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Spectral radiance characteristics and vegetative indices of crops — A ground based remote sensing technique

R. C. DUBEY, S. D. GAIKWAD, V. S. NAWATHE, R. G. DEKHANE and S. N. BIDYANTA

Meteorological Office, Pune-411005

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सार — मूंगबीन, सूर्यमुखी और मूंगफली की फसलों की बढ़वार के विभिन्न चरणों में स्पैक्ट्रमी विकिरण के अभिलक्षण और वानस्पतिक सूचकांकों का अध्ययन किया गया। उदाहरणार्थ, सरल अनुपाती वानस्पतिक, सामान्यीकृत वानस्पतिक, उर्ध्वाधर वानस्पतिक, रूपांतरित वानस्पतिक, एवं ''टैसल्ड कैप'' रूपांतरण। 1990-91 के दौरान वर्षा ऋतु के बाद, हस्तचालित बहु-स्पैक्ट्रमी रेडियोमापी की मदद से, पुणे के कृषि महाविद्यालय के फार्म में इस अध्ययन से संबंधित प्रयोग किया गया।

ABSTRACT. The spectral radiance characteristics and vegetation indices like simple difference, ratio vegetation, normalised vegetation, perpendicular vegetation, transformed vegetation and tasseled cap transformation of mung bean, sunflower and groundnut crops at different growth stages have been studied. The experiment was conducted in post rainy season during 1990-91 in the farm of Agricultural College, Pune using hand held multi-spectral radiometer. The significance of spectral variation of radiance and vegetative indices with respect to the phenological stages are discussed.

Key words — Episodic, Phenological, Vegetative index, Canopy, Substrates, Fallow, Zenith, Leaf Area Index (LAI), Imagery, Resolutions.

1. Introduction

The biomass and production of vegetation may be estimated by remote sensing the multi-spectral reflectance of the vegetation canopy. Vegetation has a characteristically high reflectance difference between regions of strong absorption and reflectance in red band and near infrared waveband respectively. Several workers have reported relationship between remotely sensed data and crop conditions. Thomas and Gerberman (1977) detected reduction in cabbage yield caused by nitrogen and water deficit by measuring the cabbage canopy reflectance. Tucker *et al.* (1979) monitored corn and soyabean growth and development by means of red and photographic infrared data collected throughout the growing season.

Crop development has been monitored by various researchers using LANDSAT MSS (Multi Spectral Scanner) data. Two band approach was proposed by Rouse *et al.* (1973) for assessing biomass. Ashleys and Rea (1975) used LANDSAT MSS 5 and MSS 7 data to depict phenological change. Other vegetative indices have been suggested by various workers but under certain limitations. Some of the better known examples are: Simple subtraction (Pearson *et al.* 1976), Simple ratio (Curran *et al.* 1981), Complex ratio (Curran 1980), Normalised difference, Transformed vegetation index (Rouse *et al.* 1973), Perpendicular Vegetative index (Richardson and Wiegand 1977) and Green vegetative index (Kauth and Thomas 1976). These indices show considerable variation with the soil background, presence of senescent vegetation, angles of sun and sensor, canopy geometry, episodic and phenological canopy changes. Taking these in view, the study was taken up to identify the specific index more sensitive to a crop and its growth stages.

In this paper, the results of the experiment conducted on mung bean (*Phaseolus aureus Roxb*), sunflower (*Helianthus annuush* L.) and groundnut (*Arachis hypogaea* L.) are presented.

2. Material and method

The data were collected by a hand held multi-spectral radiometer for mung bean, sunflower and groundnut in the field at Agricultural college, Pune. The instrument and the method of observations was same as adopted by Dubey *et al.* (1992). The central wavelengths of the bands were 483, 544, 655, 819, 480, 541, 656, 812 nm having band width of 65, 85, 61, 148, 76, 82, 62 and 87 nm

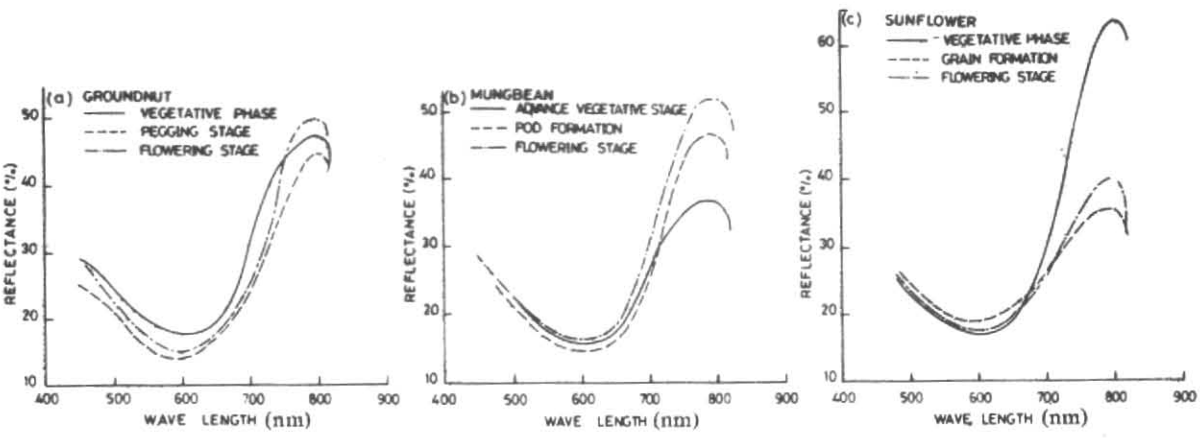

Fig. 1. Spectral variation of reflectances of three crops at different growth stages

respectively. The observations were carried out between 0900 and 1150 hrs at a height of about 1 m above the crop canopy on cloud-free days. Five random measurements from each plot in each band were taken. The mean of five measurements was used for all analyses.

2.1. *Collection of data*

The spectral measurements were taken at weekly intervals over the crop cycle.

The date of sowing, crop variety, management practices and other agronomic information were collected from the agricultural college. The monitoring of irrigation was done. Weekly observation was taken at 1100 hrs on cloud-free days.

A plot admeasuring 2×3 m was marked and GTR (Ground Truth Radiometer) observations were taken at five points in the plot. The observations over calibration plate coated with $BaSO_4$ were taken in the beginning and at the end of observation and average plate reading was calculated for each plot. The readings taken over canopy were divided by the average plate reading to obtain crop reflectance in different bands. Similar readings were taken for each crop in the nearby fields.

The reflectance in red and near infrared for a range of soils or substrates is known to have a linear relationship. So, the reflectance data in different conditions of the bare soil, like wet, dry or fallow, were also obtained at the same day and time. A linear graph between reflectance in red and near infrared bands over these soils, called the soil or substrate line, was plotted.

2.2. *Analysis of data*

In the present study, an attempt is made to compare different indices in order to identify the most sensitive index and its variation at different crop growth stages. This comparison can be obtained by measuring the temporal profiles of spectral indices measured near infrared radiance relative to that in the visible bands.

The temporal change in growth parameters of crop affects its spectral characteristics. It is important to study these changes during the growth and development for crop identification (Dubey *et al.* 1992). The spectral variations at different growth stages are shown in Fig. 1.

The leaf area and chlorophyll content increase with the growth of the crops. These affect the energy intercepted and its spectral contribution in transmittance, absorption and reflectance. The reflected part is described by radiance of the crop. Radiance values at specified eight wavelengths in the week corresponding to a particular phenological stage are plotted in Fig. 1 which depicts the sensitiveness of different bands in every growth stage of individual crops.

Large variations in the relationship between reflectance and crops is caused by differences in crop characteristics, soil background and prevailing atmospheric conditions. This complication is more prevalent when spatial and temporal analysis of reflectance are performed. These underived disturbances are minimised in most of the indices described below by subtraction or taking ratio.

2.3. *Important spectral vegetative indices*

A number of indices are presented and their utility is discussed below.

2.3.1. *Simple difference index (IR−R)*

This concept was proposed by Pearson *et al.* (1976). The difference between red (R) and infra-red (IR) reflectance provides a better estimate of LAI and biomass than either band alone. and theoretically independent varying solar irradiance and most soil types. However. it is not independent of the effects of variable solar angle and azimuth. Therefore. mathematical description of the relationship of such an index to crop characteristics is location specific. This index is. therefore. not a useful tool for monitoring vegetation.

2.3.2. *Ratio Vegetation Index (RVI)*

This is a useful index for estimating crop characteristics. It minimises the effect of atmospheric attenuation because a ratio of IR/R is taken.

2.3.3. *Normalized Difference Vegetative Index (NDVI)*

It is also a very useful index for studies of crop characteristics enhancing the range in different crops and it is expressed as :

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

2.3.4. *Perpendicular Vegetative Index (PVI)*

It was proposed by Richardson and Weigand (1977). It eliminates the effects of soil. Increasing vegetative development decreases the red reflectance and increases IR reflectance. When plotted on a graph having a substrate line. the perpendicular distance of the vegetative point from the soil line is called *PVI.* It can be calculated from the following expression.

$$PVI = [(R_{soil} - R_{veg})^2 + (IR_{soil} - IR_{veg})^2]^{1/2}$$

2.3.5. *Transformed Vegetation Index (TVI)*

In order to avoid negative value *TVI* has been used. It is expressed as :

$$TVI = [(IR - R/IR + R) + 0.5]^{1/2}$$

2.3.6. *Tasseled cap transformation*

This transformation proposed by Kauth and Thomas (1976) has proved to be a major advance in our capability to effectively work with multispectral satellite data. This transformation rotates four band data such that the majority of information is contained in two features. *i.e.*, brightness and greenness. which are directly related to physical scene characteristics. The coefficient of brightness. greenness etc. are unit vectors that indicate direction. These are explained below :

(a) Soil Brightness Index (SBI)

SBI is the weighted sum of all bands (B) and is defined as the direction of principal variation in soil reflectance and can be expressed as Soil Brightness Index $(SBI) = 0.43\,B_1 + 0.63\,B_2 + 0.59\,B_3 + 0.26\,B_4$ where. B_1. B_2. B_3 and B_4 are the components of bands.

(b) Greenness Vegetation Index (GVI)

It is approximately orthogonal to brightness and is a contrast between the near infra-red and visible bands. It is strongly related to the amount of green vegetation present in the scene. It is expressed as.

$$\text{Green Vegetation Index } (GVI) = -0.29(G) - 0.56(R) + 0.60(NIR) + 0.49(MIR)$$

where. G — Green. R — Red. NIR — Near IR. MIR — Middle IR.

The tasseled cap transformation maintains the close relationships in the data. but it typically captures 95 per cent or more of the total variability in above noted two readily interpretable features. These indices contain almost all the variations within a sample segment. The shifts in yellowness are diagnostic of a physical state of the atmosphere. These indices continually change with growth of the crop. Fig. 4 shows dynamics of some of these indices against crop growth as measured in WAS (Weeks After Sowing).

3. Results and discussion

3.1. *Spectral reflectance curves*

A canopy is an assemblage of leaves where the interaction of individual leaves becomes complex due to combined effects of leaves. plant structure. background and shadow. When the light falls over the top of canopy. a part of it is reflected and the light transmitted through the top layer of leaves is incident upon lower leaves and so on.

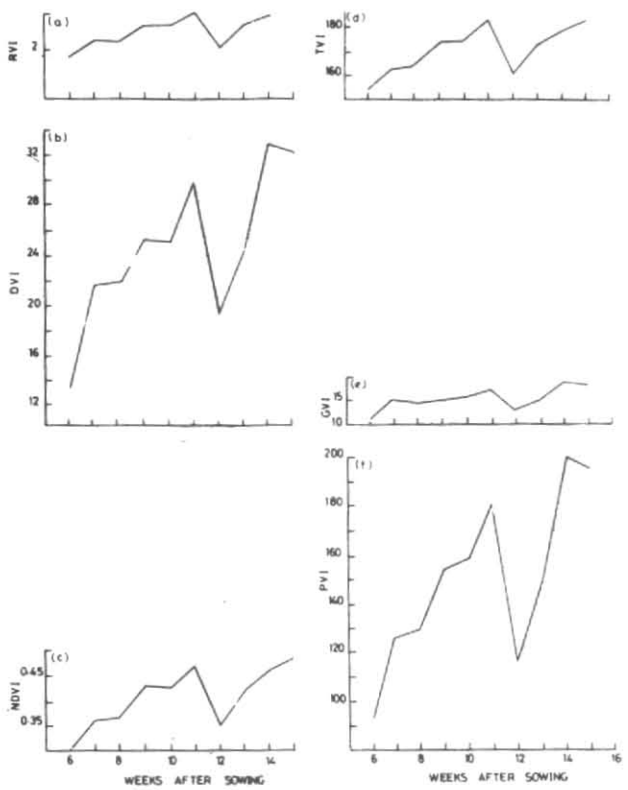

Fig. 2. Variation of RVI, DVI, NDVI, TVI, GVI and PVI indices in groundnut at different stages of growth

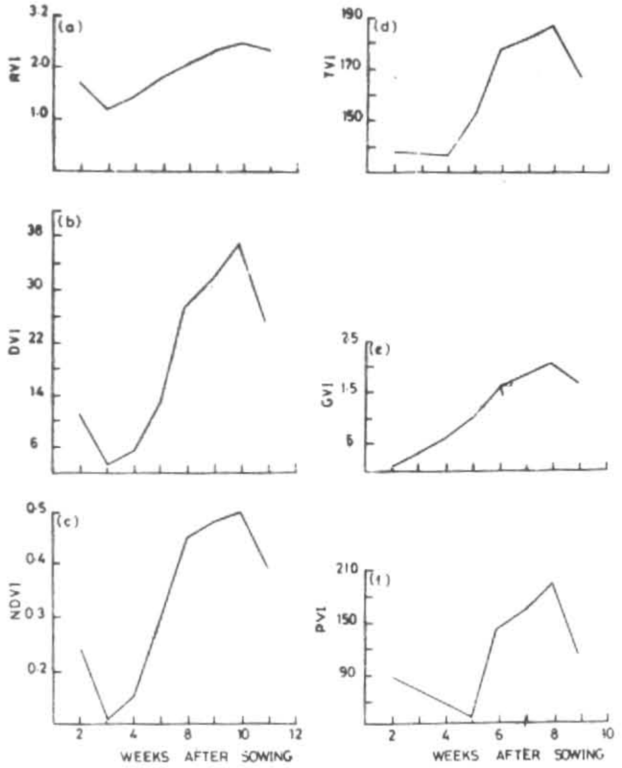

Fig. 3. Variation of vegetative indices RVI, DVI, NDVI, TVI, GVI and PVI in mung bean with Weeks After Sowing (WAS)

Some radiation is scattered among leaves of the canopy by multiple reflection which makes the albedo of canopy, as a whole, generally less than that of a single leaf. The difference increases with the irregularity of the leaf surface and with solar elevation, because sunlight penetrates further into the canopy as the sun approaches the zenith.

The variation of reflectance with wavelength of solar radiation at main growth stages of groundnut, sunflower and mung bean are depicted in Fig. 1.

For groundnut, vegetative, flowering and pegging stages are taken as the main epochs in its life cycle which can be accurately differentiated in *IR* and visible region of solar spectrum. In visible portion vegetative stage shows the highest and pegging stage the lowest reflectance. Because of differences in Leaf Area Index (LAI) there is less absorption at vegetative and more absorption at pegging stages of growth. In *IR* region, the highest reflectance is shown at flowering and the lowest at pegging stage.

In the case of mung bean, the vegetative phase shows the lowest reflectances in visible as well as in *IR* region. It indicates more absorption in visible but more reflection in *IR* which is due to lesser contribution of spongy mesophyll to increase the reflection in *IR* region. In the flowering and pod formation stages the reflection in *IR* region were found to be very much higher than in vegetative phase. But in visible region the differences in all the three stages is not much. It indicates that *IR* bands are very useful for differentiating the growth stages compared to the visible bands.

Sunflower plant has very wide and bigger leaves. These cause the reflectance to be very high in *IR* region at the vegetative stage. At seed setting stage, the reflectances in *IR* region drop suddenly which is due to senescence of leaves. There is no change in reflectance from vegetative to flowering stage.

It may be inferred that the temporal resolution in *IR* band for groundnut, sunflower and mung bean adequately identifies the stages of development of these crops; the tonal differences in colour of the imagery in visible region are relatively not appreciable.

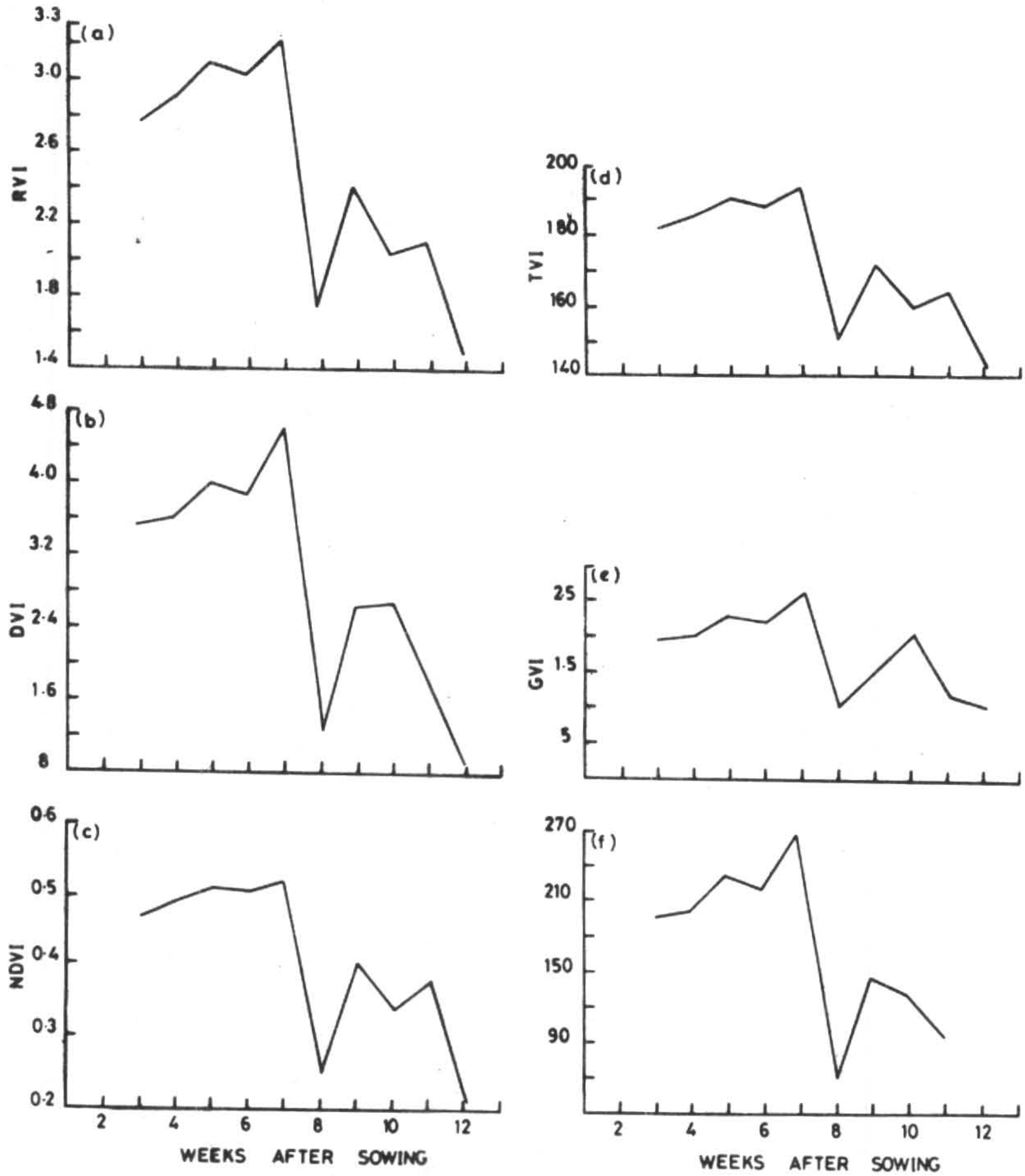

Fig. 4. Variation of vegetative indices RVI, DVI, NDVI, TVI and PVI in sunflower with Weeks After Sowing (WAS)

3.2. *Variation of vegetation indices with growth stages*

(*a*) *Ratio Vegetation Index (RVI)*

Simple ratio vegetation indices of groundnut are shown in Fig. 2 (a). There is a slow increase of this index from vegetative to flowering, followed by a sudden fall at pegging stage due to drop of reflectance in *IR* (shown in Fig. 1); a slow rise occurs upto podding stage. This index is not a useful parameter for the study of growth in groundnut. In mung bean, [Fig. 3 (a)] *RVI* is small at early vegetative stage but increases afterwards. It is at its maximum at pod formation stage and falls at the grain formation stage. In sunflower [Fig. 4 (a)] *RVI* shows an appreciable rise in vegetative phase but a sudden drop is noticed at flowering. Its again increase registers a sudden fall. This could be a useful parameter for sunflower crop studies.

(b) Difference Vegetation Index (DVI)

The variations of *DVI* for the three selected crops are : in groundnut [Fig. 2 (b)] it shows slow rise upto flowering stages with a drop in pegging and further rise in pod formation stage: in mung bean [Fig. 3 (b)] the index shows a drop at the early vegetative phase. it then rises upto flowering stage and a drop is registered at the pod formation stage. These changes are pronounced. in sunflower [Fig. 4 (b)] the index rises gradually upto flowering stage. then a sudden fall is noted at grain formation stage. In all cases this parameter seems to be useful for studying the development of selected crops and their vigour.

(c) Normalized Difference Vegetation Index (NDVI)

The changing pattern of *NDVI* with growth stages for groundnut [Fig. 2 (c)] is similar to *DVI* but is less pronounced for mung bean [Fig. 3 (c)]. In sunflower [Fig. 4 (c)] *NDVI* shows a pattern upto the end similar to *DVI* except a dip at the start of seed formation stage before its continuous fall. It may be due to solar elevation and topographic effects which might have affected *DVI* but not *NDVI*.

(d) Transformed Vegetation Index (TVI)

TVI for groundnut [Fig. 2 (d)] is very similar to *NDVI*. In mung bean [Fig. 3 (d)] *TVI* shows sudden increase from vegetatve phase to flowering phase and then drops. In sunflower [Fig. 4 (d)] it shows very slow increase from vegetative phase to the start of flower then suddenly reduces during flowering phase.

(e) Green Vegetation Index (GVI)

The variation patterns of *GVI* are almost similar in groundnut [Fig. 2 (e)]. mung bean [Fig. 3 (e) and sunflower crops [Fig. 4 (e)]. The changes with growth stages are not very pronounced. This parameter seems to be useful for crop studies.

(f) Perpendicular Vegetation Index (PVI)

The numerical values of *PVI* are shown for groundnut in Fig. 2 (f). for mung bean in Fig. 3 (f) and for sunflower in Fig. 4 (f). *PVI* shows a very sharp change with the growth stages in all the crops. *PVI* is thus a very sensitive parameter. Any changes in canopy structure due to changes in leaves. their orientation. flowering and grain formation are immediately responded.

The physical importance of *PVI* can be explained when the reflectance in *IR versus R* at any growth stage is plotted and the perpendicular is drawn over the soil curve. The change of reflectances in *IR* and *R* is linear for any soil type according to Curran *et al.* (1981).

4. Conclusions

The following conclusions can be drawn from this study :

(*i*) The reflectances in visible as well as *IR* region at various growth stages of groundnut are not separable. Therefore. growth stages of groundnut can not be well distinguished in satellite imagery.

(*ii*) The growth stages of mung bean are well separable in *IR* region but not in visible region. In sunflower the vegetative phase is well separable from flowering and grain formation stages in *IR* region but not in visible region.

(*iii*) Vegetative phase in sunflower shows light reflectance and is well distinguished from other two phases in *IR* region but all the phase show almost the same magnitude of reflectance in visible region: and

(*iv*) *DVI* and *PVI* of groundnut. *DVI*. *NDVI*. *TVI*. *PVI* of mungbean are very sensitive to the growth stages of these selected crops. These can be used as indicators for determining crop stages in remote sensing studies.

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