MAUSAM, **54**, 3 (July 2003), 705-710

551.586 : 633.2

Reflectance characteristics of irrigated and water-stressed wheat and estimation of leaf area index using different spectral vegetation indices

R. P. SAMUI, P. T. KULKARNI, P. S. NARAYANAN

and

S. R. AGALE

India Meteorological Department, Pune 411005, India

(*Received 14 February 2001, Modified 4 February 2002*)

सार – वर्ष 1997–98 के दौरान सी.ए.जी.एम.ओ., पुणे में सिंचित और जल प्रतिबलित गेहूँ पर परीक्षण किया गया। फसल उगने की अवधि के दौरान प्रत्येक बृहस्पतिवार को पूरे दिन ग्राउंड टूथ रेडियो मीटर (जी.टी.आर.) घंटेवार प्रेक्षण अभिलेखित किए गए। इस शोध पत्र में दृश्य और समीपवर्ती अवरक्त स्पैकट्रल क्षेत्र (एन.आई.आर.) में इस फसल पर किए जाने वाले क्षेत्रीय मापों के उपयोग पर विचार विमर्श किया गया है। इसमें फसल बढ़ोतरी चक्र (सी.जी.सी.) के विभिन्न घटना विज्ञानी अवस्थाओं के प्रकार्य के रूप में अनुपात वनस्पति तालिका (आर.वी.आई.) और प्रसामान्यीकृत अंतर वनस्पति तालिका (एन.डी.वी.आई.) की सापेक्षिक संवेदनशीलता पर विश्लेषणात्मक रूप से विचार–विमर्श किया गया। इसमें भारित अंतर वानस्पतिक तालिका (डब्ल्यू.डी.वी.आई.) की संकल्पना, वनस्पति में जल प्रतिबल को निर्धारित करने में एन.आई.आर परावर्तकता की सापेक्षिक सुविधाओं, पर्ण विस्तार तालिका (एल.ए.आई.) और वानस्पतिक सूचकों की परिसीमाओं पर विचार–विमर्श किया गया है। इस शोध–पत्र में स्पैक्ट्रल वनस्पति का उपयोग करते हुए एल.ए.आई. के आकलन की प्रक्रिया पर किए गए विवेचन को प्रस्तुत किया गया है।

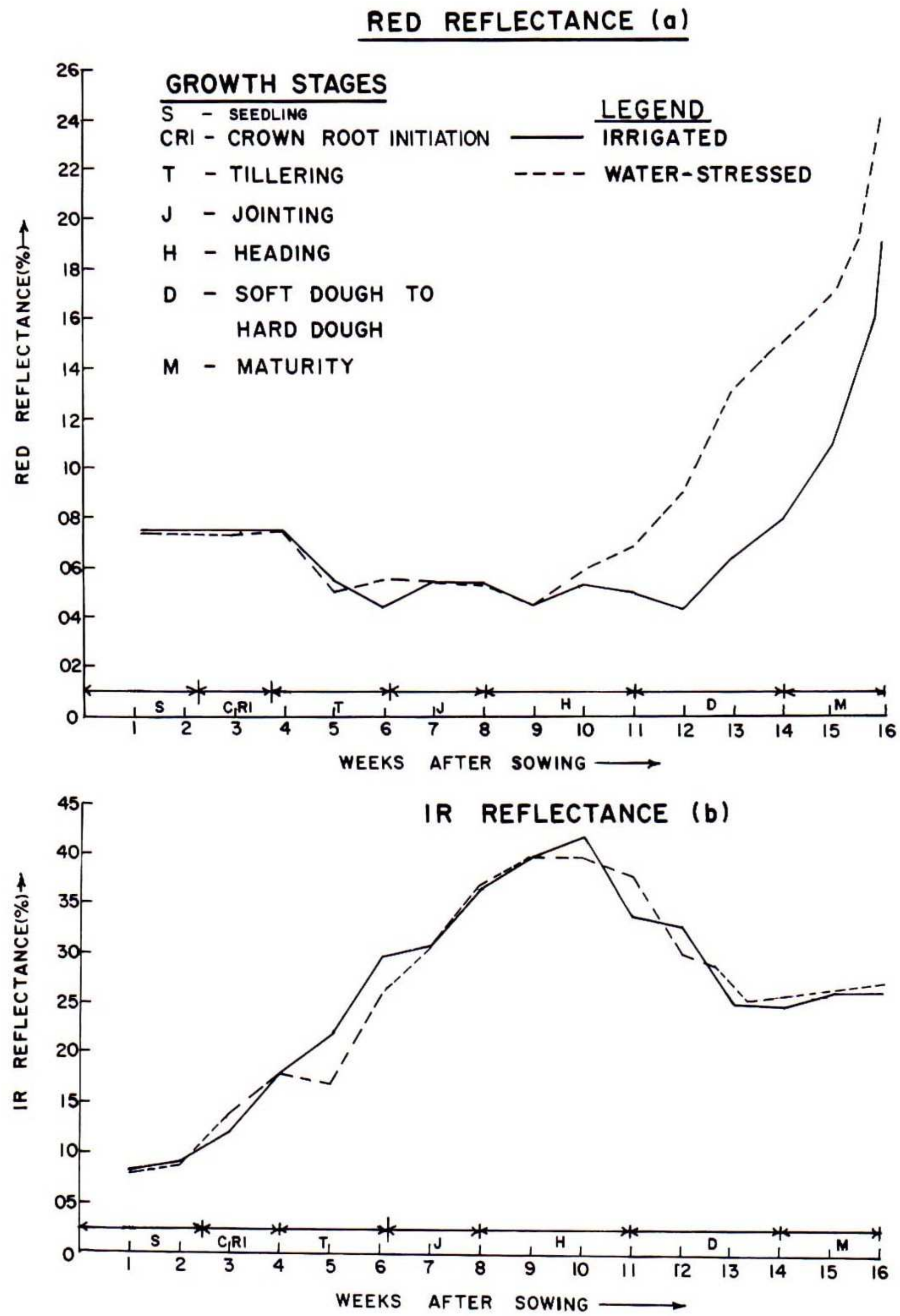
ABSTRACT. An experiment was conducted on irrigated and water-stressed wheat at CAgMO, Pune during 1997-98. An hourly observation with Ground Truth Radiometer (GTR) through out the day was recorded every Thursday during the crop growing period. The paper discusses the use of field measurements on crop in visible and near infrared (NIR) spectral regions. The relative sensitivity of Ratio Vegetation Index (RVI) and Normalized Difference Vegetation Index (NDVI) as a function of different phenological stages of crop growth cycle (CGC) has been discussed analytically. The concept of Weighted Difference Vegetation Index (WDVI), relative advantages of NIR reflectance in assessing water-stress in vegetation, Leaf Area Index (LAI) and limitations of vegetation indices in accounting the vegetative processes have been discussed. The paper presents a discussion on the procedure for estimating LAI using these spectral vegetation indices.

Key words – Reflectance, Water-stress, Vegetation index.

1. Introduction

Leaf area estimates are required for various purposes, *viz*, water-stress monitoring, irrigation scheduling and crop yield modelling. However, the measurement of leaf area index (LAI) is difficult and time consuming due to spatial sampling problems.

The development of remote sensing satellites carrying earth observational sensors has made available enormous quantities of data containing information about the conditions of the earth's surface features. Thus remote sensing technique can be utilized not only for decision making but also for crop stress monitoring, estimation of LAI and yield forecasting. Daughtry *et al.* (1983) proposed how conceptually these remotely sensed data could be used to obtain estimates of intercepted radiation by plant canopies. Fuchs *et al.* (1984) successfully used measurements of transmission of photosynthetically active radiation (PAR) to indirectly evaluate LAI in wheat canopies. Bunnik (1978) and Hatfield (1983b) suggested that the leaf area can be estimated by a ratio of near infrared to red reflectance. Clevers (1989) developed a simplified and semi-empirical reflectance model for estimating LAI of a given canopy using weighted difference vegetation index (WDVI). In all such experiments crops were grown under well watered conditions without imposing water stress during the crop growth cycle. Attempt has been made in this paper to study the reflectance characteristics of solar irradiance and to develop model for estimation of LAI based on different spectral vegetation indices.

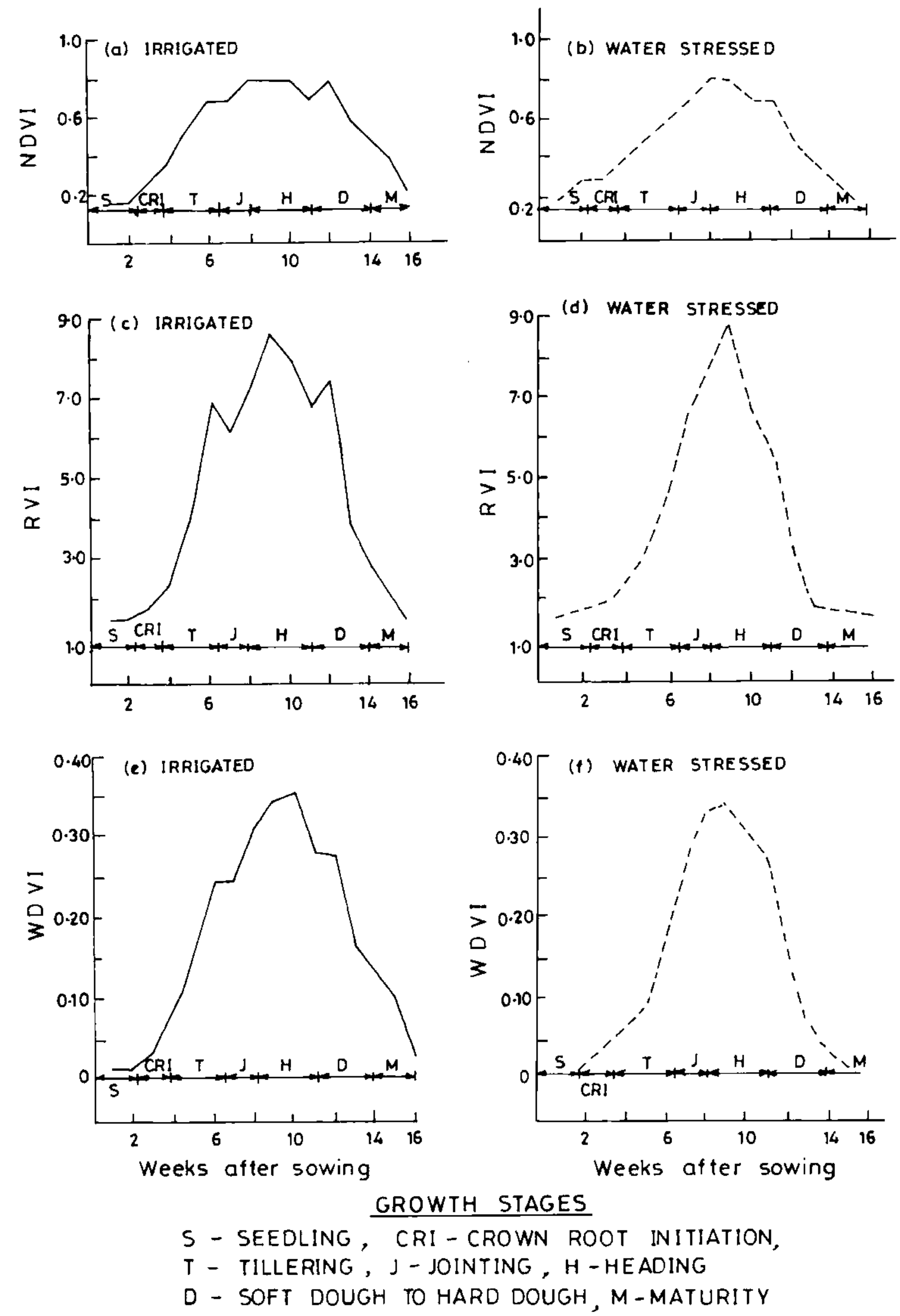


Figs. 1(a&b). (a) Red and (b) NIR reflectance of irrigated and water-stressed wheat

2. Material and methods

The experiment was carried out on fully irrigated and water-stressed wheat using a hand-held multiband Ground Truth Radiometer (GTR) in the experimental plots at the College of Agriculture, Pune, during November, 1997 to March, 1998. The hourly observations were recorded between 0730 and 1730 hr once in a week every Thursday (if it happens to be cloud free) through out the growing season of the crop.

For minimizing the error caused by positioning the radiometer the first observation and the last observation was taken over a calibrated plate coated with Barium Sulphate. The readings taken over canopy were divided by the average plate readings to obtain crop



Figs. 2(a-f). RVI, WDVI and NDVI characteristics of irrigated and water-stressed wheat

reflectance in different bands. The reflectance data under different conditions of bare soil, *viz,* wet and dry soil were also obtained on the same day and almost at the same time.

The Ratio Vegetation Index , RVI = (NIR / R), Normalized Difference Vegetation Index, NDVI = (NIR-R) / (NIR+R), Weighted Difference Vegetation Index, WDVI = NIR–CR,

Where C = (Rs,ir / Rs,r)

where NIR : Near infrared reflectance of wheat canopy

R : Red reflectance of wheat canopy

Rs,ir : Near infrared reflectance of bare soil

Rs,r : Red reflectance of bare soil,

are calculated for each observation and plotted against weeks after sowing for 1230 hours as representative value both for irrigated and water-stressed wheat.

3. Description of the instrument

GTR is a hand-held multiband Ground Truth Radiometer used to measure the radiance by holding it at nearly 1m height above the crop canopy. GTR is having 8 spectral bands out of which first four bands are identical to the four bands of LANDSAT and next four bands are identical to IRS satellites.

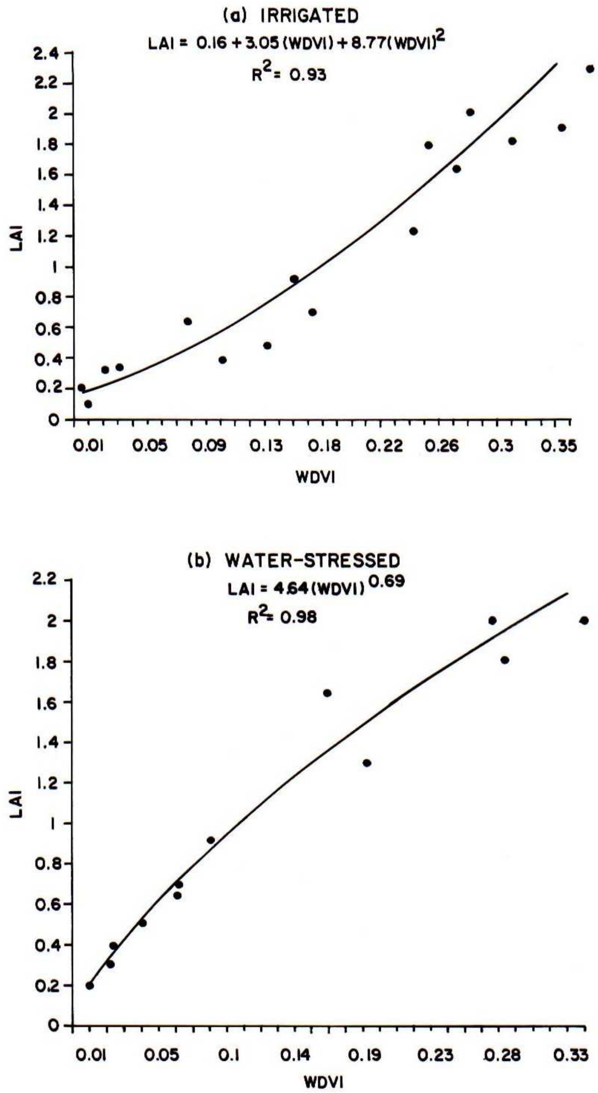
Specifications of GTR is as follows:

Field of view	15° ± 2°;
Output	On 3½ digit digital panel meter;
Band Selection	By rotating the filter wheel;
Dynamic range	0.1×10^{-6} to 30×10^{-3} watts/cm^2-Sr–μ;
Absolute accuracy	± 5%.

4. Results and discussion

The vegetation or biomass indices basically utilize the differential aspects of vegetation reflectance in Red (or visible) and near infrared (Deekshatulu and Gupta, 1994).

Initially when the water-stress was not imposed the trend of the red reflectance for both irrigated and water-stressed wheat was more or less same [Fig. 1(a)]. With the advancement of crop growth stages red reflectance remained steady upto crown root initiation (CRI) stage. Then it decreased slowly and dropped continuously upto tillering stage. Red reflectance remained more or less constant upto heading stage under water-stressed condition. After heading stage, it rapidly increased till maturity stage whereas under irrigated condition after tillering stage reflectance remained more or less steady till middle of dough stage, then it rapidly increased upto maturity stage.



Figs. 3(a&b). Relationship between LAI and WDVI under irrigated and water-stressed wheat

Under water-stressed condition absorption was more at heading stage whereas under irrigated condition absorption of red radiation was more between heading to soft dough stage. In NIR region at every stage under irrigated and water-stressed conditions the NIR reflectance have well separable patterns [Fig 1(b)]. Initially reflectance increased gradually under both conditions till CRI stage then it increased continuously upto middle of heading stage. It started decreasing slowly from middle of heading stage and continued upto hard dough stage. At maturity stage, both under water-stressed and well-watered conditions, it decreased or remained steady. Under water-stressed condition reflectance had a peak in the beginning of heading stage and under irrigated condition peak was observed at heading stage.

TABLE 1

Regression equations for LAI with different spectral vegetation indices under irrigated and water-stressed wheat

S. No.	Vegetation index		Equation	R	% Variation accounted for	Level of significance (%)
1	RVI	Irrigated	LAI = 0.22+0.27 (RVI)	0.95	91.17	1
		Water-stressed	LAI = –0.82+0.74(RVI) –0.049(RVI)^2	0.95	90.40	1
2	NDVI	Irrigated	LAI = 0.9l–4.44(NDVI)+7.38(NDVI)^2	0.95	90.77	1
		Water-stressed	LAI = –0.57 + 3.31 (NDVI)	0.94	89.48	1
3	WDVI	Irrigated	LAI = 0.16+3.05(WDVI)+8.77(WDVI)^2	0.96	93.75	1
		Water-stressed	LAI = 4.64 (WDVI)$^{0.69}$	0.99	98.00	1

Figs. 2 (a-f) present the RVI, NDVI and WDVI characteristics as a function of week after sowing (WAS) for irrigated and water-stressed wheat. Though the trend of NDVI both for irrigated and water-stressed wheat was same [Figs. 2(a&b)], yet it showed more fluctuations under irrigated condition compared to that of water-stressed. Under both conditions peaks were observed at heading stage then it decreased gradually under irrigated wheat compared to that of water-stressed. The fall was rapid after 11 weeks under water-stressed condition. The peak indicated the time when the green vegetation cover was maximum.

The trends of the graphs of RVI and WDVI were similar to that of NDVI both for water-stressed and irrigated wheat [Figs. 2 (c-f)]. RVI and WDVI increased continuously upto heading stage with a little drop at jointing stage under irrigated condition. The peak was observed at heading stage indicating full green vegetation cover when water supply was non-limiting. Thereafter, it started decreasing rapidly upto maturity with a little increase at middle of soft dough stage under irrigated condition. RVI also fluctuated more compared to that of NDVI and WDVI under irrigated condition. Under water-stressed condition, the peak was observed at heading stage. The steep fall of RVI, NDVI and WDVI values especially under water-stressed condition during 11-16 WAS may be due to decrease in the chlorophyll content and collapse of spongy mesophyll cells in the leaves during maturity stage.

The variation of NDVI and RVI were similar in nature under irrigated and water-stressed conditions. The RVI was more sensitive than NDVI during early vegetative and senescence stages of crop growth cycle. In general, RVI provided higher discriminability due to better sensitivity than NDVI. Gupta *et al.* (1993) have observed similar variation on RVI. RVI also showed much larger slope than NDVI, RVI and WDVI range from 2.0 to 9.0 and 0.01 to 0.35 both under irrigated and water-stressed conditions. Nature of graphs [Figs. 2 (a&b)] in both the cases was similar to the graphs of RVI having peak value at about 9 to 10 weeks after sowing at full green vegetation cover. For both the cases, values increased continuously and reached maximum between heading to soft dough stages, then it started decreasing continuously upto maturity stage.

At early stage of the crop, effect of green canopy in IR reflectance is negligible, as a result weighted difference vegetation index (WDVI) is almost zero. As green cover increases the effect of soil reflectance decreases and WDVI increases with increased IR reflectance from green canopy.

The relationship of LAI with RVI, NDVI and WDVI were worked out both for irrigated and water-stressed conditions for wheat. The best fit equations having the highest correlation coefficient significant at 1% level between LAI and RVI, NDVI and WDVI are presented in Table 1. The best fit equation of LAI with WDVI was found to be parabolic in nature and explained 93.8% variation whereas the relationship between LAI and WDVI under water-stressed wheat was found to be power regression and explained 98% variation.

As all these equations account for about 89 to 98% variation in LAI both under irrigated and water-stressed conditions, LAI can be estimated using these relations. WDVI was found to be the better predictor of LAI than NDVI and RVI. [Figs. 3(a&b)].

Bunnik (1978) reported that the leaf area can be estimated by a ratio of NIR to Red reflectance also. Hatfield *et al.* (1983b) and Asrar *et al.* (1984) comparing several spectral reflectance transformations confirmed that LAI of wheat could be estimated best from ratio of NIR to Red reflectance.

5. Conclusions

(*i*) The results of this experiment show that there exist a good relationship between spectral reflectance and growth stages of crop. The reflectance in red and near infrared bands have been found very suitable for the study of crop growth patterns.

(*ii*) RVI provided higher discriminability due to better sensitivity.

(*iii*) LAI can be estimated with reasonable accuracy both for irrigated and water-stressed wheat using relationships between LAI *vs* RVI, NDVI and WDVI.

Acknowledgements

The authors wish to express their sincere thanks to Deputy Director General of Meteorology (Agricultural Meteorology), Pune, for providing all the necessary facilities in carrying out this study. They also wish to thank Mr. Phillipose and Mr. P. S. Chougule, for their secretarial assistance.

References

Asrar, G., Fuchs, M., Kanemasu, E. T. and Hatfield, J. L., 1984, "Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat", *Agron. J*., **76**, 300-306.

Bunnik, N. J. J., 1978, "The multispectral reflectance of shortwave radiation by agricultural crops in relation with their morphological and optical properties", H. Veenman and Foncee, B. V. Wageningen, p176.

Clevers, J. G. P. W., 1989, "*Remote Sensing Environ*", **29**, p25.

Daughtry, C. S. T., Gallo, K. P. and Bauer, M. E., 1983, "Spectral estimates of solar radiation intercepted by corn canopies", *Agron. J*., **75**, 527-531.

Deekshatulu, B. K. and Gupta, R. K., 1994, "Remote sensing and vegetation", Proc. Indian Natn. Sci. Acad., **60**A, 1, 299-333.

Fuchs, M., Asrar, G., Kanemasu, E. T. and Hipps, L. E., 1984, "Leaf area estimation from measurements of photosynthetically active radiation in wheat canopies", *Agric. Meteorol*., **32**(i), 13-22.

Gupta, R. K., Rao, G. H., Nadham, T. S. V., Prasad, S., Vijayan, D. and Sharma, Rajesh, 1993, "Reflectance characteristics of major kharif crops of Madhya Pradesh and soil canopy temperature characteristics of soyabean", *I.J. of Radio and Space Physics*, **22**, 362-368.

Hatfield, J. L., Kanemasu, E. T., Asrar, G., Jackson, R. D., Pinter, P.J. (Jr.), Reginato, R. J. and Idso, S.B., 1983b, "Leaf area estimates from spectral measurements over various planting dates of wheat", *Int. J. Remote Sens*., **6** : 167.