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Hyperspectral radiometry for the detection and discrimination of damage caused by sucking pests of cotton

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ABSTRACT

Use of remote sensing techniques for detection of crop stress due to pests and diseases is based on the assumption that stresses induced by them interfere with photosynthesis and physical structure of the plant, affect absorption of light energy and thus alter the reflectance spectrum of plants. Field experiments were conducted to detect and estimate damage caused by sucking pests in cotton (cv. Surabi) at regular intervals using GER1500 spectroradiometer, from which canopy reflectance was recorded and vegetation indices (VI) were worked out. There was a decrease in near infrared (770-860nm) while blue (450-520nm), green (520-590nm) and red (620-680nm) reflectances increased compared to undamaged plants. The mean VI values in damaged plants were comparatively lower than undamaged plants in all days of observation. Among spectral bands, red band was highest to thrips and leafhopper damage while NIR band was found to be more sensitive to aphid damage. In the aphid damage sensitivity curves, the trough in green region was not very conspicuous while thrips and leafhopper damage curves had a clear low point in green region at 550 nm in all days of observation. Green red vegetation index (GRVI) was observed to be sensitive in differentiation of sucking pests damage.

KEY WORDS: Canopy reflectance, cotton, vegetation indices, Spectroradiometry

INTRODUCTION

Remote sensing is an economical, exhaustive, simple and fast. It is used as early warning system against possible threats (like natural calamities). The remotely sensed data provide considerable potential for estimating agricultural area and yield forecasting at local, regional, and global scales (Khajeddin and Pourmanafi, 2007; Serra *et al.*, 2007).

Earlier, multispectral remote sensing (with broadband data) has been applied to monitor crop growth status for various purposes (Shibayama and Akiyama, 1991; Cloutis *et al.*, 1996). Multispectral data was useful in identifying reflectance obtained from crop due to incidence of pests and diseases (Summy *et al.*, 1997), weeds (Brown *et al.*, 1994) and mites (Penuelas *et al.*, 1995; Fitzgerald *et al.*, 1999a, 1999b) but due to its limited spectral coverage, multispectral remote sensors may not be able to uniquely identify the damage-causing stressor.

Hyperspectral remote sensing is a technique that utilises sensors operating in hundreds of narrow contiguous spectral bands, which offers potential to improve the assessment of crop diseases and pests. Relationships between spectral characteristics and symptoms of infestations must be adequately investigated based on ground studies, before the development of the remote sensing algorithms and management schemes, thus helps to play an effective role in crop pest management (Yang *et al.*, 2007). It is a precision tool that can detect plant health through analysis of their spectral signatures (Reisig and Godfrey, 2007). So, the present study was focused on hyperspectral radiometry that detect and discriminate the damage caused by sucking pests.

MATERIALS AND METHODS

Field experiments were conducted for detecting and discriminating damage caused by sucking pests in cotton using hyperspectral radiometer at Tamilnadu Agricultural University, Coimbatore during 2012-13. The damage was studied in winter irrigated variety Surabi, with observations taken from 30 to 90 days after sowing at different intervals when incidence of pest was noticed. The plants which were marked as undamaged, protected from pest damage by spraying the suitable insecticides periodically while in the damaged plots, no measures were taken. However, all the plots were kept disease free by monitoring and spraying fungicide/ bactericide carefully whenever necessary.

Spectral reflectance

Percent spectral reflectance was recorded from 30 to 90 days after sowing using the field portable Spectroradiometer (model: GER 1500). The canopy spectral data was collected by pointing the instrument at a distance of 30cm above the cotton canopy on clear sunny days between 10AM and 1PM IST. The instrument was optimized, calibrated initially using barium sulphate panel (reference) and for every five minutes onwards to adapt to the changing atmospheric conditions as mentioned by Luther and Carroll (1999) and Abdel-Rahman *et al.*, (2010). The percent reflection is calculated using the following formulae.

$$\text{Percent reflectance} = \frac{\text{Reflectance from target (plant canopy)}}{\text{Reflectance from reference (barium sulphate panel)}} \times 100$$

The 512 values of percent spectral reflectance of approximately 1.5nm bandwidth from 276.86 to 1093.5nm were obtained. The spectral reflectance in blue (450-520 nm), green (520-590 nm), red (620-680 nm) and NIR (770-860 nm) regions of electromagnetic spectrum were recorded. The wavelength ranges used in our experiments for green, red and NIR were taken to match the bands in the LISS III, LISS IV (Linear Imaging Self Scanning Sensor) and AWiFS (Advanced Wide Field Sensor) of latest Indian remote sensing satellites namely Resourcesat 1 and 2. The blue band was taken to match with LANDSAT 7 Enhanced Thematic Mapper Plus (ETM+) sensor spectral bands.

Band sensitivity analysis

Sensitivity, at a given wavelength or band was computed by using the following formula (Carter, 1993).

$$\text{Band Sensitivity} = [(R_{INF} - R_{CTRL}) / R_{CTRL}] \times 100$$

Where, R_{INF} and R_{CTRL} were canopy reflectance of infested and control plants respectively.

The variation in light intensity between observations caused shifting of sensitivity curve along y-axis. In order to correct this, a corrected sensitivity was worked out as below. The reflectance in the wavelength range 350-370 nm was found to have no affect due to pest damage, based on preliminary observations. Hence, the average of sensitivity values between 350-370nm was taken as zero. This was taken as correction factor and was applied to sensitivity values at other wavelengths by adding or subtracting. The corrected sensitivity values have been reported as the sensitivity values.

Correlation intensity analysis

Pearson correlation coefficient (r) between the pest infestation and the reflectance at each 1.5nm wavelength was calculated from the pooled data and correlation intensity curves were plotted to assess the relationship between them. The spectral bands with high absolute correlation coefficient values at different peaks along the spectral domain were considered as sensitive bands for relating reflectance spectra to pest infestation while those with small absolute correlation coefficients are considered unrelated to the pest damage (Malthus and Madeira, 1993; Yang *et al*., 2007; Prabhakar *et al*., 2011).

Vegetative indices

Vegetation Indices (VIs) are different combinations of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. It includes differences, ratios or linear combinations of reflected light in visible and NIR wavebands (Richardson and Wiegand, 1977; Tucker, 1979).

Normalized Difference Vegetation Index (NDVI) is the normalized difference of reflectance in NIR and red bands.

$$NDVI = (R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED})$$

Ratio Vegetative Index (RVI) is the ratio of the reflectance in NIR and red bands (as described by Mirik *et al*., 2006; Yang *et al*., 2009). They were used to detect plant stress and can be saturated at high leaf area index (LAI).

$$RVI = R_{NIR} / R_{RED}$$

Green Red Vegetation Index (GRVI) (Motohka *et al*., 2010) show small changes in vegetation condition during crop growth and calculated using the following formulas.

$$GRVI = (R_{GREEN} - R_{RED}) / (R_{GREEN} + R_{RED})$$

where R_{RED}, R_{GREEN} and R_{NIR} are reflectance at red, green and NIR bands, respectively.

Sensitivity analysis of vegetative indices

Sensitivity for given vegetation index was calculated by using the following formula,

$$\text{Vegetative Index Sensitivity} = [(VI_{INF} - VI_{CTRL}) / VI_{CTRL}] \times 100$$

Similarly, VI_{INF} and VI_{CTRL} were vegetation index of infested plants and control plants. Sensitivity analyses were performed for the data obtained from field studies.

RESULTS AND DISCUSSION

Discriminating damage caused by one pest from the other has been a challenge with the help of reflectance data. However, an attempt has been made to differentiate damage caused by various sucking pests of cotton using the reflectance data and further analysis of the data.

Spectral reflectance in damaged plants

The results showed that when the percent reflectance was plotted against wavelength, there was a decrease in blue (450-520 nm) and red (620-680nm) regions while an increase in green (520-590 nm) and NIR region (770-860nm) in damaged plants compared to undamaged plants. This finding is in accordance with the findings of Carter (1993); Shibayama *et al*. (1993); Riedell and Blackmer (1999) and who reported that the stressed plants have a lower reflectance in NIR region (700–1300 nm), a higher reflectance in the far-red region of the spectrum, and a consequent shift of the red edge. Due to damage, the spectral reflectance increased in visual region and decreased in NIR at all days of observation which showed similar to work of Mirik *et al.* (2007) on Russian wheat aphid-infested wheat canopies. The difference in reflectance curve (among different regions) obtained is due to absorption of visible light by chlorophylls present in epidermal cells of leaves and multiple reflection of NIR radiation in spongy tissues. In both damaged and healthy plants, percent reflectance varied in different regions. Within visible region, the increase in red reflectance in pest damaged plants may be due to the loss of photosynthetic pigment concentration in particular chlorophylls scratching/sucking of pests. The decrease in reflectance in NIR region may be due to loss of leaf area, foliage density and other changes in canopy characteristics (Gausman, 1974).

Sensitivity of spectral bands to pest damage

The percent sensitivity was calculated to different sucking pests using the formulae given before. The pest incidence was observed regularly with 5 to10 days interval from 30 to 100 days after sowing and it was found that, aphids, leafhopper and thrips caused maximum damage at 50, 65 and 70 days after sowing respectively (Fig 1).

Among spectral bands, red band was highest to thrips and leafhopper damage while NIR band was found to be more sensitive to aphid damage when there was an active damage stage in the crop. On 50 DAS, the sensitivity of blue, green, red and NIR band were 4.0, 5.6, 8.2 and -11.4 per cent respectively indicating NIR band was comparatively more sensitive to aphid damage. The sensitivity of blue, green, red and NIR band were 5.5, -0.1, 13.3 and -8.6 for leafhopper (on 65 DAS) while 9.5, -0.2, 20.7 and 2.9 respectively to thrips damage (on 70 DAS) indicating Red band followed by blue was comparatively more sensitive to both thrips and leafhopper damage (Table 1).

The percent sensitivity of spectral bands/indices can provide information on usefulness of the band for detecting pest damage. The higher the magnitude of the percent sensitivity, the higher will be the effect explained by the band/index (irrespective of the sign either positive or negative). The sign indicates if the reflectance in the given band increases or decreases with increase in damage by pest.

Sensitivity curve

The sensitivity curve was very characteristic to the damage caused by each sucking pests on all days of observation. When a graph was plotted with sensitivity against wavelength, the shape of the sensitivity curves was more or less consistent for any given pest on different days of observation. The curve showed single peak in blue region at about 496nm (thrips), twin peaks in blue region at about 408nm and 509nm (leafhopper) while there was no conspicuous trough in green region but a clear low point in green region at 550nm (aphids) on all days of observations. In the aphid damage sensitivity curves, the trough in green region was not very conspicuous while thrips and leafhopper damage curves had a clear low point in green region at 550 nm in all days of observation (Fig 1).

Correlation intensity curve

The correlation coefficients between pest damage and reflectance values plotted against the respective wavelengths showed that 651, 689, 691, 710, 758, 766 nm wavelengths were sensitive to sucking pest damage (Fig 2). Prabhakar *et al.* (2011) observed similar correlation intensity curve in leafhopper affected cotton plants and reported 376, 496, 691, 761, 1124 and 1457 nm to be sensitive bands.

Sensitivity of spectral indices to pest damage

Among the vegetative indices, GRVI was found to be more sensitive to thrips and leafhopper damage, while RVI were found to be very sensitive to aphid damage. The sensitivity of indices RVI, NDVI and GRVI on 50 DAS to aphid damage were -16.2, -3.6 and -5.4 respectively, they were -18.8, -4.4 and -25.5 respectively at 65 DAS (leafhopper) while they were -15.5, -3.3 and -45.2 respectively at 70 DAS in case of thrips (Table 1). The sensitivity of spectral indices can be utilized for differentiating the pests. The per cent sensitivity of GRVI range from -13 to -45 in case of thrips and leafhopper damage while these values ranged between -6 and +9 in aphids damage in most of the days of observation indicating the superiority of GRVI in discriminating aphid damaged plants.

The sensitivity of spectral indices can be utilized for differentiating the pests. Among the vegetation indices, GRVI was more sensitive to thrips and leafhopper damage and aphid damage. The per cent sensitivity of GRVI in thrips and leafhopper damaged plants of range from -15 to -45 during active damaging stage. These values ranged between -6 and +9 in aphids damaged plants in most of the days of observation indicating the superiority of GRVI in discriminating aphid damaged plants. Hence, a GRVI per cent sensitivity value of -6 to +10 can be used as a diagnostic feature for aphid damage when per cent damage is around 10 to 25%.

Per cent Sensitivity of GRVI	Pest diagnosed
-6 to +10	Cotton aphids
-15 to -45	Cotton leafhopper and thrips

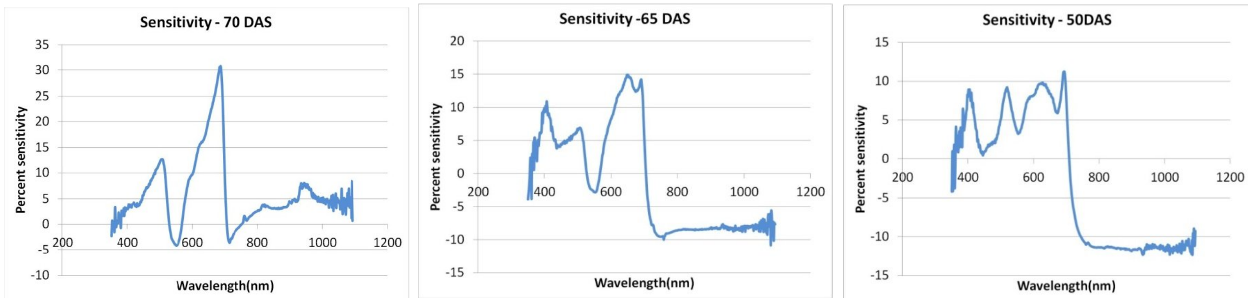
Yang *et al*. (2009) found that **r**atio-based vegetation indices (based on 800/450 nm and 950/450 nm) were found useful in differentiating the two stresses in wheat due to infestation by green bugs and Russian wheat aphids**.** However, Reisig and Godfrey (2007) found that though it was possible to detect cotton aphid and spider mite damaged leaves by tracking the spectral changes in the leaf, the damage type of each arthropod could not be distinguished spectrally.

CONCLUSION: It was found that detection and estimation of damage caused by various sucking pests of cotton can be done using hyperspectral radiometry. In addition to this, discrimination of the damage caused by one pest from the other is also possible using this technique.

Table 1: Percent Sensitivity of Reflectance bands / indices to different sucking pest damage at different days of observation

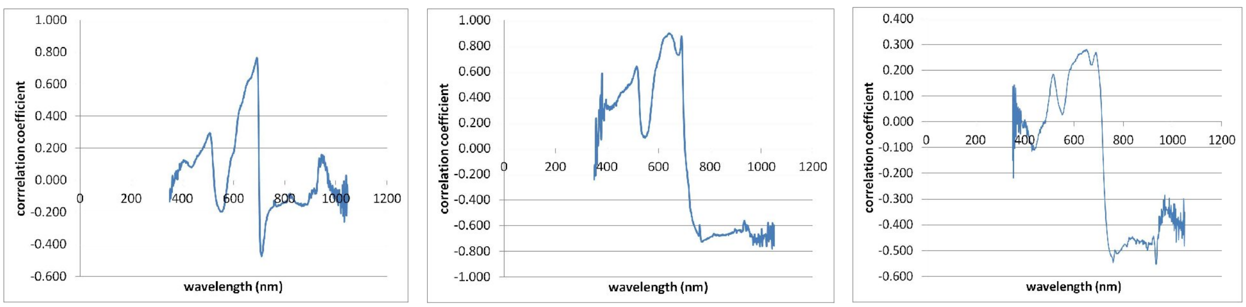
Percent Sensitivity to different sucking pest damage at different days of observation									
	Aphids			**Leafhopper**			**Thrips**		
Days after sowing	**30**	**50**	**70**	**45**	**55**	**65**	**70**	**80**	**90**
Reflectance bands									
Blue (450- 520 nm)	5.8	**4.0**	12.9	20.5	16.1	**5.5**	**9.5**	3.5	14.6
Green (520–590 nm)	16.3	**5.6**	16.1	1.3	13.0	**-0.1**	**-0.2**	-1.6	-6.9
Red (620 – 680 nm)	16.8	**8.2**	11.6	21.4	21.6	**13.3**	**20.7**	13.9	7.1
NIR (770-860 nm)	-11.3	**-11.4**	-11.5	-6.9	-9.8	**-8.6**	**2.9**	-5.6	-2.8
Reflectance indices									
RVI	-23.4	**-16.2**	-17.8	-23.9	-24.7	**-18.8**	**-15.5**	-15.8	-9.3
NDVI	-6.1	**-3.6**	-4.0	-6.3	-5.4	**-4.4**	**-3.3**	-2.9	-1.8
GRVI	-1.2	**-5.4**	9.0	-36.9	-13.3	**-25.5**	**-45.2**	-24.4	-28.4

*DAS – days after sowing; The data in the bold represents the day when maximum pest damage was observed for the concerned pest.



Thrips damaged **Leaf hopper damaged** **Aphids damaged**

Fig. 1: Sensitivity curves of damaged and undamaged cotton plants



Thrips (70DAS) **Leaf hopper (65DAS)** **Aphids (50 DAS)**

Fig. 2: Correlation of reflectance in different wavelengths to per cent leaf damage in cotton plants (Surabi, Winter Irrigated, 2012)

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