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Relationship between biophysical parameters and Normalized Difference Vegetation Index in maize*

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ABSTRACT

A field experiment was conducted for two years during *kharif* season at ARI farm, Rajendranagar, Hyderabad to study the spectral reflectance pattern of maize crop and its relationship with biophysical parameters like Leaf Area Index (LAI), stover yield and grain yield. The experiment was laid out in RBD (Factorial) with three replications. The treatments comprised of four dates of sowing and four irrigation regimes. The spectral characteristics of the crop were measured at weekly intervals using a hand-held, multiband ground truth radiometer. In all dates of sowing, rainfed (moisture-stressed) crop showed lower Normalized Difference Vegetation Index (NDVI) values than irrigated crop throughout crop growing season. The NDVI and LAI are related exponentially and the predicted values of LAI are in good agreement with observed values. The integrated NDVI of different treatments was computed and significant correlation was found between integrated NDVI and, stover yield and grain yield. The result indicates that the grain yield can be estimated using satellite image derived NDVI in large areas. The relationship was found to be logarithmic during pre NDVImax and was linear during post NDVImax period.

Key words: Spectral reflectance, NDVI, LAI, fPAR, yield, moisture stress.

Remote sensing is an important tool to provide appropriate, timely and missing information for achieving sustainable and efficient agricultural practices. Assessment of biophysical parameters like Leaf Area Index (LAI), dry biomass and its spatial variability in agriculture is important for addressing various issues such as crop growth monitoring, vegetation condition and crop yield forecasting. Leaf area is a biophysical variable that plays a major role in physiological processes.

Retrieval of LAI from remotely sensed data led to the development of various approaches for LAI estimation at different scales and over diverse canopies (Chen and Cihlar, 1996; Haboudane *et al.,* 2004). Remote sensing is a powerful tool to characterize the properties of the vegetation and to estimate yield / biomass besides, monitoring the health of the plant in terms of stress. Spectral vegetation index is derived as the ratio of various bands or a combination of spectral bands, have been related to large number of vegetation properties including yield (Wiegand *et al.,* 1990).

Various biophysical variables namely, chlorophyll, PAR and LAI are useful in site specific management by determining the stress of the crop and also to forecast the yield. The LAI and biomass are important input parameters in simulation models. Realizing the potential of remote sensing in deriving information on biophysical parameters, an experiment was conducted to study the spectral reflectance profile and to determine the relationship between biophysical parameters with spectral reflectance data in maize crop.

MATERIALS AND METHODS

A field experiment was conducted at Agricultural Research Institute (ARI) farm, ANGRAU, Rajendranagar, Hyderabad, for two years during *kharif* season of 2003-04 and 2004-05 with maize crop (Variety-DHM-103). The site of experiment is located adjacent to the meteorological observatory with 17^0 19' N latitude and 78^o 23' E longitude. The soil is sandy clay loam in texture and the soil moisture retention is 16% at 0.33 bars and 6% at 15 bars. The effective root zone depth of the soil varies from 60 to 80 cm. The bulk density is 1.57, 1.63, and 1.7 Mg m^{-3} at 0-15, 15-30 and 30-45 cm depths, respectively. The soil is neutral in reaction with a pH of 7.4. To ensure that the crop was subjected to moisture stress, staggered sowing in four dates at an interval of fifteen days starting from the onset of monsoon was

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taken up. The experiment was laid out in RBD (Factorial) with three replications and the details of the treatments are as follows.

Dates of sowing

Date of Sowing	2003-04	2004-05
D_1	30.06.2003	11.06.2004
D_2	08.07.2003	02.07.2004
D_3	30.07.2003	18.07.2004
D_4	13.08.2003	03.08.2004

Moisture regimes

I_1 - Irrigation as per water requirement of the crop

I_2 - Skipping irrigation at vegetative stage

I_3 - Skipping irrigation at reproductive stage

I_4 - Rainfed

Maize variety DHM-103 was grown by adopting recommended package of practices leaving weather and irrigation regimes as variables. The spectral characteristics of the crop were measured at weekly intervals using a hand-held, multiband ground truth radiometer (Optomech make) operating in visible and near-infrared wavelengths (0.45-0.52, 0.52-0.59 and 0.62-0.68 μm and 0.77-0.86 μm) wavelengths, with a field of view of 15^o, and the dynamic range of the output varies from 0.1*10 to 30*10 W cm^{-2} Sr^{-1} μm^{-1}. Calibration of the radiometer was done with the help of barium sulphate coated plate in the field before and after taking spectral signature data of the treatments under the study. In all the treatments, radiometric data were collected close to solar noon (solar zenith angle). The vegetation index-NDVI was calculated by the formula given by Rouse *et al.,* (1974).

$$NDVI = (NIR_{ref} - Red_{ref}) / (NIR_{ref} + Red_{ref}) \quad \text{............Eq. (1)}$$

The Integrated NDVI is calculated by summation of area under temporal NDVI curve for each treatment since their spectral emergence. The leaf area observations were made by destructive sampling using LI-3100, LICOR leaf area meter. Photosynthetically active radiation (PAR) incident on (I_o), transmitted through (T), reflected from the composite canopy-soil backgrounds provided the data for fractional absorbed PAR defined by Gallo *et al.* (1985). fPAR was measured with LICOR line quantum sensor.

RESULTS AND DISCUSSION

Effect of moisture stress on spectral reflectance pattern of maize

The increase of moisture stress in plant caused an increase in red band reflection and decrease in the near infrared spectral band. The spectral reflectance data recorded at 45 DAS in fully irrigated (I_1) and rainfed treatment (I_4) of the first date of sowing are depicted in Fig.1. The increase in reflectance in the red region is caused by the reduced activity of chlorophyll leading to decrease in absorption in rainfed maize crop. While in the near infra red region, the decline in reflectance is due to the reduced turgidity of spongy-mesophyll layer in rainfed crop compared to the turgidity levels of fully irrigated crop.

The temporal profile of NDVI for the year 2004-05 is presented in Fig.2. The NDVI values progressively increased with the age of the crop and peak values were attained at 7-9 weeks after sowing and thereafter it exhibited a declining trend. There was no significant difference observed in the crop duration between the different dates of sowing. The first date of sowing with fully irrigated treatment has recorded higher biomass as well as yield. In all dates of sowing rainfed (stressed) crop showed lower NDVI values than irrigated crop throughout crop growing season.

Leaf area index (LAI)

The peak leaf area index was recorded at 60 DAS. Maximum LAI was recorded in first date of sowing (Table 1) without stress treatments compared to other treatments. Among different moisture regimes, the LAI decreased in the order of $I_1 > I_3 > I_2 > I_4$. The difference in LAI among the treatments was found significant only at 90 DAS of the crop growth.

The perusal of grain yield (Table 2) indicates that sowing of crop after July second week significantly reduced in all the treatments. Over the two years the lowest grain yield was recorded during 2003-2004 (1.66 t ha^{-1}) as compared to 2004-05 (3.27 t ha^{-1}). The lower yield may be due to dry spell during August second fortnight to September first fortnight which coincided with reproductive stage. The highest grain yield of (2.81 t ha^{-1}) was recorded in first date of sowing (Table 2) wherein the crop did not experience stress and lowest being (1.10 t ha^{-1}) in third date of sowing with stress at reproductive stage.

Table 1: Effect of moisture stress on leaf area index at different dates of sowing and irrigation regimes during *kharif* 2004-05

Treatment	Irrigation regimes												Mean		
	I_1			I_2			I_3			I_4					
	DAS			DAS			DAS			DAS			DAS		
Dates of sowing	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
D_1	0.9	3.55	2.4	0.49	3.23	1.5	0.9	3.6	1.61	0.37	3.0	1.1	0.67	3.35	1.8
D_2	1.5	2.6	1.68	0.8	1.88	1.38	0.87	2.2	1.6	0.6	1.6	1.17	0.95	2.1	1.5
D_3	1.17	1.8	1.8	0.78	2.0	1.0	1.15	2.25	1.2	0.7	1.6	0.9	0.9	1.9	1.2
D_4	1.0	2.76	1.2	0.8	2.15	1.0	0.5	2.15	1.0	0.45	1.75	0.6	0.7	2.2	0.9
Mean	1.12	2.7	1.7	0.69	2.30	1.2	0.85	2.6	1.30	0.5	2.0	1.20			

	30 DAS		60 DAS		90 DAS	
SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	
Treatments	0.06	0.18	0.14	0.41	0.05	0.16
DOS/Irrigation	NS	NS	NS	NS	0.11	0.31

Table 2 : Effect of moisture stress on maize grain yield (t ha^{-1}) at different dates of sowing during *kharif* 2003-04 and 2004-05

Dates of sowing	Irrigation regimes				Mean
	I_1	I_2	I_3	I_4	
2003-04					
D_1	2.81	2.36	1.79	1.29	2.06
D_2	2.29	1.88	1.70	1.60	1.87
D_3	1.52	1.32	1.10	1.10	1.26
D_4	1.81	1.64	1.21	1.20	1.46
Mean	2.11	1.80	1.42	1.32	1.66
SEm±	0.03				
CD at 5%	0.08				
2004-05					
D_1	4.19	3.93	3.13	3.09	3.58
D_2	3.92	3.77	2.94	2.91	3.39
D_3	3.69	3.31	2.87	2.86	3.18
D_4	3.44	3.25	2.66	2.46	2.95
Mean	3.81	3.57	2.90	2.83	3.27
SEm±	0.35				
CD at 5%	1.0				

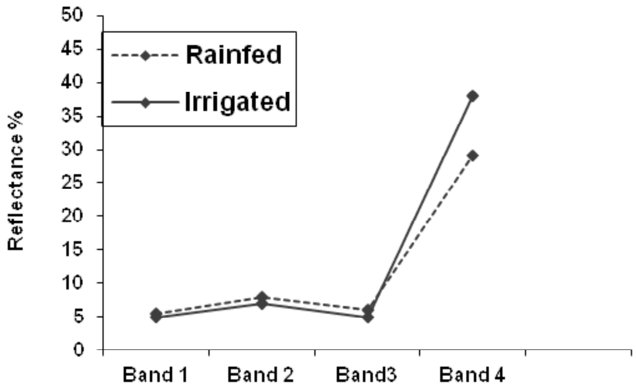

Fig.1: Spectral reflectance pattern of irrigated and rainfed maize

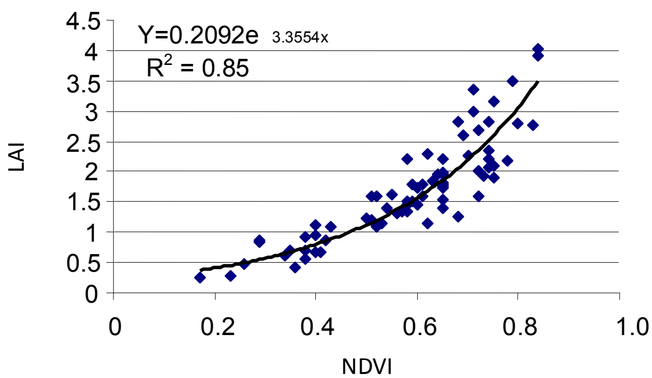

Fig.3: Relationship between LAI and NDVI

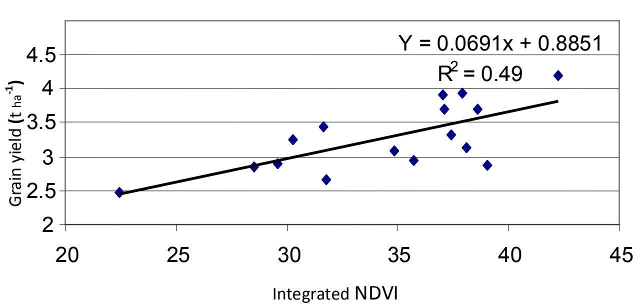

Fig. 5: Relationship between integrated NDVI and grain yield

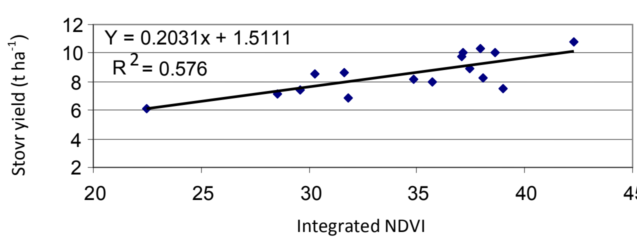

Fig.6: Relationship between integrated NDVI and stover yield

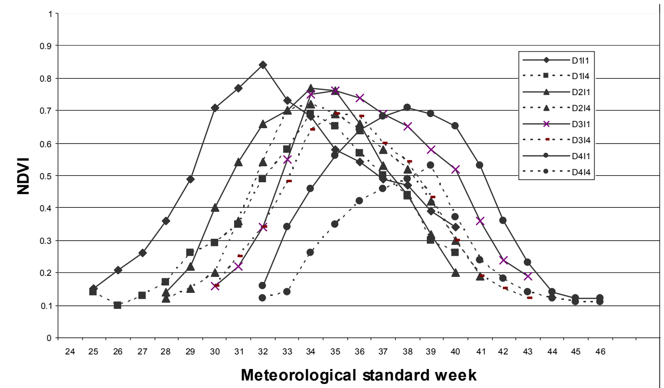

Fig.2: Temporal variation of NDVI for fully irrigated and rainfed maize

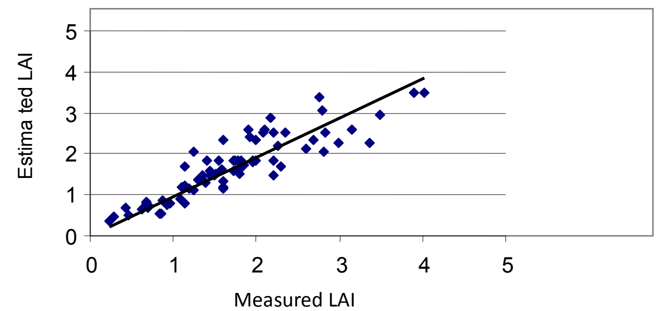

Fig.4: Comparison of measured LAI and estimated LAI from spectral reflectance data (NDVI)

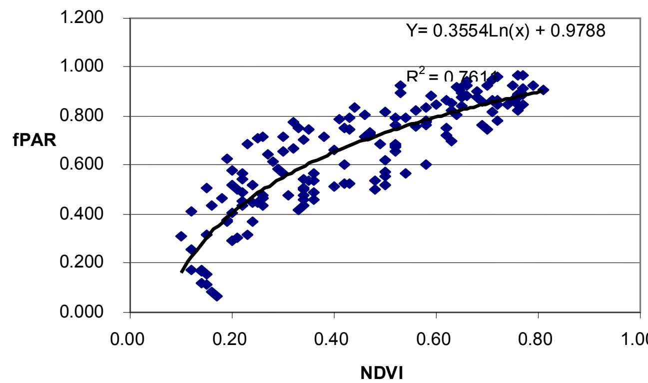

Fig.7: fPAR as a function of NDVI in maize for pre-$NDVI_{max}$ period.

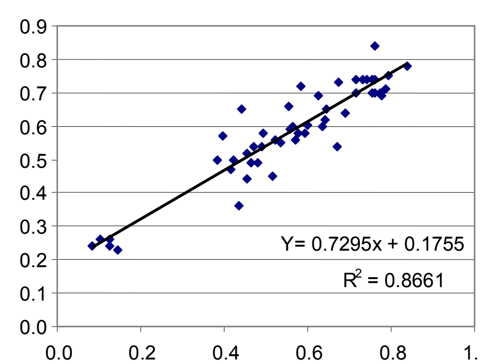

Fig.8: Absorbed PAR as a function of NDVI in maize for Post-$NDVI_{max}$ period.

During 2004-05, the treatment wherein the stress was induced at reproductive stage gave more or less similar yield (2.90) as that of rainfed crop (2.82), indicating thereby the high sensitivity of crop to water stress during reproductive phase (Table 2). The highest yield was obtained in fully irrigated treatment with first date of sowing D_1I_1 with 4.19 t ha^{-1} and the lowest being in D_4I_4 with 2.46 t ha^{-1} grain yield.

NDVI and LAI

The relationship between NDVI and LAI for pooled data over two years is presented in Fig.3. Prediction equations were developed between the spectral indices and measured LAI. The overall best fit was exponential with a coefficient of determination (R^2=0.85). An exponential relationship between LAI and NDVI was observed for soybean, beans, peas, corn and wheat (Haboudane *et al.*, 2004). The prediction equation using NDVI to predict LAI is as follows. F-test was carried out and was found to be significant at 1% level.

$Y = 0.2092e^{3.3554x}$ (RMSE = 0.2210)

Where,

Y = Leaf area index

X = Normalized Difference Vegetation Index (NDVI)

Estimated and predicted LAI values indicated that there was a good agreement between the predicted and observed data (Fig.4). Eldaw Elwadie *et al.*, 2005 modeled LAI as a function of three vegetation indices *viz,* NDVI, SAVI and GNDVI in maize and concluded that the predicted LAI from NDVI is the best among all (with lowest RMSE) but deviated from 1:1 line when LAI exceeds 2.3. In the present study also the predicted LAI deviated from 1:1 line when LAI exceeds 2.9.

NDVI and grain yield

The integrated NDVI of different treatments was computed and correlated with the grain yield (Fig.5) and biomass (Fig.6). This clearly indicates that the grain yield can be estimated using satellite image derived NDVI in large areas. Similar observation was made by Wiegand and Richardson, 1990 with respect to SVI. The prediction equation developed between NDVI and grain yield is as follows.

Y=0.06911X+0.8851 (RMSE=0.369)

Where,

Y=Grain yield (t ha^{-1})
X= Integrated NDVI

The prediction equation developed for stover yield is as follows

Y = 0.20311X + 1.51 (RMSE=0.912)

Where,

Y = Stover yield (t ha^{-1})

X = Integrated NDVI

NDVI and fPAR

fPAR is the percentage of energy available for photosynthesis and NDVI is a measure of photosynthetic size of canopy. Weigand *et al*. (1991) reported that S NDVI is related functionally to provide good estimate of yield. fPAR computed in the study as a function of NDVI are presented in Fig.7. The results of present study showed that fPAR can be estimated well from vegetation index. The fPAR increased with NDVI as logarithmic function with a RMSE value of 0.107 and there was significant positive correlation between these two parameters was observed (r=0.92). The functional relationship between two parameters is not unique. The relationship was logarithmic till NDVI reaches maximum value and linear relationship was observed during post NDVI max period (Fig.8).

Y=0.3554 ln (x)+0.9788 (RMSE=0.107)

Y=Grain yield (t ha^{-1})

X=fPAR

Thus remotely sensed vegetation index like NDVI can be used for retrieval of LAI , fPAR and grain yield of maize. These findings are significant for yield modeling studies, especially for FASAL (Forecasting Agricultural output using Space, Agromet and Land based Observations) programme where the production forecast is given through the integration of remote sensing data with biophysical parameters and meteorological inputs.

CONCLUSIONS

The biophysical parameters, namely leaf area index, stover and grain yield can be estimated from ground-based spectral reflectence measurements and index like NDVI. The study also indicated the feasibility of retrieving PAR from NDVI values. The relationship was found to be logarithmic during the pre-NDVImax stage and linear during post-NDVImax period. Strengthening of research on the use of

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REFERENCES

Chen, J. and Cihlar, J. (1996). Retrieving leaf area index of boreal conifer forest using Landsat Thematic Mapper. *Remote Sen. Environ.,* 55: 153-162.

Eldaw Elwadie, M., Pierce, F. J. and Qi, J. (2005). Remote Sensing canopy dynamics and biophysical variables estimation of corn in Michigan. *Agron. J.,* 97: 99-105.

Gallo, K. P., Daughty, C. S. T. and Bauer, M. E. (1985). Spectral estimation of absorbed photosynthetically active radiation in corn canopies, *Remote Sense.Environ.,* 17: 221-232.

Haboudane, D., Miller, J. R., Pattey, E., Zarco-Tejada, P. J. and. Strachen, I. (2004). Hyper spectral vegetation indices and novel algorithms for predicting green leaf area of canopies: Modelling and validation in the context of precision agriculture. *Remote Sens. Environ.*, 90: 337-352.

Haboudane, D., Miller, J. R., Tremblay, N. and Pattey, E. (2004). Estimation of Leaf Area Index using Ground spectral measurements over Agriculture crops: Prediction capability assessment of optical indices. *Can. J. Remote Sens.,* 23: 143-162.

Rouse, J. W., Haas, R. H., Schell, J. A., Deering, D. W. and Harlan, J. C. (1974). Monitoring the vernal advancements and retrogradation of natural vegetation. NASA/GSFC, Final Report, Greenbelt, MD, USA, pp. 1-137.

Wiegand, C. L. and Richardson, A. J. (1990). Use of spectral vegetation indices to infer leaf area, evapotranspiration and yield:1 Rationale. *Agron. J.,* 82: 623-629.

Wiegand, C. L., Richardson, A.J., Escobar, D. E. and Gerbermann, A. H. (1990). Use of spectral vegetation indices in crop assessment. *Remote Sens. Environ.,* 35:105-119.