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Damage assessment of chilli thrips using high resolution multispectral satellite data

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ABSTRACT

Remote sensing technology offers an effective, rapid and reliable tool for assessing pest severity in vegetation. Ground based hyperspectral radiometry studies revealed significant difference in the reflectance spectra between healthy and thrip damaged vegetation. Space borne multispectral reflectance from Sentinel 2A satellite data of chilli thrip infested canopy has significant differences in red region (Band 4 – 664.6 nm), NIR region (Bands 5, 6, 7, 8 & 8A having central wavelengths at 704.1, 740.5, 782.8 & 832.8 nm, respectively) and SWIR region (Bands 11 & 12 having central wavelengths at 1613.7 and 2202.4 nm). In this study, an attempt was made to discriminate healthy and pest affected chilli crop in the multispectral satellite imagery using several multispectral vegetation indices. Of these, land surface water index, LSWI (p=0.018) and normalized difference water index, NDWI (p=0.001) were found significant. These indices were used to classify chilli fields in the satellite imagery into severe, moderate and healthy classes. Superior performance of LSWI over NDWI with overall accuracy of 93.80 and Kappa Coefficient of 0.89 was observed. Moran's Index was used to study the spatial distribution of chilli thrips and observed strong clustering (I= 0.9073, p=0.0001).

***Keywords*: Pest, crop stress, spectral vegetation index, remote sensing, spatial distribution**

Chilli, *Capsicum annum* L. (Family: Solanaceae) is the most important commercial crop commonly known as hot pepper, chilli pepper, *paprika* and *aji* (Mahasuk *et al.*, 2009). It is mainly grown for its fruits, both green and ripe (dried form) to impart pungency to the food. Chilli is cultivated globally in about 1.5 million hectares with production of 7 million tonnes. India is the leading country in chilli production with a share of 50-60 %, followed by China and Pakistan (Thamaraikannan *et al.*, 2011). In India, green chilli is cultivated in 0.29 million hectares with production of 2.95 million tonnes, while dried chilli is grown in 0.81 million hectares with production of 1.52 million tonnes. Andhra Pradesh is the leading state in India with cultivated area of 0.02 and 0.16 million hectares under green and dried chillies with production of 0.34 and 0.62 million tonnes, respectively (Anonymous, 2017). Damage by insect pests is a major production constraint in chilli cultivation. Thrips (*Scirtothrips dorsalis* Hood) is one of the most important pest on chillies in India and is reported to cause yield loss up to 12-90 % (Patel *et al.,* 2009; Rai *et al.,* 2014). Thrip infestation manifests into damage symptoms viz., leaf curl, leaf drop, dropping of fresh buds, besides a vector for mosaic and leaf curl viral diseases.

Timely assessment of severity of pest and disease incidence is crucial for estimating economic impact and deciding upon adoption of appropriate control measures. Traditionally, area-wide pest and diseases damage is assessed through visual observation by field scouts. However, it is time consuming, laborious, difficult to cover large area in a short time and often error prone. Recent advances in remote sensing offer immense scope to assess area-wide crop pest damage (Sindhuja *et al*., 2010; Prabhakar *et al.,* 2011). The basic premise on use of remote sensing for pest management is that when plants are infested by pests, the canopy is subjected to various changes *viz.*, internal damage in chlorophyll pigments, tissue structure, photosynthesis and metabolism. Consequently, the damaged plants will have different spectral features compared to healthy plants depending on the nature and magnitude of damage. Optical remote sensing discriminates these spectral differences to identify the damaged plants in field (Prabhakar *et al*., 2013).

Previous studies on use of ground based and spaceborne remote sensing have been reported for assessing pest and disease damage in field crops like rice, cotton, wheat, groundnut, soybean, mustard and sugarcane (Zhihao and Minghua 2005; Reisig and Godfrey 2006; Bauriegel *et al.,* 2011; Prabhakar *et al.,* 2013; Das *et al.,* 2013; Varsha *et al.,* 2017). Qin and Zhang (2005) used multispectral ADAR imagery to detect rice sheath blight disease. While, Willers *et* *al.* (2005) used broad band airborne multispectral imageries to identify the differences in growth pattern induced by tarnished bug infestation. Du *et al.* (2008) also used multispectral remote sensing to detect beet army worm and cabbage looper damage in cotton, and greasy spot disease in citrus, respectively. Elliott *et al.* (2007) used a three band multispectral imaging system to differentiate varying levels of injury caused by Russian wheat aphid, Diuraphis noxia. But such studies on vegetable crops are very few (Apan *et al.,* 2005; Dutta *et al.,* 2014). The objectives of the study were to examine the feasibility of remote sensing based indices to identify pest infestation in chilli crop and mapping of chilli thrip affected fields using space borne multispectral data.

MATERIALS AND METHODS

Field survey

Chilli crop with severe outbreak of thrip, *Scirtothrips dorsalis,* Hood in Manopad and Itikyal mandals of Mahaboobnagar district (15° 59' 0" N to 16° 20" N and 77° 55' 0"E to 78° 1 0" E), Telangana State was identified for the study during the *rabi* season of 2015-2016. The soil in the study site was deep vertisols and the total rainfall is about 705 mm. The major commercial crops cultivated during the period were cotton, chilli and tobacco. A total of 51 fields were randomly surveyed in these two predominantly chilli growing mandals. Based on the visible appearance of symptoms, plants were categorized into one of the three severity grades *viz.,* healthy, moderate (upto 50 % leaves with curling and puckering symptom) and severe (>75% foliage showing curling symptoms). Location details of the fields were recorded using DGPS (Trimble Geo XT, USA).

Ground based spectral reflectance data

Reflectance data was recorded with hand held FieldSpec3 Hi-Res spectroradiometer (ASD Inc., Boulder, USA; spectral range: 350-2500 nm). The sampling interval was 1.4 nm at 350-1000 nm range, and 2 nm at 1000-2500 nm range. The spectral resolution (Full Width Half Maximum) was 3 nm at 700 nm, 6.5 nm at 1400 nm, and 8.5 nm at 2100 nm. The instrument is attached to standard foreoptic with 25° Field of View (FOV) through a permanent fiberoptic cable. Plant probe with an in built 100W reflectorized halogen lamp was used to collect reflectance spectra from individual leaves with different severity grades. The instrument was warmed-up for 15 min prior to field measurements to avoid spectral steps at detector overlap wavelength region. Large numbers of chilli plants with varying levels of thrip damage symptoms in the field from different fields were used for the collection of reflectance spectra. The radiometer was configured to record 30 scans for each sample. Every surface measured by the foreoptic was processed as a ratio between digital number (DN) of the surface relative to DN of the Spectralon white reference. Collected spectral data were interpolated using ASD ViewSpecPro software in the post processing to produce values at each nanometer interval (ASD, 1999).

Satellite data procurement and processing

Sentinel 2A, level 1c data was used to assess the damaged areas of the chilli crop in the study area. This satellite has high resolution multispectral camera on board with 13 spectral bands covering from 443 to 2190 nm, with a swath width of 290 km and a spatial resolution of 10 m (three visible and one near-infrared bands), 20 m (four red edge and two shortwave infrared bands) and 60 m (three atmospheric correction bands). The data were procured for the two selected dates of 10th January, 2016 and 9th February, 2016 when the pest infestation was at its peak. The satellite images were geo-referenced using ground truth GCPs with the second order polynomial equation and then processed with the Sen2Cor processor (version 2.5.5; European Space Agency http://step.esa.int/main/third-partyplugins-2/sen2cor/), which performs topographic correction and transforms top-of-atmosphere reflectance to bottom-of-atmosphere reflectance.

Spectral reflectance from healthy and different levels of thrips damaged chilli crop, was used to calculate the spectral vegetation indices viz., Normalized Difference Vegetation Index (NDVI), Soil-adjusted Vegetation Index (SAVI), Land Surface Water Index (LSWI), Normalized Difference Infrared Index (NDII) and Normalized Difference Water Index (NDWI) (Table 1). Independent t-test (SPSS version 23.0, IBM Corporation, Armonk, USA) was performed between different spectral vegetation indices of healthy and damaged crop to identify the significant vegetation indices specific to the chilli thrips damage. Significantly superior indices were used to classify the crop into different categories of infestation (healthy, medium and severe) based on the ground truth. Classified images were assessed for accuracy using confusion or error matrix (Congalton and Green, 1999).

Spatial distribution of chilli thrips damage

Moran's I test was performed to study the spatial distribution of the thrips damage in different fields by the following formula:

$$I = \frac{N \sum_{1=i}^{n} \sum_{1=j}^{n} w_{ji} \ (x_i - \bar{x}) x(_j - \bar{x})}{(\sum_{1=i}^{n} \sum_{1=j}^{n} w_{ji} \ ) \sum_{1=i}^{n} (x_i - \bar{x})}$$

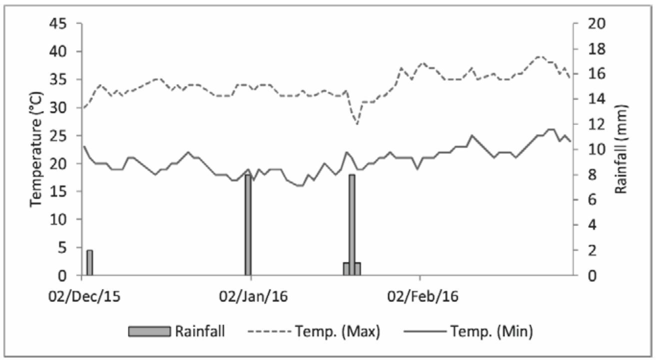

Fig. 1: Weather during the study period

Where N is the number of observations, x is the variable of interest, is $\bar{x}$ the mean of the variable, x_i and x_j are the variable values at a locations *i* and *j*, and w_{ij} is a weight index of the location of *i* relative to *j* (Moran, 1950).

Z-score and corresponding p-value indicate whether or not we can reject the null hypothesis that the point feature values are randomly distributed across the study area. The Z-score was calculated with the following formula:

$$Z = \frac{I - E[I]}{\sqrt{V[I]}}$$

Where, E[I] = -1/(n-1) and V[I] = E[I2]-E[I]2 .

The LSWI image data values were converted to point feature data for the analysis of spatial distribution of thrips damage. Spatial autocorrelation (Moran index) was done by using ArcGIS 10.3.

RESULTS AND DISCUSSION

Weather plays a key role in determining the seasonal abundance and damage by pests. Weather data of the area showed scanty rainfall during the study period (December 2015 to February, 2016) and the mean maximum temperature was relatively high (33.94°C) (Fig. 1). Such dry and hot weather is highly favourable for thrip outbreak on chillies (Rai *et al.,* 2014, Yadav *et al.,* 2014; Seal and Klassen, 2015).

Ground based radiometry

The mean reflectance spectra of plants with different levels of thrips infestation clearly showed that the spectral response of the chilli canopies was affected by thrip infestation (Fig. 2). Healthy and thrips infested plants showed that the reflectance in NIR region was significantly lower from the infested plants compared to healthy ones. Conversely, in the visible region (blue and red region), less light was absorbed, or reflectance of light energy in the visible region was high from the infested plants. Damage to chilli by thrips is due to sucking of cell sap, leading to cell damage (Kirk, 1997), accelerate the aging process and reduction in photosynthesis (Ellsworth *et al.,* 1995).

Spaceborne remote sensing

Variations in absorption of light in the visible and NIR region are due to changes in plant pigment and internal structure (Singh *et al.,* 2013). Thrips prefer to feed on the upper young leaves mainly due to high nitrogen content in these leaves (Mattson, 1980). Increased reflectance in Bands 4 and 5 (visible region) could be attributed to decrease in chlorophyll content due to thrip infestation. Whereas increase of reflectance in Bands 6 to 9 (NIR region) could be due to absorption feature in this region for plant pigment, particularly chlorophyll, low nitrogen content could have resulted in decreased chlorophyll pigment, and thereby a reduced absorption of radiation. Increase of reflectance from bands 11 and 12 could be due to loss of water content (Roy, 1989). These findings are similar to Thomas *et al.* (1966) who reported that chilli plants damaged by thrips contain low nitrogen content, low chlorophyll pigment and hence more reflectance observed in visible region. While low reflectance reported in infrared region due to damage to internal structure of chilli leaves. Sentinel-2A satellite data was used to assess area-wide damage by thrips on chilli crop. Broadband spectral vegetation indices derived from the satellite data acquired for two time periods (10.01.2016 and 9.02.2016) was used to estimate chilli infestation.

Among the five spectral vegetation indices that were evaluated to assess thrip damage using space borne remote sensing data, only two indices *viz.,* LSWI (p=0.018) and NDWI (p=0.0001) were found more significant. This may be because these two indices are based on water content in the target. Whereas the other three indices *viz.,* NDII, NDVI and SAVI are not directly related to moisture content, thereby their ability to discriminate thrips damage was not significant (Table 2). Kolb *et al.* (1991) reported similar findings and found LSWI effective in monitoring thrip damage in chilli as the damaged crop experienced water stress and reduced photosynthesis. Similarly, the NDWI has been successfully used to assess changes of vegetation water content (Gao, 1996; Zarco-Tejada *et al.,* 2003).

The two best performing indices *viz.,* LSWI and NDWI were used to classify chilli fields in the Sentinel 2A satellite data into different categories of infestation (healthy, medium and severe). Values of LSWI in the range of 0.04 to 0.18 were classified as severe, whereas values between 0.18 to 0.24 and

Table 1: Vegetation indices used in this study.

S. No	Spectral vegetation index	Formula	Corresponding Sentinel bands used	References
1	Normalized Difference Vegetation Index (NDVI)	$\frac{\rho_{in} - \rho_{er}}{\rho_{in} + \rho_{er}}$	$\frac{naB\ 8 - naB\ 4}{naB\ 8 + naB\ 4}$	Rouse *et al.* (1974)
2	Land Surface Water Index (LSWI)	$\frac{\rho_{in} - \rho_{iws}}{\rho_{in} + \rho_{iws}}$	$\frac{naB\ 8a - naB\ 11}{naB\ 8a + naB\ 11}$	Xiao *et al.* (2004)
3	Soil-adjusted Vegetation Index (SAVI)	$\frac{(1+\mathrm{L})\,(\rho_{800} - \rho_{670})}{(\rho_{800} + \rho_{670} + \mathrm{L})}$	$\frac{(1+\mathrm{L})\,(\mathrm{Band\ 8} - \mathrm{Band\ 4})}{(\mathrm{Band\ 8} + \mathrm{Band\ 4} + \mathrm{L})}$	Huete (1988)
4	Normalized Difference Infrared Index(NDII)	$\frac{\rho_{819} - \rho_{1600}}{\rho_{819} + \rho_{1600}}$	$\frac{naB\ 8 - naB\ 11}{naB\ 8 + naB\ 11}$	Hardisky *et al.* (1983)
5	Normalized Difference Water Index (NDWI)	$\frac{\rho_{858} - \rho_{2130}}{\rho_{858} + \rho_{2130}}$	$\frac{naB\ 8a - naB\ 12}{naB\ 8a + naB\ 12}$	Gu *et al.* (2007)

Table 2: Comparison of vegetative indices for chilli healthy and damaged crop.

Vegetation indices	GRADE	Mean ± SD	Independent t-test	
			t	p
LSWI	Healthy	0.35 ± 0.03	23.873	0.018*
	Infested	0.15 ± 0.05		
NDII	Healthy	0.29 ± 0.04	23.448	0.314NS
	Infested	0.08 ± 0.05		
NDVI	Healthy	0.56 ± 0.04	17.792	0.498NS
	Infested	0.40 ± 0.05		
SAVI	Healthy	0.37 ± 0.03	18.054	0.552NS
	Infested	0.24 ± 0.03		
NDWI	Healthy	0.62 ± 0.04	22.771	0.0001**
	Infested	0.38 ± 0.06		

*significant at $p<0.01$, **significant at $p<0.001$, NS=non-significant, sample size=51 fields

0.24 to 0.50 were classified as medium and healthy, respectively (Fig. 3). Whereas the NDWI values between 0.5 to 0.72, 0.4 to 0.52 and 0.2 to 0.4 were categorized as healthy, moderate and severe classes (Fig. 4). The classification accuracy assessment using error matrix for the two indices (LSWI and NDWI) is presented in Tables 3 and 4.

The producer's accuracy of LSWI classified image showed that healthy, moderate and severe infestation in chilli were to be 98.78, 89.46 and 86.27%, respectively, and user's accuracy were found 55.39, 23.04 and 21.57%, respectively. The error matrix indicated that Kappa Coefficient was 0.89 and overall classification accuracy was 93.80%. Whereas, the producer's accuracy for NDWI classification of chilli under healthy, moderate and severe infestation was found to be 91.50, 82.70 and 85.01%, respectively and users' accuracy were found to be 91.33, 74.71 and 94.53%, respectively. The error matrix indicated that Kappa Coefficient for NDWI was 0.89 and overall classification accuracy was 86.92%. Based on the overall accuracy and Kappa coefficient values, the LSWI was found to be superior compared to NDWI. Therefore, the LSWI was used to estimate area damaged by thrips and their infestation levels from the satellite imagery. The results showed that the chilli area under healthy fields was reduced from 2244.6 ha to 840.6 ha over a period of one month (10th January and 9th February 2016), mostly due to thrip damage. Whereas, the chilli area under medium and severe thrip damage categories increased from 174.28 ha to 807.48 ha and 215.04 ha 786.16 ha, respectively (Fig. 5). Earlier studies using ground based hyperspectal radiometry in vegetable crops by Apan *et al.* (2005) showed that defoliation caused by spotted lady bird beetle in tomato and yellowing/drying off symptoms caused by early blight disease in egg plant could be distinguished by differences in spectral regions corresponding to Red Edge (690-720nm), Visible (400-700nm), NIR (735-1142nm) and SWIR (1590-1766nm). Dutta *et al.* (2014) showed that LSWI and NDVI could be used successfully to discriminate healthy and late blight affected potato in West Bengal, India using AWiFS and MODIS satellite data.

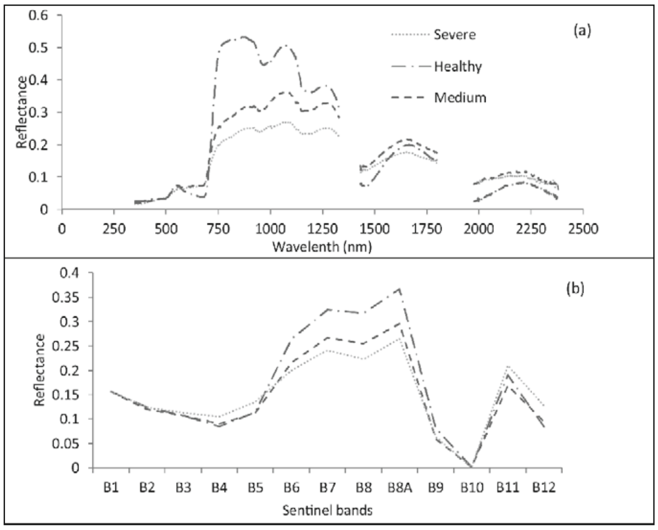

Fig. 2: Changes in spectral reflectance in chilli canopy due to thrip damage (a) Hyperspectral handheld radiometer-ASD Fieldspec (b) Multispectral Spaceborne-Sentinel-2A

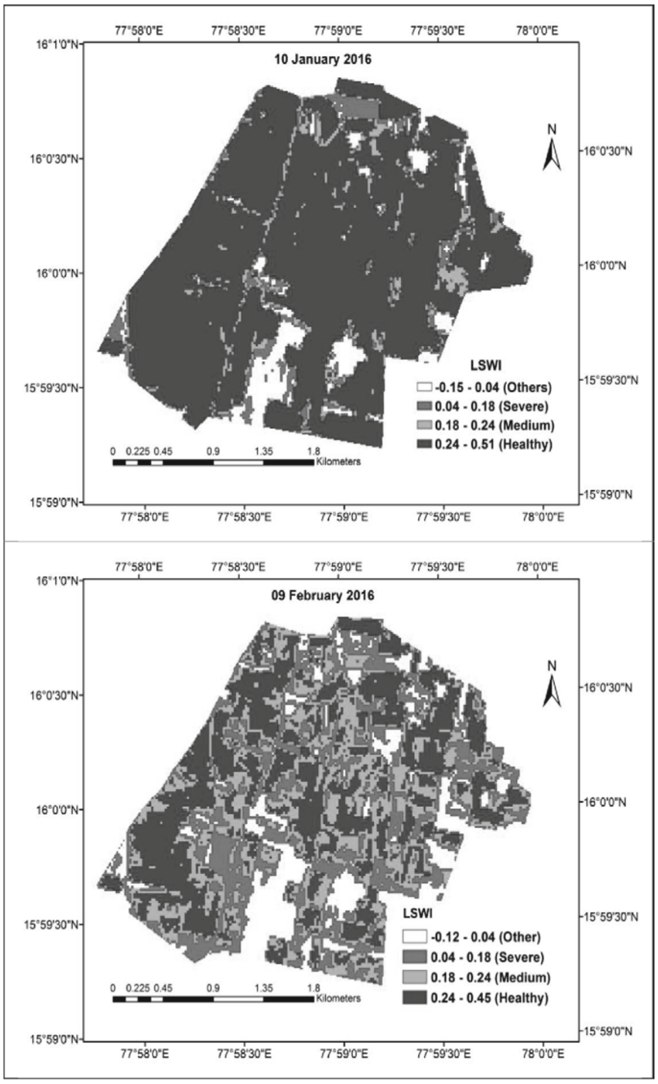

Fig. 3: Classified image of chilli based on LSWI

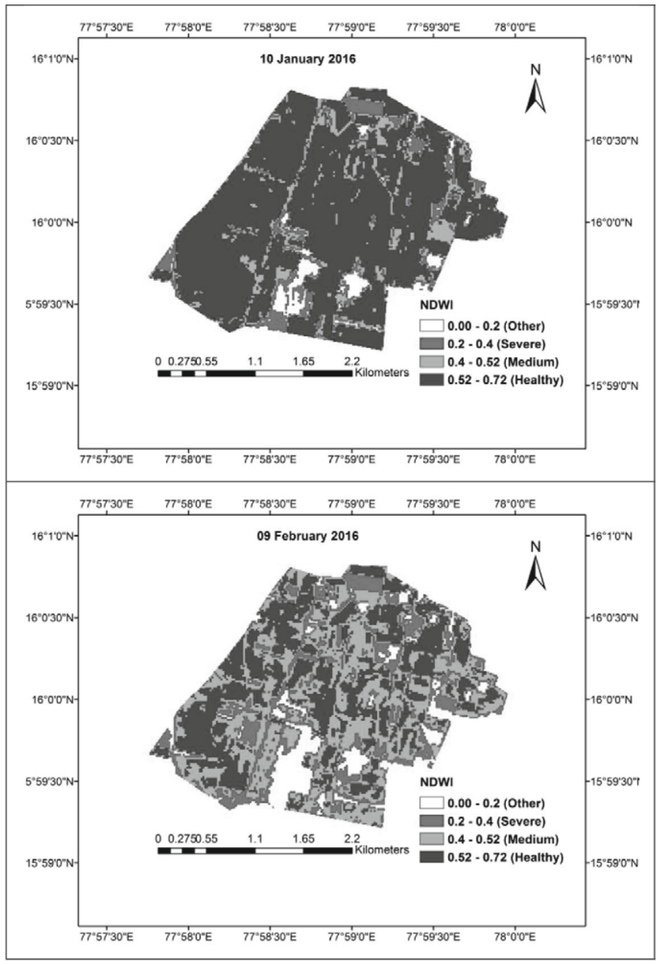

Fig. 4: Classified image of chilli based on NDWI

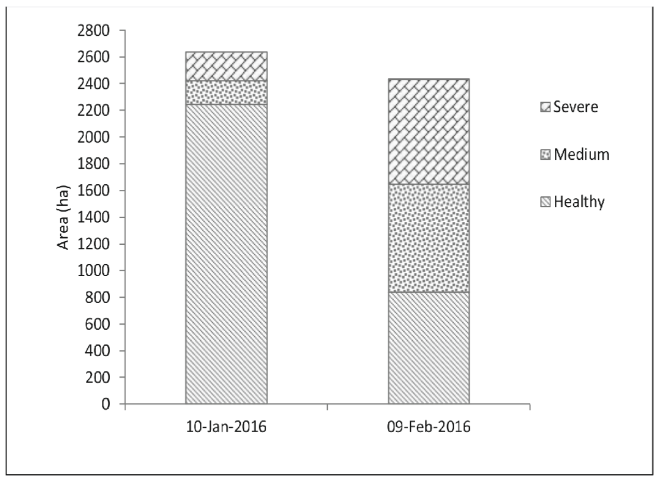

Fig. 5 : Area estimates of chilli thrips damage from Sentinel 2A satellite data

Within the field, spatial distribution studies of thrips using Moran's Index provide strong evidence for clustering (I=0.907324, p=0.0001) (Table 5). Moran's Index is a correlation coefficient that measures the overall spatial autocorrelation. Spatial autocorrelation usually describes the

Table 3: Accuracy assessment of crop classification using the error matrix (%) based on LSWI.

Class	Healthy	Moderate infestation	Severe infestation	User's accuracy
Healthy	98.78	0	10.06	96.15
Moderate infestation	0	89.46	3.68	96.62
Severe infestation	1.22	10.54	86.27	84.79
Producer's accuracy	98.78	89.46	86.27	

Overall Accuracy = 93.80%, Kappa Coefficient = 0.89

Table 4: Accuracy assessment of crop classification using the error matrix (%) based on NDWI.

Class	Healthy	Moderate infestation	Severe infestation	User's accuracy
Healthy	91.50	11.96	0	91.33
Moderate infestation	8.5	82.70	14.99	74.71
Severe infestation	0	5.34	85.01	94.53
Producer's accuracy	91.50	82.70	85.01	

Overall Accuracy = 86.92%, Kappa Coefficient = 0.80

correlation among values of a given variable in dependence on the relative locations between the spatial units (Getis, 2007). If the feature values tend cluster together, then the field exhibits high positive spatial autocorrelation, if the values tend to be located away from each other then there is a negative spatial autocorrelation. If there is no apparent relationship between attribute values and location then there is zero spatial autocorrelation. Distribution studies on clustering of brown stink bug, *Halyomorpha halys* in peach orchards provided strong evidences of clustering when the population density was high (Hahn *et al.,* 2017). Moran's Index based maps of interpolated stink bug, *Nizara viridula* density showed distinct aggregations at borders when the peanut growing season was ending and cotton bolls was a preferred food source (Tillman *et al.,* 2009).

In this study, we identified multispectral vegetation indices suitable for distinguishing chilli thrip damage and demonstrated feasibility of using high resolution multispectral satellite data for assessing area-wide pest damage in chilli. The

Table 5 : Moran's I statistic for the measurement of spatial autocorrelation of chilli damaged fields.

Date of sampling	Moran's I Statistic	p-value
10-Jan-2016	0.45	0.001**
09-Feb-2016	0.90	0.001**

**significant at $p<0.001$

need for such high resolution space borne data has been emphasized for crop pest and disease damage assessment (Sindhuja *et al*., 2010; Prabhakar *et al.,* 2011). Results from the spatial distribution of chilli thrip are useful for planning control operations involving precision application methods and reduce quantity of pesticide usage, thereby lower environmental pollution.

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