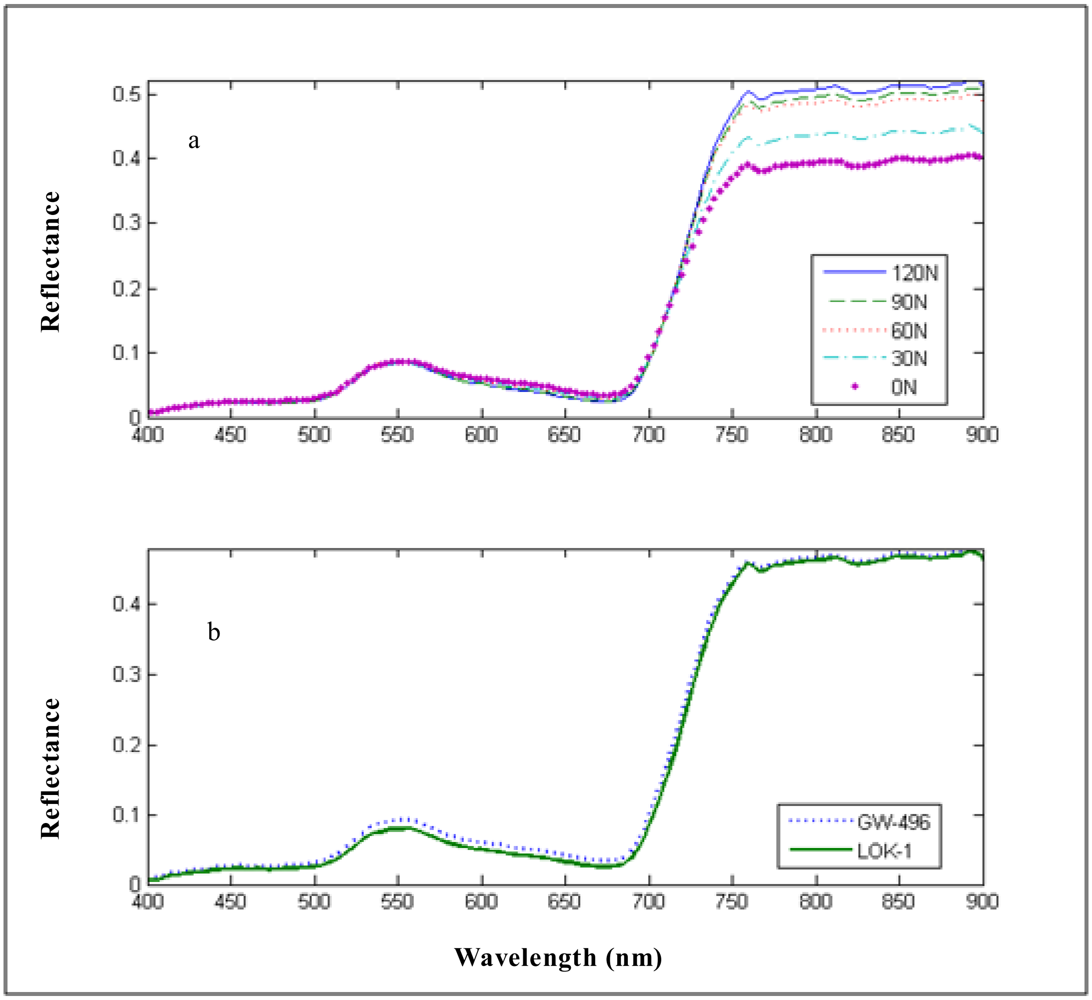

Fig. 1: Spectral behavior of wheat crop at 45 DAS for (a) Nitrogen and (b) variety

differentiate the nitrogen stress occurred in wheat crop from 35-45 DAS or period when soil is fully covered with crop canopy.

For rest of growth period up to beginning of grain filling similar results were observed. But it is necessary to detect nitrogen deficiency at early growth stage to avoid nitrogen deficiency effects on subsequent growth period and thus in biomass production. Nitrogen application during early growth stage is more effective than that application of nitrogen after 40-45 DAS (Hamid and Sarwar (1976), Halikatti (1980), Gami *et al*. (1986), Strong (1986), Dhuka *et al*. (1992), Patel (1999), Samra and Dhillon (2002) and Ramu N. (2008)). However, spectral observations recorded before 30 days of crop age are spectral signatures having more contribution of soil reflectance due to soil not being fully covered since wheat is in early stages. Thus, spectral observations recorded during 35-45 DAS are representing nitrogen deficiency status of crop due to full crop cover. In present investigation spectral observations were recorded throughout growth period of crop but only spectral observations recorded at 35-45 DAS were used for development of model for detecting nitrogen stress in wheat crop.

Effect of varieties on vegetative indices:

The vegetative indices *viz*. NDVI, mSR and NDRE calculated at 45 DAS, 65 DAS and 75 DAS for each variety revealed that the values of NDVI were higher in case of variety V2 (LOK-1) as compared to variety V1 (GW496) during booting stage (45 DAS) of the crop in most of all the years under study. More or less the similar kind of trend was also observed at 65 DAS and 75 DAS, but there was no significant difference at any of the phenological stage. It was observed that the values of NDVI, NDRE and mSR were not significantly different due to variety at any stage of the crop (Table 3). The highest values of NDVI (0.922), mSR (0.928) and NDRE (0.472) in V2 at 45 DAS were observed in year 2010-11. The non significant differences in spectral indices due to

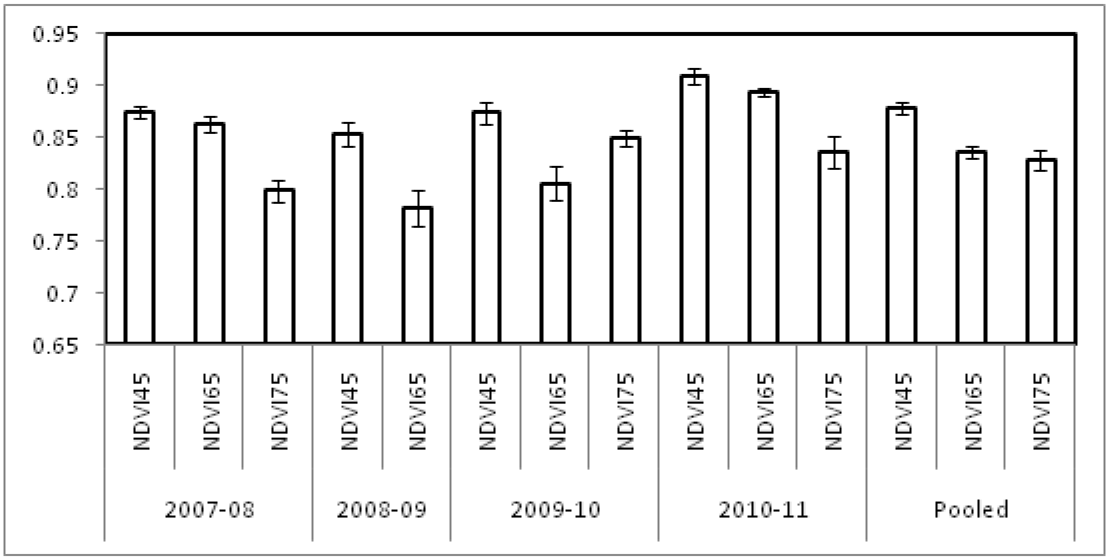

Fig. 2: NDVI of wheat crop at 45, 65 and 75 DAS growing under varying nitrogen treatments

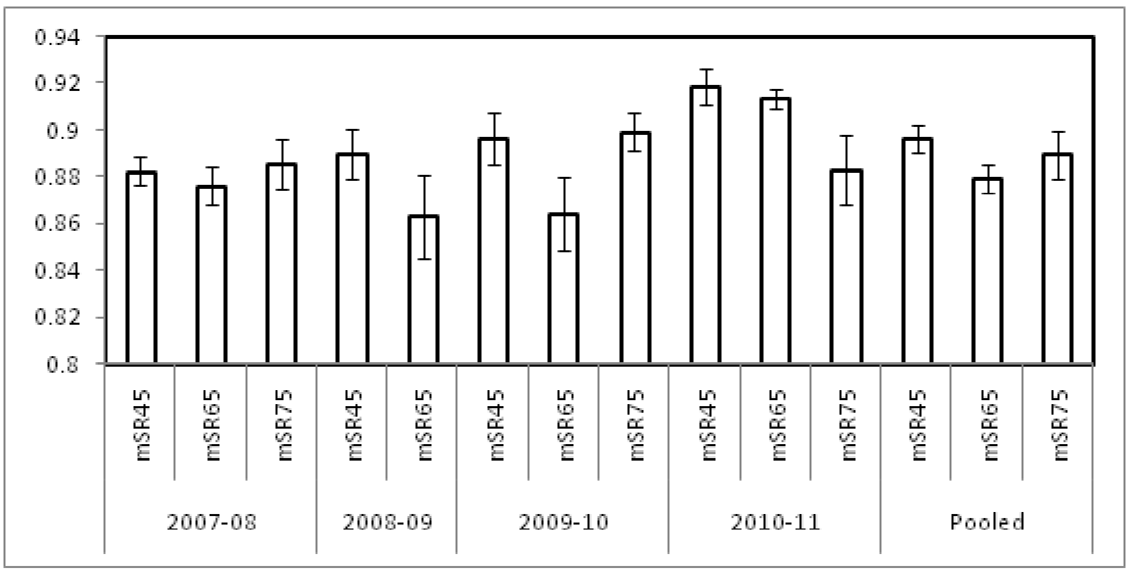

Fig. 3: mSR of wheat crop at 45, 65 and 75 DAS growing under varying nitrogen treatments

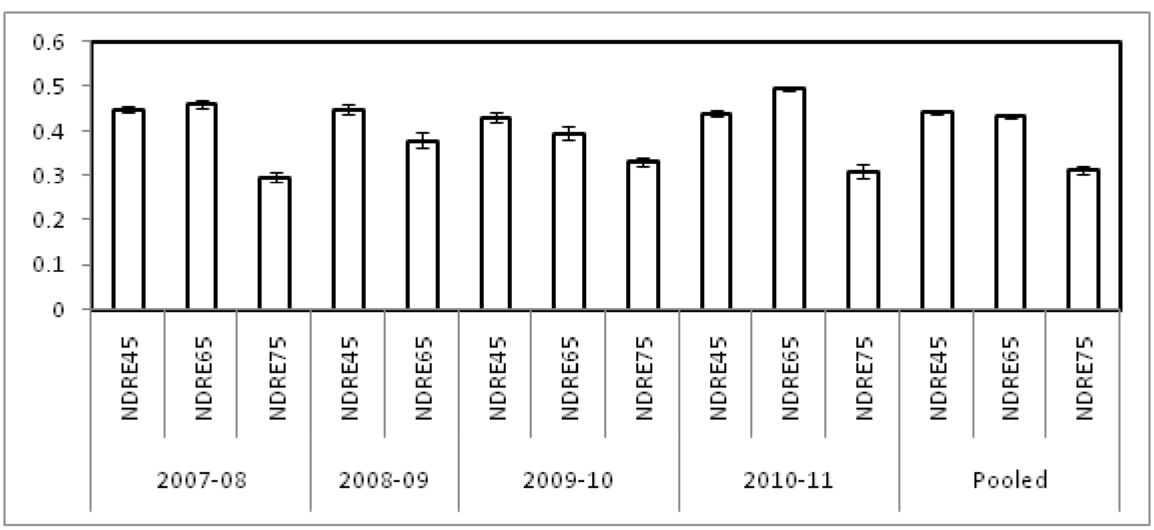

Fig. 4: NDRE of wheat crop at 45, 65 and 75 DAS growing under varying nitrogen treatments

variety revealed that the spectral indices cannot used to differentiate these two varieties under field conditions. The relatively higher values of different indices in LOK-1 at 45DAS were due to higher early growth, higher LAI and ground cover compared to GW496.

Effect of nitrogen level on vegetative indices:

NDVI

The values of NDVI at 45 DAS during the year of 2007-08 in N1, N2, N3, N4 and N5 were 0.900, 0.895, 0.886, 0.877 and 0.814 respectively (Fig. 2). From these values, it was found that the values of NDVI higher in N1 treatment as compared to all treatments, however, it was significantly higher in N5 while at par with N2, N3 and N4 treatments. The values of NDVI in pooled result in N1 treatment were also significantly higher as compared to N5 treatment ($P<0.05$). The same trend was also observed in NDVI at 65 DAS and at 75 DAS during all the years under study as well as in pooled result. This indicated that higher green biomass produced by higher dose of nitrogen could be detected NDVI values. similar results were reported by Stan hill *et al*. (1972) and Ansari *et al.* (2006).

mSR

It was observed that the values of mSR at 45 DAS during the year of 2007-08 and in pooled result in N1, N2, N3, N4 and N5 were 0.896, 0.894, 0.886, 0.883, 0.852; 0.908, 0.907, 0.901, 0.892 and 0.875 respectively. In all individual years the highest mSR values were recorded in N1 treatment while lowest mSR values reported in N5 treatment. Similarly in the pooled results highest mSR (0.908) value was observed in N1 treatment while lowest mSR (0.875) value reported in N5 treatment. The pooled results of statistical analysis showed the values of mSR in N1 treatment were significantly higher as compared to N5 treatment, whereas they were at par with N2, N3 and N4. The similar trend was also observed in mSR at 65 DAS and at 75 DAS during all the years under study (Fig. 3).

NDRE

The values of NDRE at 45 DAS during the year of 2007-08 in N1, N2, N3, N4 and N5 were 0.491, 0.479, 0.463, 0.445 and 0.371 respectively (Fig. 4). It was observed that the values of NDRE higher in N1 treatment as compared to rest of the treatment ($P<0.05$). The pooled analysis of the NDRE indicated that the values of NDRE in N1, N2, N3, N4 and N5 were 0.481, 0.470, 0.457, 0.427 and 0.375 respectively, which were significantly differ in varying nitrogen level. The same trend was also observed in NDRE at 65 DAS and at 75 DAS during all the individual years and pooled over years under study ($P<0.05$). From the statistical analysis of the vegetative indices in relation to varying nitrogen level treatment it was revealed that the NDRE parameter of remote sensing technique was found more powerful tool to detect nitrogen responses of standing crop growing under deficient nitrogen level at early stage of the crop (45 DAS) as compared to NDVI and mSR. It was observed that within same treatment NDVI values were showing increasing trend as LAI and biomass increases, while NDRE did not show any trend with LAI and biomass. However, NDRE showed highly significant correlation with nitrogen applications ($r= 0.88$).

The values of NDVI, mSR and NDRE in pooled result at 45 DAS in N1 treatment were about 8%, 4% and 24% higher as compared to the values observed in N5 nitrogen level treatment, which indicated that the vegetative indices NDRE and NDVI are found most appropriate parameters in detecting the stress caused by nitrogen deficiency at early stage of the wheat crop.

The results of statistical analysis indicated that the interaction effect between Variety × Nitrogen treatment combination as well as Year × Treatment regarding NDRE were found non-significant in individual year as well as in pooled years.

Estimation of nitrogen deficiency

Looking to the results obtained from this study regarding the utilization of remote sensing techniques in detecting the stress caused by insufficient amount of nitrogen available to the plant in the wheat crop field, it is possible to separate out the healthy crop and adversely affected by nitrogen stress crop at 35-45 DAS. This technique is most useful in understanding the crop growth behavior relationship and physico-chemical property of the plants at early crop growing stage of the standing crop, so as appropriate dose of nitrogen application can be given to crop. Many studies have found that nondestructive measurements of leaf or canopy reflectance can be used for detecting N-deficient stress in crops like rice (Wang *et al*., 1998 and Chang *et al.,* 2005), wheat Voullot *et al*., 1998 and corn Blackmer et al., 1996.

It was observed that use of the NDVI, NDRE and mSR vegetative indices computed from narrowband spectral reflectance measured using spectro-radiometer

Table 3: NDVI, mSR and NDRE of wheat crop at 45, 65 and 75 DAS as influenced by variety V1 (GW 496) and V2 (LOK-1)

NDVI	45 DAS					65 DAS					75 DAS			
	07-08	08-09	09-10	10-11	pooled	07-08	08-09	09-10	10-11	pooled	07-08	09-10	10-11	pooled
V1	0.870	0.860	0.870	0.895	0.874	0.864	0.798	0.797	0.899	0.840	0.798	0.835	0.827	0.820
V2	0.879	0.845	0.878	0.922	0.881	0.862	0.766	0.814	0.887	0.832	0.798	0.865	0.844	0.836
SEM	0.002	0.008	0.009	0.008	0.004	0.005	0.011	0.023	0.005	0.007	0.006	0.012	0.011	0.006
CD at 5 % level	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
mSR	45	65	45											
V1	0.879	0.897	0.895	0.909	0.895	0.879	0.873	0.865	0.919	0.884	0.887	0.892	0.881	0.887
V2	0.886	0.883	0.898	0.928	0.898	0.874	0.852	0.863	0.908	0.874	0.884	0.906	0.885	0.892
SEM	0.001	0.005	0.004	0.004	0.005	0.003	0.006	0.010	0.004	0.003	0.003	0.004	0.004	0.002
CD at 5 % level	0.003	NS	NS	NS	NS	NS	NS	NS	NS	0.010	NS	NS	NS	NS
NDRE	45	65	75											
V1	0.432	0.451	0.422	0.407	0.428	0.452	0.394	0.384	0.493	0.431	0.292	0.313	0.296	0.300
V2	0.468	0.447	0.437	0.472	0.456	0.466	0.361	0.408	0.501	0.434	0.230	0.348	0.321	0.323
SEM	0.003	0.011	0.013	0.010	0.010	0.006	0.009	0.023	0.011	0.007	0.004	0.009	0.011	0.005
CD at 5 % level	0.015	NS	NS	0.043	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.016

are correlated with nitrogen application during booting to flowering period. Hence, these VI can be used to detect the nitrogen stress in wheat crop. The multiple regression and stepwise regression equations were developed to detect nitrogen stress in wheat crop. Stepwise regression analysis revealed that only NDRE is the most sensitive index ($P<0.01$) for nitrogen stress and can be used to judge the nitrogen stress. Using NDRE nitrogen requirement of the crop can be approximated early enough (35-45 DAS) to apply additional fertilizer if necessary. This indicate that, during wheat crop growth if there is any nitrogen stress faced by crop, it can be detected remotely by calculating NDVI, mSR and NDRE vegetative indices at any stage. Though all three indices had correlations with nitrogen applications, but only NDRE showed significantly sensitive index ($P<0.01$) for nitrogen deficiency. However if vegetation indices were calculated at very early growth stage (before 35 DAS) the reflectance was more noisy due to contribution of mixed reflectance from soil and crop canopy. Similarly, if vegetation indices were measured at later stage of crop growth (after 50 DAS) nitrogen deficiency can be detected but it is not advisable to apply nitrogen at later stages wheat growth in India. In India, recommended nitrogen dose of 120 kg N ha^{-1} is applied in two split applications i.e. 50% at time of sowing and remaining 50% at 30 DAS. If nitrogen is applied during later stage (after 50 DAS) it can not recover physiological stresses imposed by nitrogen deficiency during early growth stage. Therefore, timely detection of nitrogen deficiency and application of nitrogen is most important for getting maximum wheat grain yield specially in precision farming. Hence, NDRE vegetation index measured between 35 to 45 DAS can be used for detecting nitrogen deficiency. The correlation, regression and stepwise regression analysis were performed between all vegetation indices and yield of wheat under different nitrogen treatments. Statistical analysis revealed that only NDRE showed significant correlation and regression ($P<0.01$) with nitrogen applications. Therefore, using NDRE at early growth stage (35-45 DAS) Nitrogen requirement of the wheat crop can be approximated as early as 35 to 45 DAS using stepwise regression equation with consideration that recommended dose of nitrogen is 120 kg N ha^{-1}.

$$N = 468.084 - 923.371 * NDRE \qquad (R^2 = 0.78^{**})$$

Where,

N = Nitrogen requirement in kg ha^{-1}

NDRE = NDRE at 35-45 DAS

The model can be used to find out direct nitrogen deficiency in wheat in kg nitrogen required per hectare.

REFERENCES

Ansari M. S., Rajkumar. M., Sidhu S. S. and Bahl G. S. (2006). Spectral response of nitrogen fertilization in cotton. www.regional.org.au/au/asa/2006/poster/technology / 4579_ansarm.

Barnes E.M., Clarke T.R. and Richards S.E. (2000). Coincident detection of crop water stress, nitrogen status and canopy density using ground based Multispectral data, Proceedings of the 5fh International Conference on Precision Agriculture. Bloomington, MN, USA.

Blackmer, T.M., Schepers, J.S., Varvel, G.E., Walter-Shea, E.A., (1996). Nitrogen deficiency detection using reflected shortwave radiation from irrigated corn canopies. *Agron. J.,* 88, 1–5.

Chang, K.W. Shen, Y., Lo, J.C. (2005). Predicting Rice Yield Using Canopy Reflectance Measured at Booting Stage *Agron. J.,* 97(3): 872 - 878.

Dhuka, A. K., Sadaria, S. G., Patel, J. C. and Patel, B.S., (1992), Effect of rate and time of nitrogen application on late sown wheat. *Indian J. Agron.,* **37**(2): 354-355.

Gami, J. K., Parmar, M. T., Patel, J. C. and Malavia, (1986), Effect of rates and methods of nitrogen application on late sown wheat. *Indian J. Agron.,* **31** (4): 401-402.

Gates, D.M., Keegan, H.J., Schleter, J.C.,Weidner, V.R., 1965. Spectral properties of plants. Appl. Opt.. 4: 11–20.

Gitelson, A.A., Vina, A. Arkebauer,T.J., Rundquist, D.C., Keydan, G. and Leavitt, (2003). Remote estimation of leaf area index and green leaf biomass in maize canpies. *Geophys. Res. Let.,* 30: 1248-1255.

Haboudane D, Miller J.R., Tremblay N, Zarco-Tejada P.J. and Dextraze L. (2002). Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application in precision agriculture. Remote Sensing of Environment. 81: 416-426. Elsevier Science Inc.

Halikatti, S. I., (1980), Effect of levels, time and method of nitrogen application on growth and yield of wheat (*Triticum aestivum*) under irrigation. *M.Sc.(Agri.) Thesis,* Univ. Agric. Sci., Dharwad.

Hamid, A. and Sarwar, G., (1976), Effect of split application on N uptake by wheat from N15 labelled ammonium nitrate and urea. *Exptl. Agric.,* **12** (2): 189-193.

Patel, J. R., (1999), Effect of levels and methods of nitrogen application on wheat yield. *J. Maharashtra Agric. Univ.,* **24** (1): 108-109.

Ramu N., (2008). Nitrogen management in wheat under irrigated conditions. *M.Sc.(Agri.) Thesis,* Univ. Agric. Sci., Dharwad.

Raun, W.R., Solie, J.B., Stone, M.L., Martin, K.L., Freeman, K.W., Mullen, R.W., Zhang, H., Schepers, J.S., Johnson, G.V., (2005). Optical sensor-based algorithm for crop nitrogen fertilization. Commun. Soil Plant Anal. 36, 2759–2781.

Rodriguez D, Fitzgerald GJ, Belford R and Christensen L (2006), Detection of nitrogen deficiency in wheat from spectral reflectance indices and basic crop eco-biophysiological concepts. Australian Agric. Res. 57. 781- 789

Rouse J. W., Haas, R. H., Schell J. A., Deering D. W. and Harlan J. C. (1974). Monitoring the vernal advancement of retrogradation of natural vegetation.NASA, USA. pp.1-371.

Samra, J.S. and Dhillon, S. S., (2002), Response of durum wheat (*Triticum durum* Def.) to rate and time of nitrogen application under irrigated conditions. *J. Res., Punjab Agric.Univ.,* **39**: 46-49.

Schepers, J.S., Blackmer, T.M., Wilhelm, W.W., Resende, M., (1996). Transmittance and reflectance measurements of corn leaves from plants with different N and water supply. *J. Plant Phys.,* 148, 523–529.

Stanhill G., Kafkafi U., Fuchs. M. and Kagan. Y. (1972). The effect of fertilizer application on solar reflectance from a wheat crop. *Israel J. Agric.,* Res. 22:109-18.

Stone M. L., Solie J. B., Raun W. R., Whitney R.W., Taylor S. L. and Ringer J. D. (1996). Use of spectral radiance for correcting in – season fertilizer nitrogen deficiencies in winter wheat. *Trans. ASAE* 39:1623-31.

Strong, W. M., (1986), Effect of nitrogen application before sowing, compared with the effects of split application before and after sowing for irrigated wheat on the Darling Downs. *Aus. J. Exp. Agric. Anim. Husb.,* **22**:34-42.

Tilling A. K., G. J. O'Leary, J. G. Ferwerda, S. D. Jones, G. J. Fitzgerald, D. Rodriguez, R. Belford. (2007). Remote sensing of nitrogen and water stress in wheat. Field Crops Res. 104:77–85

Voullot, M.O., Huet, P., Boissard, P., (1998). Early detection of N deficiency in a wheat crop using physiological and radiometric methods. *Agronomie,* 18: 117–130.

Walburg,G.,Bauer,M.E.Daughtry,C.S.T.and Housley.T.L. (1982). Effect of nitrogen nutrition on the growth,yield and reflectance characteristics of corm canopies. *Agron.J.,*74:677-83.

Wang, R.C., Wang, K., Shen, Z.Q., (1998). Feasibility of field evaluation of rice nitrogen status from reflectance spectra of canopy. *Pedosphere* 8: 121–126

Zhaoa, D. K. Raja Reddya, Vijaya Gopal Kakania, V.R. Reddyb. (2005). Nitrogen deficiency effects on plant growth, leaf photosynthesis, and hyperspectral reflectance properties of sorghum. *Europ. J. Agron.22.* 391–403.

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