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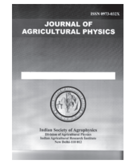

Identification of Aphid Infestation in Mustard by Hyperspectral Remote Sensing

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ABSTRACT

Spectral reflectance was taken in healthy as well as aphid infested canopies of mustard in field as well as in the laboratory. The spectral reflectance of aphid infested canopy and healthy canopy taken in the laboratory had significant difference in NIR region. In the visible region, the reflectance peak occurred in healthy canopy at around 550-560 nm while this peak was lower by 31% in the aphid infested canopy. The reflectance for healthy crop was found to be more in visible as well as NIR region as compared to aphid infested canopy. The most significant spectral bands for the aphid infestation in mustard are in visible (550-560nm), and near infrared regions (700-1250 nm and 1950-2450 nm). The different level of aphid infestation can be identified in 1950-2450 nm spectral regions. Spectral reflectance of the mustard canopy for different varieties had significant difference in the reflectance at different phenological stages in NIR (720-1360 nm) region. Also the peak at 550-560 nm in the visible region was lower at maturity stages as compared to vegetative, flowering and pod formation stages. Spectral indices viz NDVI, RVI, AI and SIPI had significant correlation with aphid infestation. Hence these indices could be used for identifying aphid infestation in mustard.

Key words: Mustard, Aphid, Hyperspectral remote sensing, Vegetation index, AI, NDVI, SIPI, RVI

Introduction

Hyperspectral remote-sensing approach, using remotely sensed reflectance for many continuous narrow wavelength bands, has been proposed for various aspects of crop management such as the identification and classification of plant species, yield estimation, as well as estimation of different crop bio-physical and bio-chemical parameters. Affect of pests and disease status on the spectral properties of the crop can be used to control site-specific application of insecticide (Pinter *et al*., 2003). The structure and physiological status of a crop controls incident energy reflected, transmitted and absorbed. The amount of reflected light depends on leaf-related factors, such as external morphology, internal structure, pigment concentration, moisture and internal distribution of biochemical components.

Using remote sensing instruments, it is possible to monitor changes in crop health over the course of a growing season (Richardson *et al*., 2004). The presence of disease or insect feeding on a plant or canopy surface causes changes in chlorophyll, chemical concentrations, cell structure, nutrient and water uptake, and gas exchange, which leads to differences in color and temperature that can modify canopy reflectance characteristics (Raikes and Burpee, 1998).

Developments in hyperspectral remote sensing have provided additional bands within the visible, near infrared and shortwave infrared. Most hyperspectral sensors acquire radiance information in less than 10 nm bandwidths from the visible to the SWIR (400-2500 nm) (Asner, 1998).

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Hyperspectral systems have made it possible for the collection of several hundred spectral bands in a single acquisition, thus producing many more detailed spectral data (Govender *et al*., 2007). Hyperspectral remote sensing is best alternative to the major limitation of broadband remote sensing products with average spectral information over broad band widths which results in loss of critical information available in specific narrow bands. Hyperspectral remote sensing can capture data in contiguous, narrow bands in the electromagnetic spectrum. The large numbers of bands provide with vast quantities of information. Therefore, hyperspectral data can often capture the unique spectra or 'spectral signature' of an object and this signature can be used to differentiate and identify materials and their chemical compositions and can been utilized for wide range of applications (Kruse, 1998).

Crop yield is influenced by several factors such as crop genotype, soil characteristics, agronomic practices, weather conditions and biotic stresses *viz*., weeds, disease and pests.The spectral data of crop is an integrated modification of the combined effects of all these factors on crop growth.

To improve crop production and prediction it is essential to have better tools for detecting stress. Spectral vegetation indices could be used for detecting Russian wheat aphid (*Diuraphis noxia Morlvilko*) and greenbug stresses (Riedell and Blackmer, 1999; Yang *et al*., 2005). Riedell and Blackmer (1999) conducted a greenhouse study to characterize leaf reflectance spectra of wheat stressed by Russian wheat aphid. In this study, it was concluded that leaf reflectance in the 625–635 nm and 680–695 nm as well as the normalized total pigment to chlorophyll a ratio index (NPCI) were good indicators of chlorophyll loss and leaf senescence caused by aphid feeding. Yang *et al.* (2005) used radiometer in greenhouse to characterized greenbug stress in wheat. They found that waveband centered at 694 nm and spectral vegetation indices derived from wavelengths centered at 800 nm and 694 nm were most sensitive to greenbug-damaged wheat. Nino (2002) used a multispectral hand-held radiometer to predict greenbug densities in a greenhouse study. He showed that the associations measured by the correlation coefficients (r) between greenbug density and vegetation indices varied from weak (r = 0.31) to very strong (r = 0.98). Apan *et al.* (2004) created the Disease-Water Stress Indices (DWSI1–5) to evaluate orange rust disease on sugarcane (*Saccharum spp*.). However, these indices have not been largely used or tested for different stresses. A few spectral indices among many were created to retrieve spectral information on vegetation stress caused by biotic stresses. Penuelas *et al.* (1995) designed the normalized phaeophytinization index (NPQI) to estimate cumulative mite (*Panonychus ulmi Koch*) days on apple trees (*Malus domestica*). Although remote sensing technique have been used to study the effect of many ecological variables, abiotic and biotic stresses on agricultural crop over decades, the potential of these technique for identifying the infestation and damage in mustard crop is yet to be explored. Remote sensing research in real time field use is desirable to provide spatial and temporal information for natural aphid infestation. Hence in-depth study is needed to explore the applicability and feasibility of using hyperspectral reflectance characteristics to identify and discern spectral signature of healthy and aphid infested mustard crop. Keeping in view the above facts, present study was carried out.

Materials and Methods

Field experiments were conducted during 2009-10 *rabi* season at research farm of IARI, New Delhi, India. Three varieties of Mustard viz., Pusa Gold, Pusa Jaikisan and Pusa bold were sown on 19th October, 3rd November and 18th November, 2009. The crops were raised following the standard recommended agronomic practices with three replications in a randomized block design (RBD). Pusa Gold is more susceptible to aphid infestation as compared to other two varieties therefore this variety is sown in the pot under net house to observe the aphid infestation and for measuring spectral reflectance by Spectroradiometer.

Spectral reflectance of healthy as well as aphid infested canopies of Pusa Gold were taken using Field Spec™ 3 ground held spectroradiometer on clear sunny days between 1100 and 1300 hours. The Field Spec™ 3 spectroradiometer is a general purpose spectrometer useful in application areas requiring the measurement of reflectance, transmittance, radiance or irradiance. It is specifically designed for field environment remote sensing to acquire visible near-infrared (VNIR) and short-wave infrared (SWIR) spectra. The spectroradiometer covers the spectral range between 350 to 2500 nm. The sampling interval over the 350-1000 nm range is 1.4 nm with a resolution of 3 nm (bandwidth at half maximum). Over the 1000-2500 nm range, the sampling interval is about 2 nm and the spectral resolution is between 10 and 12 nm. The results are then interpolated by the ASD software to produce readings at every 1nm. A 1.2 m long fiber optic cable with a 25° field of view was used for the measurements. Spectral reflectance was derived as the ratio of reflected radiance to incident radiance estimated by a calibrated reference. Spectral observations were taken at different growth stages of each variety sown at different dates.

The spectral data were analysed in Excel 2007. Spectral data in the range 1362-1403 nm and 1772-1944 nm were removed because of noise in these ranges due to water absorption.

The spectral reflectance of aphid, healthy plant and plant with aphid infestation were measured in laboratory. The spectral reflectance of non-stressed and stressed canopies from aphid feeding, at different aphid population, were also measured in the laboratory. The spectral reflectances of aphid infested canopies in the pot were also measured.

Spectral Indices

The spectral data were processed and exported to Microsoft excel through ASD View Spec Pro software. Using the spectral data RVI, NDVI, SIPI and AI were calculated using the formulae given in Table 1.

Results and Discussion

Spectral Characterization of Mustard Canopy Affected by Aphid Infestation

The spectral reflectance of healthy canopies and aphid infested canopies were taken by Spectroradiometer in the field (Fig 1). There was difference in the reflectance pattern of both healthy as well as aphid infested canopy. The spectral reflectance of aphid infested and healthy plants taken in the laboratory had significant difference in NIR region. In the visible region the reflectance peak occurred in healthy canopy at around 550-560 nm while this peak was missing in the aphid infested plants (Fig. 2). In aphid infested plants the reflectance was increasing while there was sharp increase in the reflectance for healthy canopy at 700-750 nm and decreases sharply at 1250 nm. Therefore aphid infestation can be identified in 750-1250 nm range. Again between 1950-2450 nm spectral range there was significant difference in the spectral reflectance of aphid infested plants and healthy plants as well

Table 1. Spectral indices and their formula as used in the study

S. No.	Indices	Computation	Reference
1.	NDVI (Normalised difference vegetation index)	$=\frac{(NIR - RED)}{(NIR + RED)}$	Rouse *et al.* (1974)
2.	RVI (Ratio vegetation index)	$=\frac{(NIR)}{(RED)}$	Jordan (1969)
3.	AI (Aphid index)	$=\frac{(R_{761} - R_{908})}{(R_{712} - R_{719})}$	Mirik et al. (2006)
4.	SIPI (Structural independent pigment index)	$=\frac{(R_{800} - R_{445})}{(R_{800} - R_{650})}$	Penuelas *et al*. (1993)

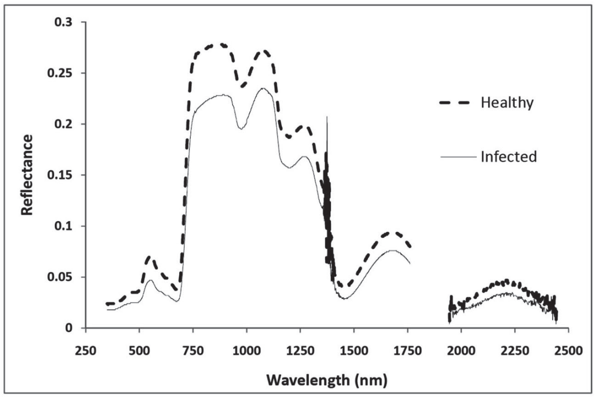

Fig. 1. Spectral reflectance of aphid infested canopy measured in field

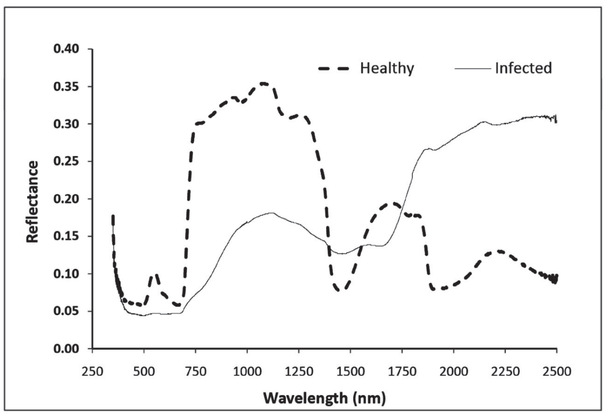

Fig. 2. Spectral reflectance of aphid infested canopy measured in laboratory

as different level of aphid infested canopies. Therefore this spectral wavelength region could be used for identifying aphid infestation as well as different levels of aphid infestation in mustard crop.

Spectral signature taken in the laboratory (Fig. 2) and in the field (Fig.1) differs in relative reflectance, indicating that it is not easy to compare field data to the laboratory data. The reflectance for healthy crop was found to be more in visible as well as NIR region as compared to aphid infested canopy. There was large difference between the laboratory and field data because aphid density in the laboratory data was much higher than in field and there was no background noise from exposed soil and other uninfested plants. The spectral reflectance measured in the field, lab and pot condition at different aphid density are shown in Fig. 3. The 750–1250 nm

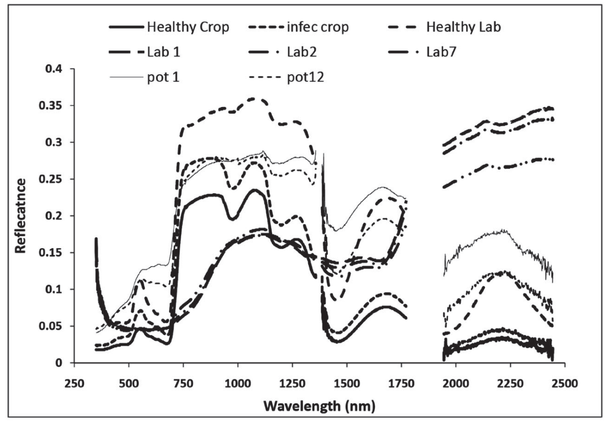

Fig. 3. Spectral reflectance of aphid infested canopy in field, laboratory and pot at different level of infestation

region (Fig. 3) shows that there was significant difference between infested and healthy canopy. Between different levels of infestation there was no difference in reflectance spectra in 750–1250 nm but in 1950–2450 nm ranges there was a significant difference hence this range can be used for identifying different level of infestation in mustard.

A significant decrease in the reflectance from the aphid infested canopies in the visible and NIR region was clear evidence that aphid feeding reduced the photosynthetic pigment concentration, in particular chlorophylls, which leads to lowered photosynthetic rate of crop (Riedell and Blackmer, 1999). The reflectance peak from undamaged crop at around 550-560 nm occurred due to green light (500-600 nm) being reflected by the green leaf pigments (Riedell and Blackmer, 1999). This reflectance peak was missing in the aphid infested canopies.

Aphid infested canopies had the lower value of reflectance in NIR region as compared to healthy canopies. This was most likely due to degenerated internal leaf structure, reduced leaf area and stunting plant growth caused by aphid feeding (Castro *et al.*, 1988; Morgham *et al.*, 1994). Spectral response of field bean leaf infected by *Botrytis fabau* (Malthus and Madeira, 1993) and winter wheat infested by greenbug (Riedell and Blackmer, 1999) showed similar patterns in the reflectance. Infected leaf reflectance was lower in the NIR spectrum than uninfected leaves, which was similar to the spectral properties of greenbug damaged wheat leaves (Riedell and Blackmer, 1999) and canopies found in present study. Remote sensors can quantify what fraction of the photosynthetically active radiation is absorbed by vegetation. In the late 1970s, scientists found that net photosynthesis is directly related to the amount of photosynthetically active radiation that plants absorb. In short, the more a plant is absorbing visible sunlight (during the growing season), the more it is photosynthesizing and the more it is being productive. Conversely, the less sunlight the plant absorbs, the less it is photosynthesizing, and the less it is being productive.

Spectral Characterization of Mustard Canopy at Different Phenological Stage

Spectral reflectance of the mustard canopy was taken at different phenological stage for Pusa Gold (Fig.4), Pusa Jaikisan (Fig.5) and Pusa Bold (Fig.6). There was significant difference in the reflectance in different phenological stage at 720-1360 nm. In the visible region the peak occurred at 550-560 nm in vegetative, flowering and pod formation stage. However, this peak was lower at maturity stage. This is because at vegetative, flowering and pod formation stage green light (500-600nm) being reflected by the green leaf pigments (Riedell and Blackmer, 1999). At maturity, the green leaf pigments become minimum, therefore the peak is smaller as compared to vegetative, flowering and pod formation stages.

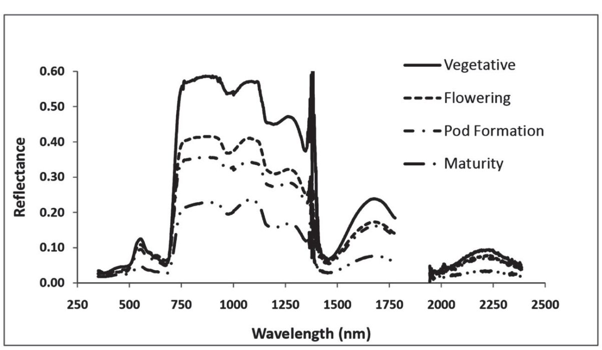

Fig. 4. Spectral reflectance of Pusa Gold at different phenological stages

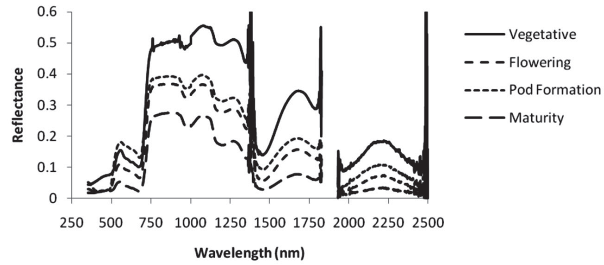

Fig. 5. Spectral reflectance of Pusa Jaikisan at different phenological stage

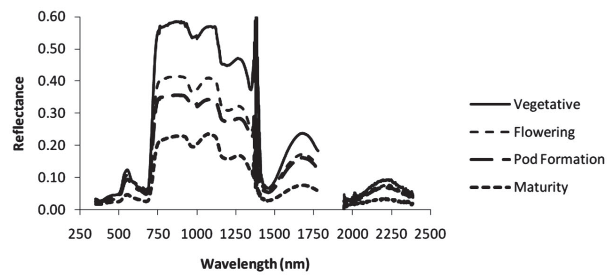

Fig. 6. Spectral reflectance of Pusa Bold at different phenological stage

Spectral Characterization of Different Mustard Varieties

Spectral reflectance of the mustard canopy for Pusa Gold, Pusa Jaikisan and Pusa Bold at vegetative stage are shown in Fig. 7. All three varieties showed similar pattern of spectral reflectance. The reflectance peak at 550-560 nm in visible region was found to be more in Pusa Jaikisan followed by Pusa Gold and Pusa bold. But in 720-1360 nm region the reflectance was more for Pusa Gold followed by Pusa Jaikisan and Pusa Bold. In 1420-1800 nm region the reflectance was more for Pusa Jaikisan followed by Pusa Gold and Pusa Bold.

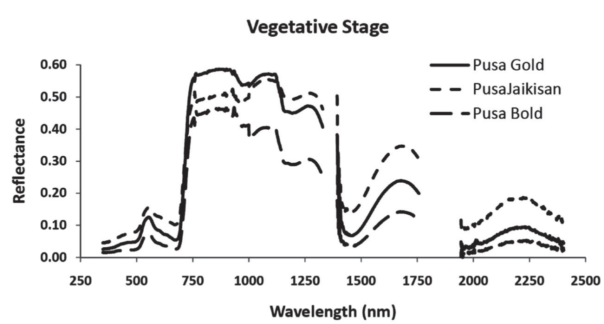

Fig. 7. Spectral Reflectance in different varieties of mustard at vegetative stage

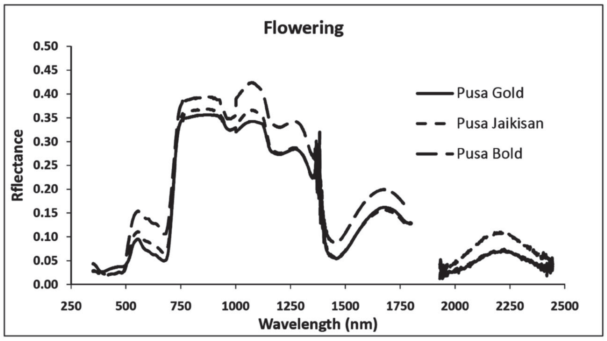

Fig. 8. Spectral Reflectance of different varieties of mustard at flowering stage

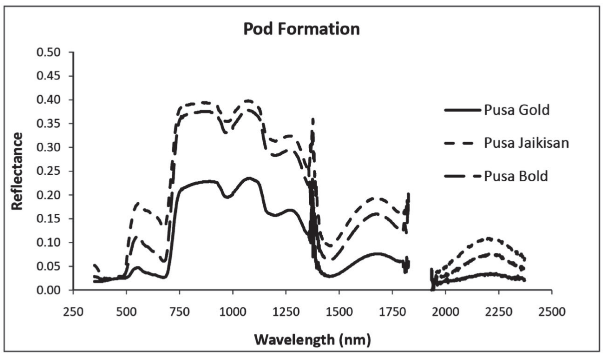

Fig. 9. Spectral Reflectance of different varieties of mustard at pod formation stage

Spectral reflectance of the mustard canopy for all three varieties taken at flowering stage is shown in Fig. 8. All three varieties showed similar pattern for spectral reflectance. The reflectance peak occurred at 550-560 nm in visible region was found to be more in Pusa Bold followed by Pusa Jaikisan and Pusa Gold. The reflectance was found to be more for Pusa Bold as compared to other two varieties.

Spectral reflectance of the mustard canopy for all three varieties taken at pod formation stage is shown in Fig. 9. All three varieties showed similar pattern for spectral reflectance. The reflectance peak occurred at 550-560 nm in visible region was found to be more in Pusa Jaikisan followed by Pusa bold and Pusa Gold. The reflectance was found to be more for Pusa Jaikisan as compared to other two varieties.

Spectral reflectance of the mustard canopy for all three varieties taken at maturity stage is shown in Fig. 10. All three varieties showed

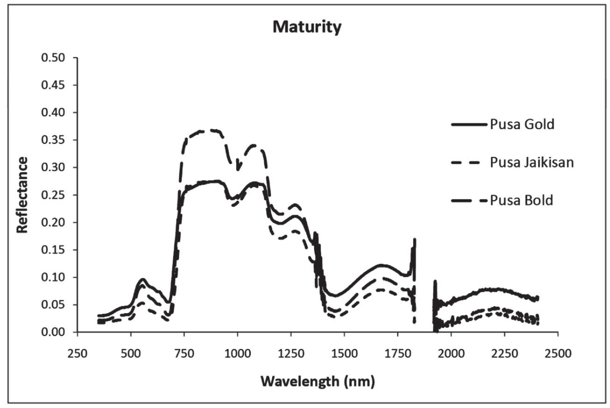

Fig. 10. Spectral Reflectance of different varieties of mustard at maturity stage

similar pattern for spectral reflectance. The reflectance peak occurred at 550-560 nm in visible region was found to be smaller in Pusa Jaikisan as compared to other two varieties. In 720-1360 nm region the reflectance was more for Pusa Bold as compared to other two varieties. In 1420-1800 nm region the reflectance was more for Pusa Gold followed by Pusa Gold and Pusa Jaikisan.

Spectral Indices

The different spectral indices viz. NDVI, AI, RVI and SIPI were calculated from the spectral data taken in the field, laboratory and mustard raised in the pot (Table 2).

The correlation coefficient (Table 3) was found to be positive between aphid infestation and AI. However, NDVI, RVI and SIPI had negative correlation with aphid infestation. Mirik *et al*. (2006) recommended NDVI for studies of damage by aphids in wheat. Because NDVI was strongly related to damage by greenbug.

Table 2a. Spectral indices of aphid infested mustard crop at different density levels of infestation in the field

INDEX	Infested plant (level1)	Infested plant (level 2)
hNDVI	0.78	0.74
AI	0.58	7.85
SIPI	1.01	1.01
RVI	8.14	6.74

Table 2b. Spectral indices of aphid infested mustard crop at different density level of infestation in the laboratory (Control Condition)

INDEX	Infested plant (level 1)	Infested plant (level 2)	Infested plant (level 3)
hNDVI	0.71	0.48	0.46
AI	0.46	22.0	35.0
SIPI	1.00	0.94	0.90
RVI	5.60	2.87	2.71

Table 2c. Spectral indices of aphid infested mustard crop at different level of infestation measured in the Pot (net house condition)

INDEX	Infested plant (level 1)	Infested plant (level 2)
hNDVI	0.45	0.33
AI	1.23	2.00
SIPI	1.54	1.18
RVI	2.61	1.98

Table 3. Correlation coefficient among different spectral indices

	NDVI	AI	SIPI	RVI
NDVI	1	-0.934*	0.962**	0.975**
AI		1	-0.971**	-0.873
SIPI			1	0.916*
RVI				1

** Significance at the level of $p<0.01$

* Significance at the level of $p<0.05$

In general, NDVI reflects growing status of green vegetation, so crop monitoring and crop yield estimation could be realized by using remote sensing technique on the basis of time serial NDVI data together with agriculture calendars. Either scenario results in an NDVI value that, over time, can be averaged to establish the normal growing conditions for the vegetation in a given region for a given time of the year. In short, a region's absorption and reflection of photosynthetically active radiation over a given period of time can be used to characterize the health of the vegetation there, relative to the normal.

There are many studies attempting to correlate spectral vegetation indices with damages by greenbug or any other damages estimated through digital image analysis. However correlating the estimates of leaf area index to spectral vegetation indices has been a well established practice in remote sensing studies (Anderson *et al*., 2004; Hu *et al.,* 2004; Walthall *et al*., 2004; Schlerf *et al*., 2005). Another comparison that has long been used is the relationship between vegetation indices and plant chlorophyll concentration (Broge and Mortensen, 2002).

Conclusion

The conclusion derived from this study is that remote sensing can be a useful tool for monitoring the effect of aphid infestation in mustard crops using hyperspectral data. The most significant spectral bands for the aphid infestation in mustard are at visible (550-560 nm), near infrared region (700-1250 nm) and 1950-2450 nm. The different level of aphid infestation can be identified in 1950-2450 nm. RVI, SIPI and NDVI had positive correlation with each other and negative correlation with AI. The different phenological stages of mustard can be identified using hyperspectral data.

Acknowledgements

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