MAUSAM, **54**, 4 (October 2003), 901-908

551.584.42 : 633.15

Reflectance characteristics of maize and application of vegetation indices for estimation of leaf area index

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(*Received 3 September 2001, Modified 13 May 2003*)

सार – इस शोध–पत्र में वर्ष 1999 के खरीफ–पूर्व मौसम के दौरान महात्मा फुले कृषि विद्यापीठ के अधीन कृषि विश्वविद्यालय, पुणे के प्रयोगात्मक फार्म में ग्राउंड टूथ रेडियोमीटर सहित सिंचित और आंशिक रूप से सिंचित अवस्थाओं में फॉडर फसल के रूप में उगाई जाने वाली, मकई पर परीक्षण किए गए। फसल उगने के मौसम के दौरान साफ आकाश वाले दिनों में 1000 और 1100 बजे (भा.मा.स.) के मध्य साप्ताहिक अंतरालों पर प्रेक्षण लिए गए। स्पेक्ट्रल विकिरण अभिलक्षणों और फसलवृद्धि क्षांकों जैसे सामान्यकृत अंतर फसलवृद्धि सूची (एन.डी.वी.आई.), अनुपात फसलवृद्धि सूची (आर.वी.आई.), भारित अंतर फसलवृद्धि सूची (डब्ल्यू.डी.वी.आई.), लम्बवत फसल वृद्धि सूची (पी.वी.आई.) और पर्ण क्षेत्र सूची (एल.ए.आई.) के साथ उनके संबंध का अध्ययन किया गया है। इस शोध पत्र में फसल की ऋतुजैविकी अवस्थाओं के संबंध में विकिरण के स्पेक्ट्रल भिन्नताओं और फसल–वृद्धि अक्षांकों की संवेधता पर विचार विमर्श किया गया । फसल वाले खेतों से लाल और अवरक्त बैंडों के निकट लिए गए स्पेक्ट्रल परावर्तकता प्रेक्षणों को रिकार्ड किया गया है। फसल वृद्धि के अक्षांक फसल वृद्धि के अध्ययनों के अनुकूल पाए गए हैं। इस शोध पत्र में विभिन्न फसल वृद्धि अक्षांकों का उपयोग करते हुए एल.ए.आई. के आकलन की पद्धति पर भी विचार विमर्श किया गया है। यह देखा गया है कि फसल वृद्धि की प्रारम्भिक अवस्था के दौरान आर.वी.आई., एल.ए.आई. के बेहतर पूर्व सूचक पाए गए हैं जबकि अन्य फसल–वृद्धि अक्षांकों की तुलना में फसल वृद्धि के अंतिम चरण में एन.डी.वी.आई. बेहतर पूर्वसूचक पाए गए हैं।

ABSTRACT. An experiment was conducted on maize (*Zea mays* L), grown as a fodder crop, under irrigated and partially irrigated conditions with Ground Truth Radiometer at the experimental farm of the College of Agriculture, Pune under Mahatma Phule Krishi Vidyapith, Rahuri during pre-kharif season of 1999. Observations were taken at weekly intervals between 1000 and 1100 hrs. (IST) on cloud free days during the crop growing season. The spectral radiance characteristics and vegetation indices like Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI), Weighted Difference Vegetation Index (WDVI), Perpendicular Vegetation Index (PVI) and their relationship with Leaf Area Index (LAI) have been studied. The paper discusses the significance of spectral variation of radiance and sensitivity of vegetation indices with respect to phenological stages of the crop. The spectral reflectance observations in red and near infrared bands were recorded from the crop field. Vegetation indices were found suitable for crop growth studies. The procedure for estimating LAI using different vegetation indices is also discussed in the paper. It has been found that RVI is a better predictor of LAI during the early stage of growth while NDVI is a better predictor during the later part of growth as compared to other vegetation indices.

Key words – Maize, Reflectance, Vegetation index, Leaf Area Index (LAI).

1. Introduction

The interaction of light with soil and plants is a means for remote sensing signals from cropped areas. Gausman *et al.* (1969) demonstrated that optical reflectance of crops is determined by the interaction of solar radiation with crop canopy. The amount and characteristics of reflectance from leaf surfaces are affected by the structure of plant leaves. As light passes through interfaces between materials of different refractive indices within a leaf, the amount of light reflected in any given direction changes. The amount of this change is wavelength dependent.

From the late sixties, the interaction processes between solar radiation and crop canopy have been extensively studied and it has been shown that canopy reflectance is highly related to crop growth variables such as Leaf Area Index (LAI) as a fraction of ground cover (Suits 1972; Bunnik 1978). LAI is a very useful estimate for various purposes, *viz*. water stress monitoring, crop condition monitoring and crop yield modelling. Price and

Bausch (1995) computed LAI from visible and near infrared reflectance. Bunnik (1978) and Hatfield *et al*. (1983) also suggested that the leaf area could be estimated by a ratio of near infrared to red reflectance. Clevers (1988) estimated LAI as an exponential function of Weighted Difference Vegetation Index (WDVI). Gruszczynska *et al*. (1998) found a good relationship of LAI with Normalized Difference Vegetation Index (NDVI) and Water Deficit Index (WDI), and derived an equation for the estimation of LAI using these two indices.

Keeping these in view, an attempt was made to study the variations of spectral characteristics and some vegetation indices at different growth stages of maize (*Zea mays* L) under irrigated and partially irrigated conditions in order to develop a model for estimation of LAI. This research, it is hoped, will give guidelines for exploring the possibility of using satellite data for the identification of growth stages of maize crop under two contrasting soil moisture conditions.

2. Materials and methods

Maize (*Zea mays* L. cv. African Tall) was grown as a fodder crop under fully irrigated and partially irrigated conditions from January to April, 1999 at the experimental farm of the College of Agriculture, Pune, Maharashtra (Lat : 18° 32′N; Long : 73° 51′E; ele : 559 m (amsl)) .

During the growth period of the crop, spectral reflectance in the visible and near infrared regions was observed with a hand held multiband Ground Truth Radiometer (GTR) having a field of view of 15° $\pm$ 2°. The crop was harvested just after it reached the tasseling stage.

2.1. *Description of instrument*

Eight spectral bands are available in multiband GTR of which first four bands are identical to four bands of LANDSAT and next four bands are identical to IRS satellites. The specifications of the wavelength bands of the instrument supplied by the manufacturer* are given in the Table 1.

2.2. *Method of observations*

The observations were taken from a height of 1m above the crop canopy at weekly intervals on cloud free days between 1000 and 1100 hrs (IST)[†] Before taking the observation, the initial measurements consisted of one dark level (background reading allowing no light to enter the lens) zero setting of the reading and one reading over a calibration plate painted with barium sulphate.

[†] IST : (Indian standard time = GMT + 5 hr 30 m)

TABLE 1

Filter details of multiband Ground Truth Radiometer

Band No.	Central wavelength of filter (µm)	Band-width of filter (µm)
1.	0.4830	0.0654
2.	0.5442	0.0854
3.	0.6555	0.0610
4.	0.8189	0.1484
5.	0.4798	0.0757
6.	0.5408	0.0816
7.	0.6557	0.0625
8.	0.8122	0.0871

**Source* : Optomech Engineering Pvt. Ltd., Hyderabad.

Observations were taken in each crop field in all eight bands. Reflectance data in different conditions of bare soil were also obtained simultaneously. The second observation over calibration plate was taken after observations from the cropped field. For determining the reflectance factors, crop radiance was divided by the average of calibration plate readings.

2.3. *Applied vegetation indices*

Canopy reflectance has been shown to be related to crop growth variables such as LAI and fraction of ground cover (Suits 1972; Bunnik 1978). For accurate estimation of these variables, vegetation indices, *viz*. NDVI and Ratio Vegetation Index (RVI), which are a combination of reflectance values in visible and near infrared bands, have been calculated as :

$$NDVI = (IR - R) / (IR + R)$$

$$RVI = IR / R$$

Where, IR and R are the reflectance in the infrared and red band from crop canopy.

The soil background reflectance, was corrected as per the definition given by Clevers (1988) for WDVI, where

$$WDVI = IR - (IR_S / R_S)R$$

Where, IR_S and R_S are the infrared and red reflectance of the bare soil, respectively.

Perpendicular Vegetation Index (PVI), formulation of Richardson and Wiegand, 1977, was computed from the equation :

$$PVI = [(R_S - R)^2 + (IR_S - IR)^2]^{1/2}$$

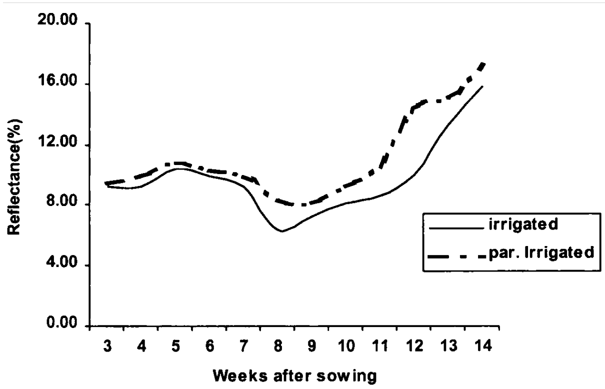


Fig. 1. Reflectance in red wavelength band during crop growth of irrigated and partially irrigated maize

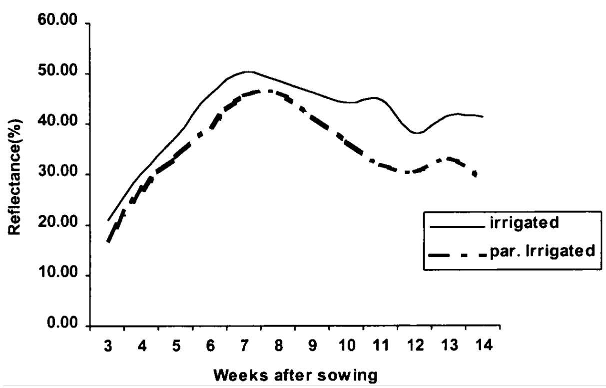


Fig. 2. Reflectance in near infrared wavelength band during crop growth of irrigated and partially irrigated maize

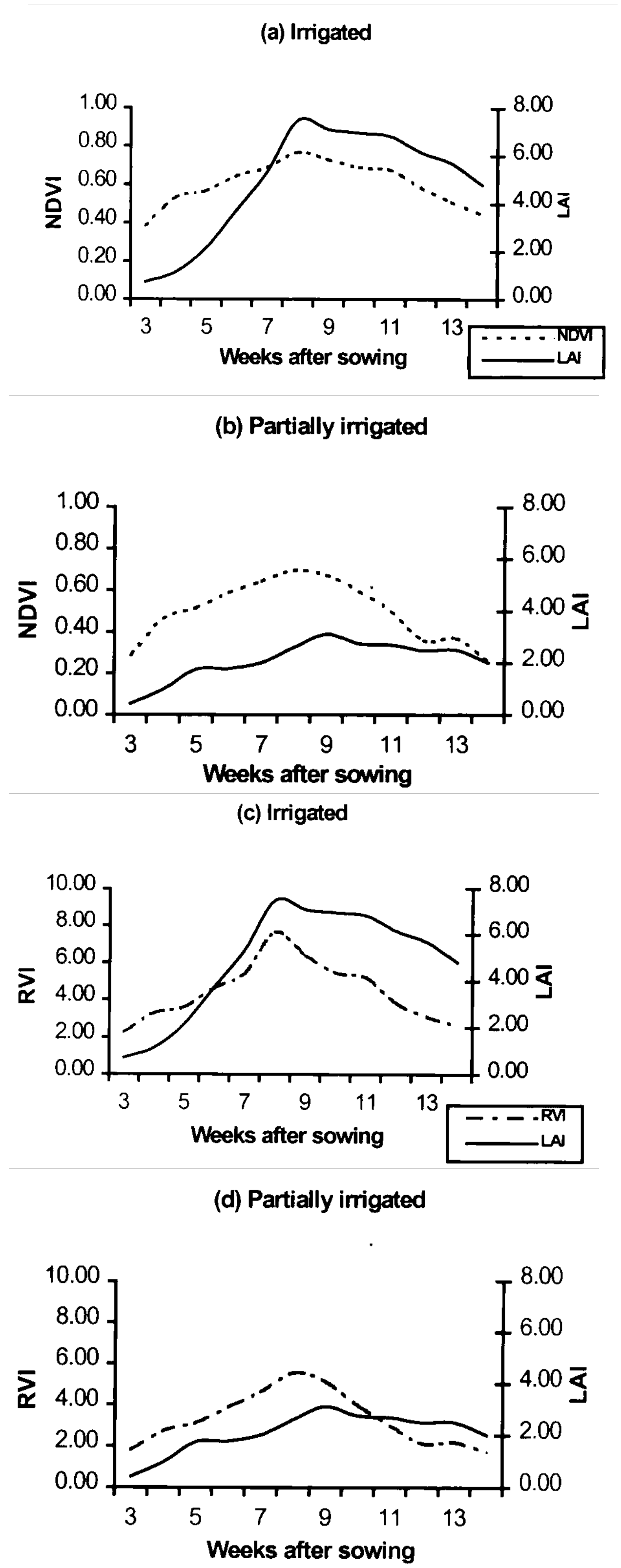
All these vegetation indices were calculated, plotted against time after sowing and used for the estimation of LAI of both the irrigated and partially irrigated crops.

3. Results and discussion

The spectral reflectance characteristics and vegetation indices of maize during increasing and decreasing phases of LAI both under irrigated and partially irrigated conditions are presented in Figs. 1 to 4 and discussed below.

3.1. *Spectral reflectance at different growth stages*

During early vegetative stage, red reflectance for both irrigated and partially irrigated maize was more or less steady. Red reflectance dropped gradually during active vegetative stage because of the attainment of maximum LAI. Thereafter, up to tasseling stage, red reflectance showed an increasing trend due to a



Figs. 3(a-d). NDVI and RVI of irrigated and partially irrigated maize

TABLE 2

Regression equations for LAI with different Vegetation Indices of irrigated and partially irrigated maize

S. No.	Vegetation Index		Equation		Correlation coefficient	Variation accounted (%)	Level of significance
1.	NDVI	Irrigated	Increasing phase of LAI	LAI = –7.48 + 18.26 NDVI	0.93	86	1
			Decreasing phase of LAI	LAI = 1.49 + 7.85 NDVI	0.99	98	1
		Partially irrigated	Increasing phase of LAI	LAI = –1.49 + 5.98 NDVI	0.93	86	1
			Decreasing phase of LAI	LAI = 1.60 + 2.19 NDVI	0.95	90	1
2.	RVI	Irrigated	Increasing phase of LAI	LAI = –2.68 + 1.37 RVI	0.99	98	1
			Decreasing phase of LAI	LAI = 4.03 + 0.49 RVI	0.95	90	1
		Partially irrigated	Increasing phase of LAI	LAI = –0.64 + 0.64 RVI	0.94	88	1
			Decreasing phase of LAI	LAI = 1.83 + 0.26 RVI	0.91	83	1
3.	WDVI	Irrigated	Increasing phase of LAI	LAI = –2.00 + 0.20 WDVI	0.93	86	1
			Decreasing phase of LAI	LAI = 2.66 + 0.12 WDVI	0.95	90	1
		Partially irrigated	Increasing phase of LAI	LAI = 0.04 + 0.08 WDVI	0.91	83	1
			Decreasing phase of LAI	LAI = 1.95 + 0.04 WDVI	0.93	86	1
4.	PVI	Irrigated	Increasing phase of LAI	LAI = –1.56 + 0.21 PVI	0.85	72	1
			Decreasing phase of LAI	LAI = 0.36 + 0.22 PVI	0.72	52	5
		Partially irrigated	Increasing phase of LAI	LAI = 0.12 + 0.08 PVI	0.87	76	1
			Decreasing phase of LAI	LAI = 1.19 + 0.08 PVI	0.86	74	1

continuous reduction of LAI. Throughout the crop growing season, because of its relatively lower LAI, partially irrigated crop showed higher reflectance in red band as compared to the irrigated crop. The difference was well marked as the growing season advanced. Maximum difference was observed at 12 weeks after sowing (Fig. 1).

Reflectance in NIR band increased continuously upto active vegetative stage with a rapid increase of LAI both of irrigated and partially irrigated crops. After the grand growth stage, the reflectance slowly dropped upto the tasseling stage of the crop. Rate of decrease of NIR reflectance during the later part of the growth phase was more rapid in partially irrigated crop as compared to the irrigated crop. Reflectance in NIR band was more at all the growth stages in the irrigated crop compared to that of the partially irrigated crop. The difference between the irrigated and the partially irrigated crops was prominent during later part of growth phase *i.e.* from active vegetative to tasseling stage. The canopy reflectance difference was maximum at 11 weeks after sowing (Fig. 2). This was due to a higher LAI recorded in the irrigated plot. Deekshatulu and Gupta (1994) also reported that NIR reflectance increased and red reflectance decreased in general for all healthy crops.

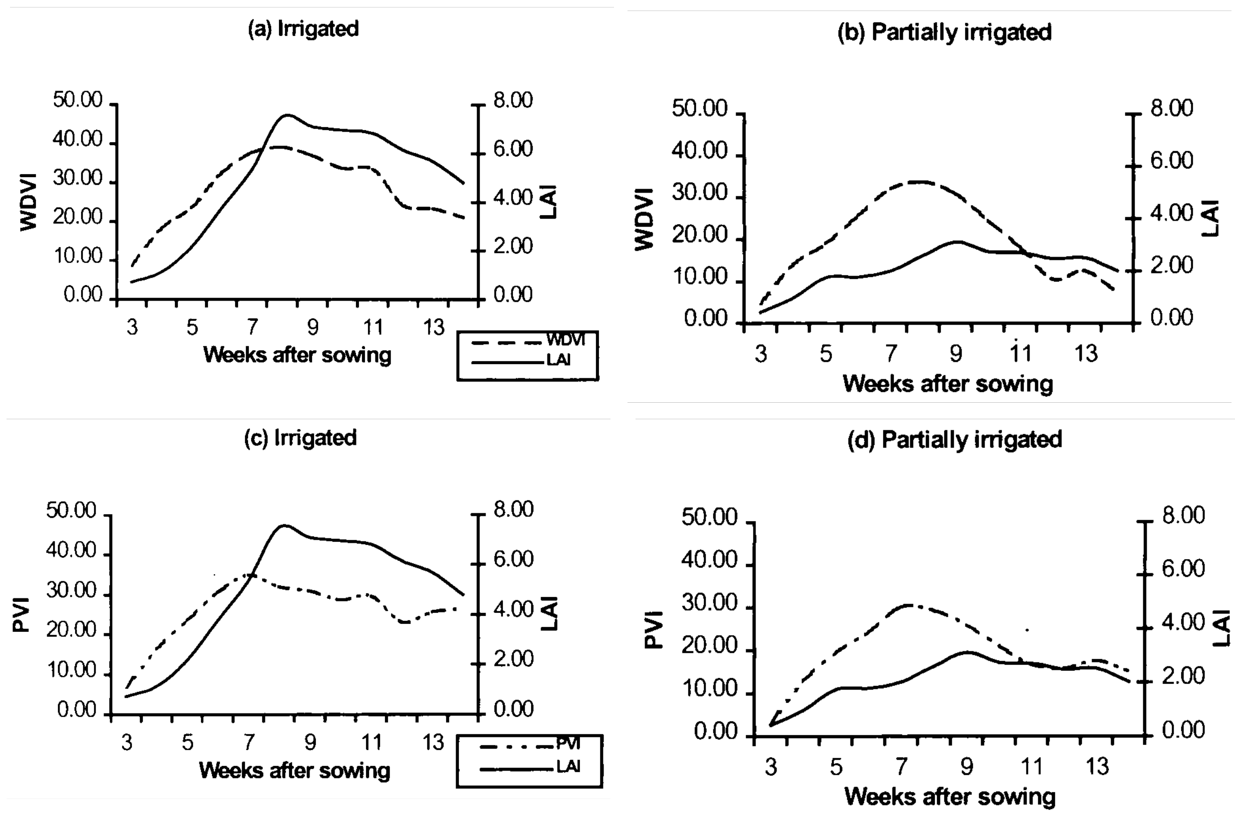
3.2. *Temporal variation of vegetation indices and estimation of LAI*

The LAI can be estimated from different vegetation indices; the relationship however depends upon the vegetation development stage of the crop.

3.2.1. *Normalized Difference Vegetation Index (NDVI)*

A steady increase in NDVI of maize was noted upto the active vegetative stage both in the irrigated and the partially irrigated maize [Figs. 3(a-d)]. For the irrigated crop, NDVI and green vegetation cover were maximal 8 weeks after sowing, afterwards both decreased continuously. However, under the partially irrigated maize, after the NDVI reached its peak value, it dropped gradually upto flower initiation stage of the crop, it then remained steady for a couple of weeks, and again it continuously decreased. NDVI values ranged from 0.384 to 0.768 and from 0.260 to 0.694 for the fully irrigated and for the partially irrigated maize crops respectively.

Equations derived for estimating LAI using NDVI are presented in Table 2. The correlation coefficient between NDVI and LAI was significant at 1% level both



Figs. 4(a-d). WDVI and PVI of irrigated and partially irrigated maize

for irrigated and partially irrigated crops both for the increasing and decreasing phases of the LAI curve. Gruszczynska *et al*. (1998) estimated LAI for wheat using NDVI values and obtained similar results.

3.2.2. *Ratio Vegetation Index (RVI)*

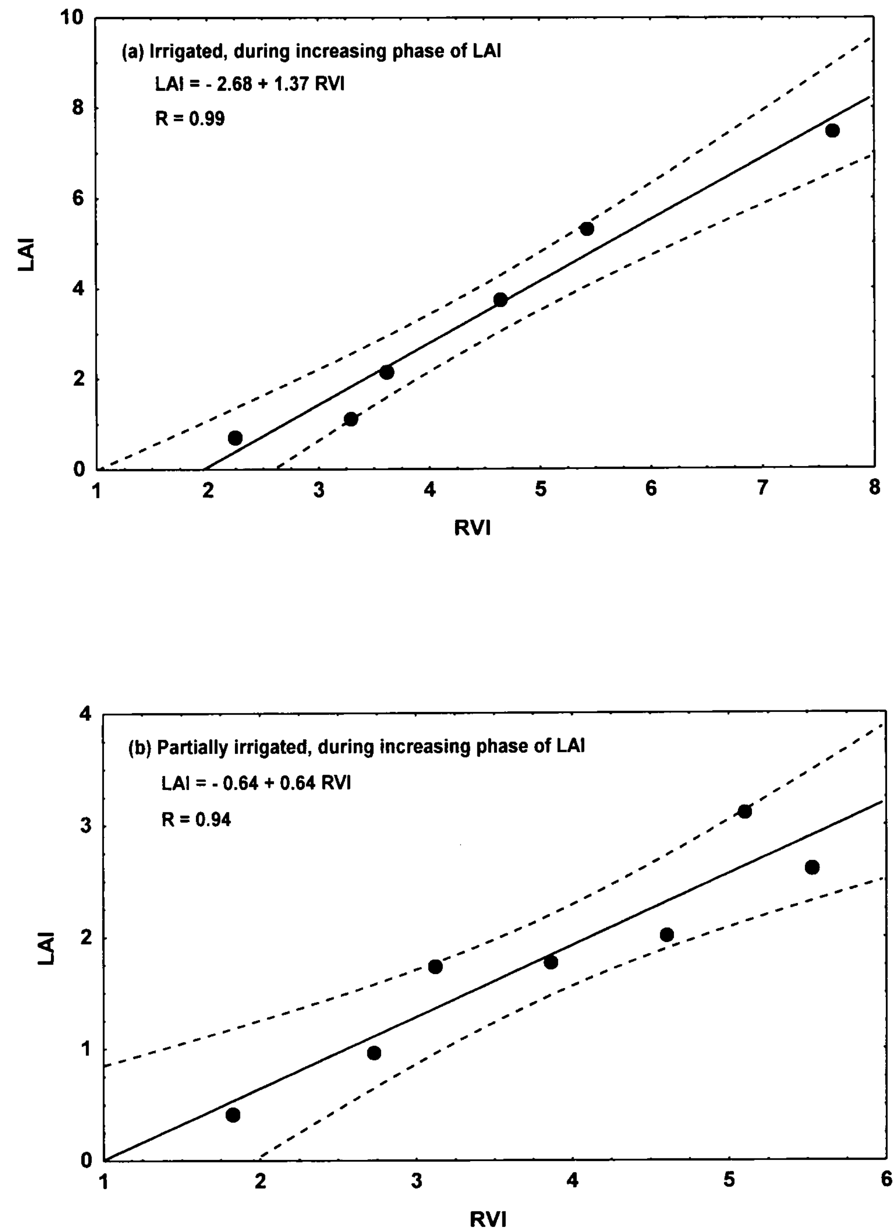
RVI of maize showed a similar trend as observed in the NDVI [Figs. 3(a-d)]. RVI increased sharply upto the active vegetative stage both under irrigated and partially irrigated maize. Thereafter, it dropped continuously under irrigated conditions due to an increase in the red reflectance together with a decrease in IR reflectance. But, under the partially irrigated maize, RVI decreased continuously upto the beginning of the tasseling stage; thereafter, the rate of decrease of RVI was very slow. Maximum RVI was noted 8 weeks after sowing which indicated maximum vegetation cover under both irrigated and partially irrigated maize. RVI showed a larger slope and showed more discrimination at different growth stages due to its better sensitivity compared to NDVI. Gupta *et al*. (1993) also observed similar variations of RVI in kharif crops (soybean, sorghum, sunflower, pigeon pea and castor).

In Table 2 the equations for the calculation of LAI using RVI are presented. These show very high correlation for the maize crops grown under irrigated and partially irrigated moisture conditions (significant at 1% level).

3.2.3. *Weighted Difference Vegetation Index (WDVI)*

At the early stage of maize growth, because of the very negligible influence of green canopy on NIR and red reflectance, WDVI was little (8.70 for the irrigated and 4.80 for the partially irrigated maize) at 3 weeks after sowing [Figs. 4(a-d)]. WDVI increased gradually with a continuous increase of LAI upto the active vegetative stage of maize, both under irrigated and partially irrigated conditions.

After reaching its peak, WDVI of irrigated maize remained more or less steady during its active vegetative growth stage but showed a sudden fall at the tasseling stage. Thereafter, rate of decrease of WDVI slowed. However, the partially irrigated maize showed that after



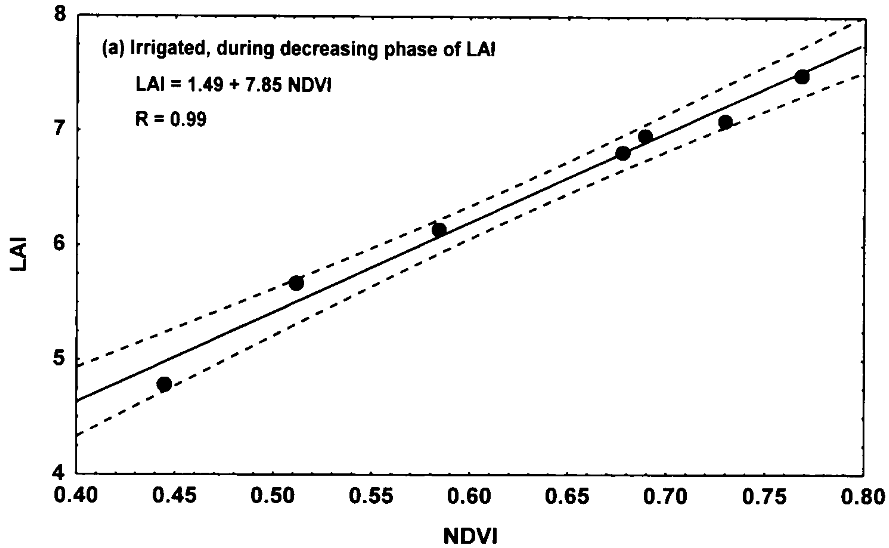
Figs. 5(a&b). Relationship between LAI and RVI of irrigated and partially irrigated maize

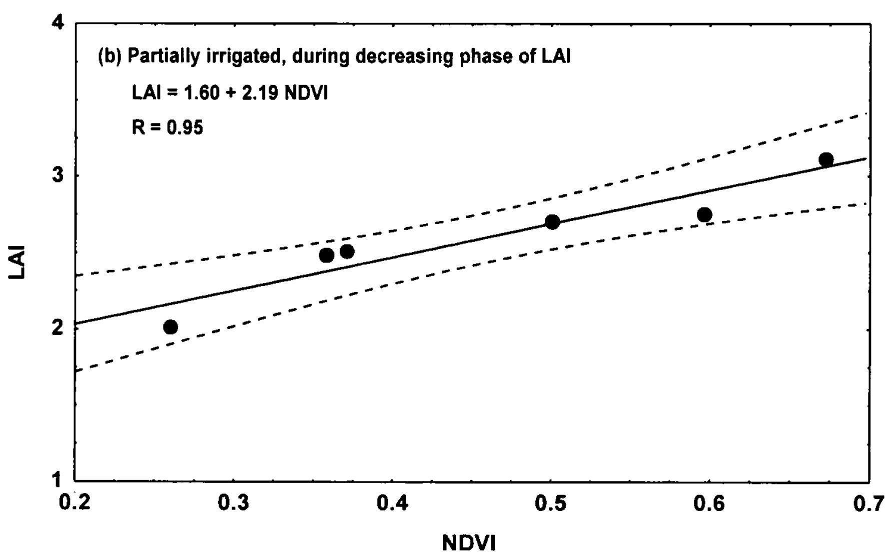
the attainment of maximal value, WDVI showed a continuous fall upto the end of active vegetative stage which was followed by a minor rise, followed by a little drop of the curve during tasseling stage of the crop.

WDVI showed good correlation with LAI during early and late stages of the crop grown under both irrigated and partially irrigated conditions. Equations presented here with LAI and WDVI could be used for estimating LAI (Table 2). Clevers (1988) also estimated LAI using WDVI for cereals and found that WDVI showed a greater sensitivity to changes in biomass.

3.2.4. *Perpendicular Vegetation Index (PVI)*

PVI is known to eliminate the effects of soil. Its value during its early vegetative stage for the 3-week old crop was very low (6.9 for the irrigated maize and 3.3 for





Figs. 6(a&b). Relationship between LAI and NDVI of irrigated and partially irrigated maize

the partially irrigated crop) [Figs. 4(a-d)]. With the advancement of the crop growth, as LAI increased gradually, PVI also showed a continual increasing trend upto the beginning of active vegetative stage. Thereafter, PVI of irrigated maize, during the active vegetative stage did not change much but it registered a fall during its tasseling stage. In the partially irrigated maize, the PVI after reaching its peak showed a decreasing trend upto the end of active vegetative stage and remained more or less steady during the tasseling stage. Thus the equations developed with LAI and PVI shown in Table 2 may be used for the estimation of LAI in maize with advantage.

The data [Figs. 5(a&b)] showed that during the increasing phase of LAI curve upto its active vegetative stage, RVI showed a better correlation with LAI as compared to other vegetation indices, whereas, during its decreasing phase [Figs. 6(a&b)], NDVI showed a higher correlation compared to the other vegetation indices.

4. Conclusion

(*i*) The results of the experiment show a good relationship between spectral reflectance characteristics and crop growth of maize grown for forage. The reflectance in red and near infrared bands can be utilized for monitoring crop condition.

(*ii*) There exists a good relationship between reflectance in red and near infrared bands and maize crop growth stages. Spectral reflectance characteristics have been found suitable for studying maize crop growth.

(*iii*) Relationship between LAI with NDVI, RVI, WDVI and PVI could be used for estimating LAI of maize grown under irrigated and partially irrigated soil moisture conditions.

(*iv*) RVI has been found to be a better predictor of LAI for the increasing phase of LAI curve and NDVI has been found to be a superior predictor for the decreasing phase of LAI curve compared to other indices.

Acknowledgements

Authors are thankful to Deputy Director General of Meteorology (Agricultural Meteorology), Pune, for providing all the necessary facilities and encouragement in carrying out this study. They are also thankful to Mrs Padma Sundaram, for rendering help in carrying out the analysis work.

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