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RESEARCH ARTICLE

On Spectral Indices as a Function of Soil Variability in Safflower Crop

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Keywords

One of the major applications of remote sensing tools in agriculture pertains to studies on yield forecasting, irrigation requirement, pest management etc. However, research reports on spectral changes in relation to crop management practices and soil related factors are scarce for oilseed crops in general and safflower crop in particular. Safflower (*Carthamus tintorius* L.) is a major oilseed crop in India with 98 per cent of the total acreage spread in the states of Maharashtra, Karnataka and Andhra Pradesh (Anonymous, 1994). It is grown in heavy textured clay soils of Vidarbha region (Maharashtra) primarily due to the characteristics like drought tolerance and ability of the tap root to penetrate into deep soil layers (Weiss, 1983). Objective of this study was to explore potential of using spectral indices in indirect and accurate estimation of physiological traits affecting yield of safflower as a function of soil variability.

It was conducted during 1997-98 and 1998-99 at Futala Experimental Farm of Dr. Punjabrao Deshmukh Krishi Vidyapeeth (Dr.PDKV) located at College of Agriculture, Nagpur. The experiment was conducted in three representative types of soil (Table 1). The soils differed taxonomically and it could be seen from table 1 that properties like depth, available water capacity (AWC), organic carbon content (OC) differed accordingly. Reflectance, biometrical and phenological data were gathered from safflower crop grown in the three types of soil. Spectral measurements were made at 15, 30, 45, 60, 75, 90 and 120 day after sowing (DAS) using Ground Truth Radiometer (GTR Model 041). Observations were recorded in four spectral bands in 0.48 to 0.83 µm region. The radiometer was mounted at 1 m height

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above ground level and observations were recorded between 10 AM to 12 noon. The two spectral indices used in this study were normalized differential vegetation index (NDVI) and ratio of spectral reflectance acquired in infra red and red region (IR/R). Two plant parameters-leaf area and dry matter yield were recorded. A regression analysis was run on vegetation spectral indices at various phenological stages. Temporal behaviour of vegetation indices was regarded as a function of plant ontogenesis and used as a yield predictor. The models (empirical equations) were evaluated using R^2 (co-efficient of determination) criteria.

The two year safflower yield data (table 2) clearly showed significant yield difference in different soils. During the two years, highest yield was recorded in S3 soil (clay texture with 90 cm depth) followed by S2 and S1. Spectral properties also showed significant difference as indicated by NDVI (Fig. 1). The lower value of NDVI at initial growth stage may be due to exposure of soil to sensor and higher at later stages due to better canopy (Verma *et al.*, 1998). It could be argued that the NDVI could not bring out the difference in crop growth as a function of soil type in early stages such that the yield could be predicted. However, observations in later stages proved utility of NDVI in predicting yield and even judging type of soil in which the crop was grown. Fig.1 & 2 presents the temporal NDVI behaviour of safflower (Vr. Bhima) as a function of type of soil. The dependence was conspicuous throughout growth period, revealing information about the current and past plant status vis-à-vis development.

Table 1 Soil characteristics

Soil	Depth (cm)	Texture	Classification	AWC (%)	CEC (cmol(p)kg^{-1}	OC (%)
S1	22	Sandy clay	*Lithic Ustorthents*	11.5 (10.9-12.1)	26.10 (25.18-26.5)	0.47 (0.44-0.51)
S2	60	Clay	*Vertic Haplustepts*	18.9 (17.0-20.7)	45.15 (44.30-49.50)	0.61 (0.50-0.64)
S3	90	Clay	*Typic Haplusterts*	23.2 (21.6-24.3)	54.63 (51.12-55.46)	0.82 (0.68-0.84)

Figures in parenthesis indicate the range in the data

Table 2 Grain and straw yield of safflower as influenced by soil types during 1997-98 and 1998-99

Treatments /soil	Grain yield kg/ha			Straw yield kg/ha		
	1997-98	1998-99	Pooled	1997-98	1998-99	Pooled
S1	325	295	305	476	453	464
S2	535	465	501	725	658	691
S3	678	580	628	872	785	828
SEm±	003	001	003	002	002	004
CD at 5%	009	005	008	006	006	011

During the first year highest NDVI was recorded at 75 DAS irrespective of the soil type. A clear increasing yield (Fig.1) in NDVI was observed till the crop reached reproductive stage (75 DAS) after which it declined. NDVI is directly related to the photosynthetic capacity and hence energy absorption of plant canopies (Sellers 1985 and Myneni *et al*., 1995). Reduction in NDVI after 75 DAS could be attributed to the masking effect of yellow flowers at the top of the crop (Sarma and Das 1994, Verma *et al*., 2001). In deep soil, the difference between NDVI at 75 DAS and 90 DAS was marginal (Fig.1). In the subsequent year, the highest NDVI (fig.2) was observed at 75 DAS. Thus, it was evident that NDVI at 75 DAS was a better indicator of plant status as a function of soil as well as potential yield because maximum yield was recorded in soil S3 with consistently higher NDVI. It was also clear that a specific period must be selected for recording spectral values so that effective forecasting could be done. NDVI and ratio (IR/R) at 120 DAS, values dropped drastically (NDVI = 0.211 and 0.134 and IR/R 1.97 and 1.67) for S2 soil and similar trend was also observed in S1 and S3 soils, which may be due to the loss in green colour at latter stage, thereby reflecting more red energy in visible spectrum (Hoffer, 1978 and Verma *et al*., 1998).

IR/R was comparatively less effective (fig. 3 &4) in bringing out the disparity in crop response to soil type. However, peak values of IR/R (90 DAS) differed significantly that could facilitate interpretation for plant status and yield.

Biometric parameters

Leaf area index (LAI) and dry matter (DM) yield recorded at different crop stages exhibited a trend similar to NDVI and IR/R. However, peak values (90 DAS for LAI and 105 for DM) differed. The disparity of LAI as a function of soil type was nevertheless discernible during both years. The highest leaf area was observed at 75 DAS in *Lithic Ustorthents* (S1) and at 90 DAS in *Typic Haplustepts* (S2) and *Typic Haplusterts* (S3). Lowest NDVI was observed in soils characterized by shallow depth, lowest clay content and lowest AWC. The influence of soil, plant and management interaction on spectral indices and growth parameters indicated highly significant differences at 75 and 90 (reproductive stage) DAS which may be because of attainment of maximum leaf area and dry matter at that stage.

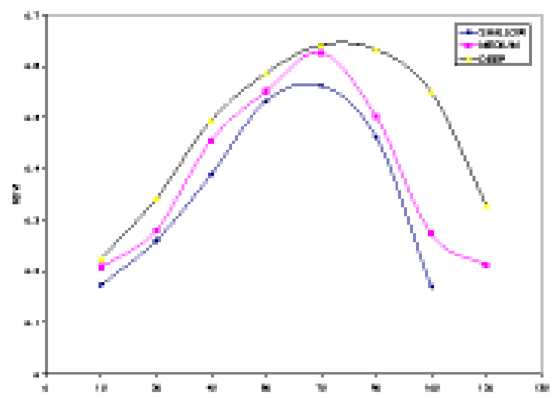

Fig. 1 Variation in NDVI at different growth stages in three types of soil during 1997-98

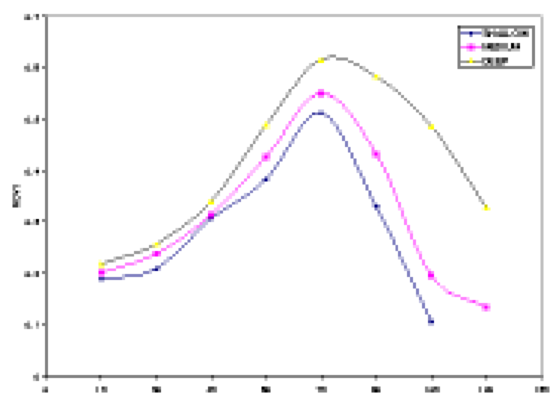

Fig. 2 Variation in NDVI at different growth stages in three types of soil during 1999-99

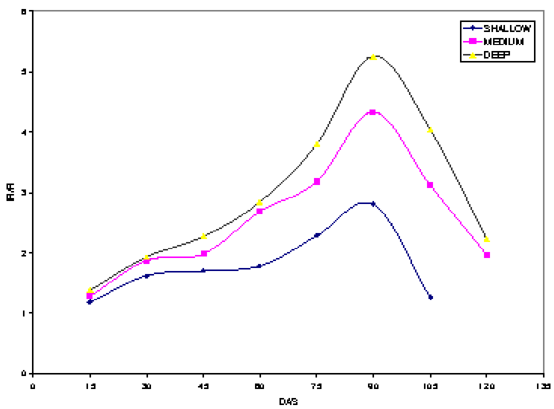

Fig. 3 Variation in IR/R at different growth stages in three types of soil during 1997-98

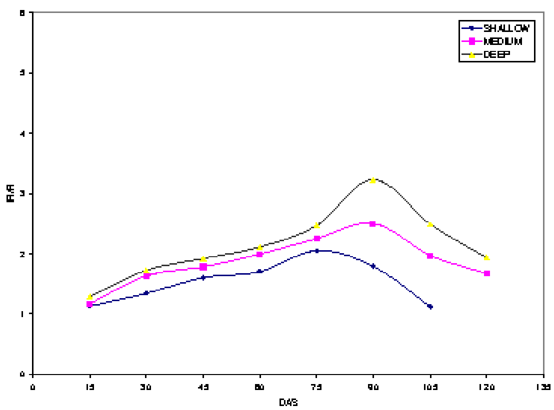

Fig. 4 Variation in IR/R at different growth stages in three types of soil during 1998-99

Relationship between biometric parameters and spectral indices

Regression models relating plant spectral features to biometric parameters were developed to identify the most consistent parameter for further applications. The NDVI showed strong positive relationship with leaf area, dry matter and yield in all the soils during both years. Better correlation was observed in S2 and S3 soils as indicated by values for leaf area (r = 0.99), dry matter (r = 0.97) and yield (r = 0.97) during 1997-98 as well as 1998-99. The leaf area and dry matter values showed an expected increase in 90 DAS as compared to 75 DAS and the increase was well correlated to NDVI and IR/R with parallel increase. But such parallel increase was not expressed in NDVI values at 90 DAS. This inconsistency could be attributed to masking effect of profuse yellow flowers which are maximum at 90 DAS (Verma *et al.*, 2001). The yellow flowers change the reflection pattern at 90 DAS in safflower. Hoffer and Johansen, (1969) have reported that the yellow coloration resulting from the normal autumn breakdown of the chlorophyll, exposed the presence of carotenes and xanthophyll resulting in sharp increase in reflectance throughout the red and green portion of the spectrum. However, in the near infrared regions the reflectance was lower than the green leaves. Sarma and Das (1994) have also reported similar observations on mustard. The masking effect was more pronounced in S2 and S3 soils, whereas the effect was not clear in S1 soil at 90 DAS. It could be due to paucity of moisture that might have hastened flowering.

The strongest and consistent relationship was obtained between IR/R ratio and leaf area (r = 0.96), dry matter (r = 0.99) and yield (r = 0.97) in S2 soil at 90 DAS (1998-99). Similar trend was also noticed in S3 soil. It may be noted that in the plants of indeterminate growth habit where vegetative and reproductive stages progresses side by side, the masking effect in NDVI preclude its inclusion for productivity evaluation while consistent relationship of ratio with advance in growth stage proved its fitness to be preferred for evaluating the productivity of safflower (Patel *et al.*, 1995).

Yield prediction

Spectral indices computed for critical growth stages were related to yield. Precision of these equations is significant for the studies that depend on minimum field truthing. A single equation accounted for variability in the dataset. Such temporal stability in the relationship creates the possibility of transforming NDVI maps (satellite data) to LAI units and consequently applications like yield forecasting. Following are the best performing models for each soil type.

Yield = - 0.68 + 7.96 NDVI (R^2 = 0.89) for S1 soil at 75DAS

Yield = - 0.81 + 10.89 IR/R (R^2 = 0.95) for S2 soil at 90 DAS

Yield = 1.19 + 0.87 IR/R (R^2 = 0.98) for S3 soil at 90 DAS

These relationships clearly established potential of radiometric data in ground truthing and consequently complementing satellite data.

Spectral indices were shown to be reliable predictors of safflower yield from this experiment. The variation in soil type was also indicated by spectral values. Utility of spectra-temporal data as a pointer of plant development status and yield was also demonstrated. The results also demonstrated that soil variation causes statistically significant variations of plant reflectance properties. In shallow sandy clay soil, the NDVI at 75 DAS stage of crop was better indicator of crop yield than other crop stages. In medium and deep clay soils, IR/R at 90 DAS was better correlated to yield. It was concluded that spectral indices at different growth stages need to be observed for different soils for reliable prediction of safflower yield. The established empirical dependences illustrated the information potential of radiometric spectral data which would complement estimates based on satellite imagery.

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