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Remote Sensing for Detection of Cotton Mealybug (Hemiptera: Pseudococcidae) in Sirsa District, Haryana

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Abstract*: Detection of crop stress is one of the major applications of remote sensing in agriculture. Many types of research have confirmed the ability of remote sensing techniques for detection of pest/disease on cotton. Hence, this research was designed to examine the ability of several vegetation indices to detect mealybug infestations and their effects. The mealybug-infested cotton crop had a significantly lower reflectance in the near infrared region and higher in the visible range of the spectrum when compared with thenoninfested cotton crop. Multiple Linear regression analysis showed that there were varying relationships between mealybug severity and spectral vegetation indices, with coefficients of determination (r^2) ranging from 0.59 to 0.21. Model developed in this study for the mealybug damage assessment in cotton crop yielded significant relationship (r^2=0.825) and was applied on satellite data of 21st September 2009 which reveals high severity of mealybug and it was low on 24th September 2010 which confirms the significance of the model and can be used in the identification of mealybug infested cotton zones. These results indicate that remote sensing data have the potential to distinguish damage by mealybug and quantify its abundance in cotton.*
Key words: *LST, TVDI, LSWI, MSI-1, Mealybug, Severity Index and remote sensing*

I. Introduction

Plants respond to pest and disease stress in a number of ways, including leaf curling, wilting, chlorosis or necrosis of photosynthetically active parts, stunted growth, or in some cases reduction in leaf area due to severe defoliation [1,2]. Many of these plant responses are difficult to visually quantify with acceptable levels of accuracy, precision and speed. These responses also affect the amount and quality of electromagnetic radiation reflected from plant canopies.

Cotton mealybug Phenacoccus solenopsis spread from infected to healthy plants via wind, irrigated water, rain, ants, and birds or by sticking/clinging to equipment, animals or people. Mealybugs can feed on all parts of a plant, but prefer actively growing leaf tissue, petioles, andleaf veins. They damage the plants by sucking sap from leaves, twigs, stems, roots and fruiting bodies. They inject toxic saliva into the plant parts causing chlorosis, stunting, deformation and death of plants [3]

The first incidence of the Solenopsis mealybug on cotton in India was recorded in 2005 in the north-western state of Gujarat (Jhala et al. 2008), and subsequent damage was reported in 2007 in the state of Haryana where it infested 4800 ha [4].

Mealybugs overrun the leaves, bolls, and branches, feed upon phloem sap and discharge extensive honeydew, on which dark dirty mold growth develops, accordingly influencing the photosynthetic capacity of the plant. Manifestations of plants infested during the vegetative stage incorporate distorted and bushy shoots, crinkled curved leaves, and hindered plants that dry totally in extreme cases. Late season indications incorporate plants with less, less and disfigured bolls, reduced vigor and early crop senescence. Mealybugs can also stain cotton lint and reduce quality [5,6]

The application of remote sensing for detection of crop pest and disease depends on the assumption that stresses actuated by them interferes with photosynthesis and physical structure of the plant, and influences the retention of light energy, in this way modifying the reflectance attributes of the plants [7]. In cotton, effective use of remote sensing for pest scouting [8], spatially variable insecticide application [9] and recognition of crop damage because of pest, tarnished plant bugs [10], beat army worm [11], spider mites [12,13], aphids [14] and leafhoppers [15] have been reported with other investigations underway worldwide.

The objective of the present study was (1) examine the ability of several vegetation indices to detect mealybug infestations and their effects.

Study Area

Sirsa is situated in the northwestern part of Haryana State, India and confined within $29^0$13’ to $29^0$59’ North and 74^0 30’ to 75^0 7’ East (Fig. 1), lies in the arid, hot agro-ecological zone of India. It has two types of soils viz Sierozem and Desert soils. The sierozem soils are found throughout except southern part has desert soils. Ghaggar river is a major drainage. Cotton is the major crop in Kharif season (June-October) and sowing starts May to June and the picking starts in the month of October-November. The annual rainfall of the district is 318 mm, about 80% received during the southwest monsoon and 20% rainfall received during the non-monsoon period due to western disturbances and thunderstorms. Mean minimum andmaximumtemperaturesare 5.1 ^{0}C and 41.1 ^{0}C.

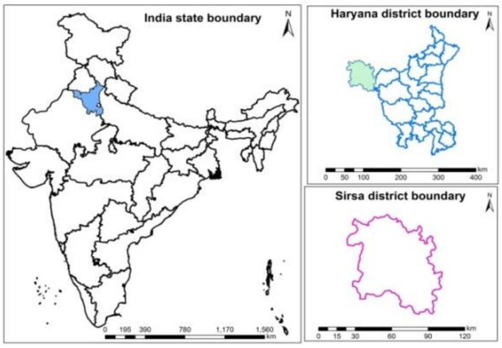

Fig.1 Study area map

II. Materials And Methods

Field data collection

For calculation of mealybug severity infestation, ground survey was conducted to establish sampling plots. Initially healthy and infested crop locations were identified and then randomly locations were choosing for sampling of mealybug severity. The geographic locations of healthy and infested cotton crop were recorded with the help of GPS. 100 plants were sampled for the severity computation and grading of plant severity was given according to the infestation (Table 1). Severity Index (SI), an index of infestation level, was calculated based on equation 1-3. Range of SI varies from 1, low infestation to 4, high infestation. Table 1 and Table 2 shows grading of mealybug infestation and general format for calculating severity index of mealybug. Reason for using SI, as infestation of crop instead of percentage infestation was due to severity index indicated severity of infestation of mealybug on cotton crop while percentage infestation does not account for severity of infestation i.e. if 100 plants were graded as 1 then percentage infestation would be 100% while SI value would be 1 which shows low infestation of mealybug. Mealybug infested cotton crop, close and field view collected during ground observation is shown in fig.2

Table 1: Description of the symptoms of damage due to different levels of *Solenopsis* mealybug feeding effect in cotton. Source: [5]

Level of Infestation	**Symptoms of damage**
Grade-0	Healthy Plant
Grade-1	About 1–10 mealybugs scattered over the plant
Grade-2	At least one branch heavily infested with mealybugs
Grade-3	Two or more branches heavily infested with mealybug crinkled or twisted top few leaves with bunchy appearance, slight sooty mold development
Grade-4	Complete plant infested, stunted growth with sooty mold all over the plant, dry, reduced crop vigor and early crop senescence

Table 2: General format of grades and plants infested

Grades	0	1	2	3	4
No of Plants	X1	X2	X3	X4	X5

Multiple, Percentage infestation and Severity Index were calculated based on the following formula.

Multiple =Grade1*X2+ Grade2*X3+ Grade3*X4+ Grade4*X5…… (1)

% Infestation =Infected Plant / Total Plant……………………….… (2)

Severity Index (SI) =Multiple/Total Plant infested……………..(3)

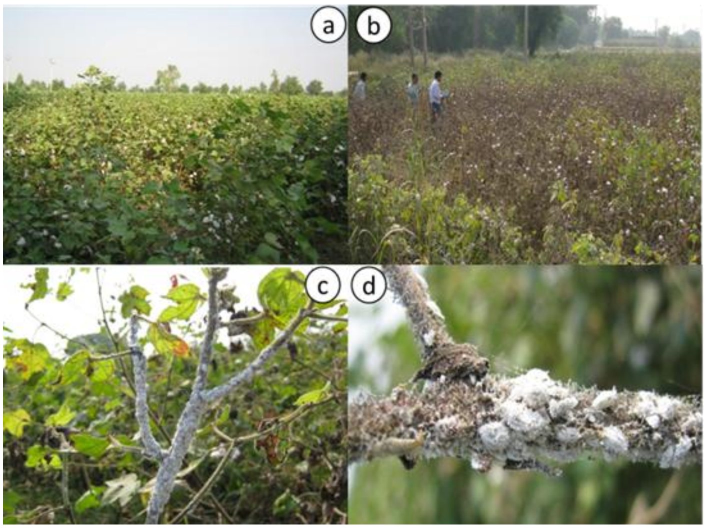

Fig.2(a) Healthy cotton crop (b) Field view of cotton crop damage by mealybug (c) Severely Infested cotton plant (d) close-up view of the mealybug infestation on cotton plant

Remote Sensing Data Processing and Preparation of Database

Landsat TM5 data with seven spectral band viz. Blue, Green, Red, Near Infrared, Shortwave infrared, Thermal and Shortwave infrared bands. Multi-date satellite data were downloaded for the year 2009 and 2010.For the pixel level reflectance conversion, FLAASH module, (Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction module in ENVI 4.4 software was used. It adapts MODTRAN (MODerate spectral resolution atmospheric TRANSmittance) algorithm to satellite data and output in surface reflectance were obtained for individual satellite data. Spectral Vegetation Indices (SVIs) based on reflectance data (Table 3) were computed. ISODATA clustering technique in ERDAS Imagine 2011, image processing software was used for classification and preparation of land use land cover. Within the Cotton area, mask was used to extract cotton pixel; within the cotton pixels, SVIs and reflectance value of different band of were extracted for different sites observed as mealybug infested and healthy. The relationship between SVIs and SI were evaluated and finally used for the model development and validation.

Table 3: Details of remote sensing indices used in the analysis

Index	Description	Reference
$\mathrm{LSWI} = \frac{(\rho_{nir} - \rho_{swir})}{(\rho_{nir} + \rho_{swir})}$	Land surface water index; sensitive to change in liquid water content of vegetation canopies	[16]
$Ts = \frac{K_2}{Ln\left(\varepsilon * \left(1 + \frac{K_1}{L\lambda}\right)\right)}$	Land surface Temperature; sensitive to land surface temperature	[17]
$\mathrm{MSI{-}1} = (\rho_{green} + \rho_{nir} + \rho_{swir}) - [\rho_{swir} / (\rho_{green} + \rho_{nir})]$	Mealybug Stress Index-1; sensitive to change leaf water content, chlorophyll content and leaf greenness	[18]
$\mathrm{TVDI} = \frac{\text{Ts-Tsmin}}{\text{a+bNDVI-Tsmin}}$	Temperature Vegetation Dryness Index, sensitive to soil moisture	[19]

III. Data analysis

Multiple Regression analysis (SPSS 16, statistics software) was performed on the mean value of SVIs from the healthy and mealybug infested cotton crop. Correlation coefficient (r) and coefficient of determination (r^2) between the SI and SVIs were estimated from the data of different infested location (n = 93), during the year 2009 and 2010. Model were developed and validated with blind data set was not used in model development.

IV. Results & Discussion

Reflectance profile of healthy and mealybug infested cotton crop

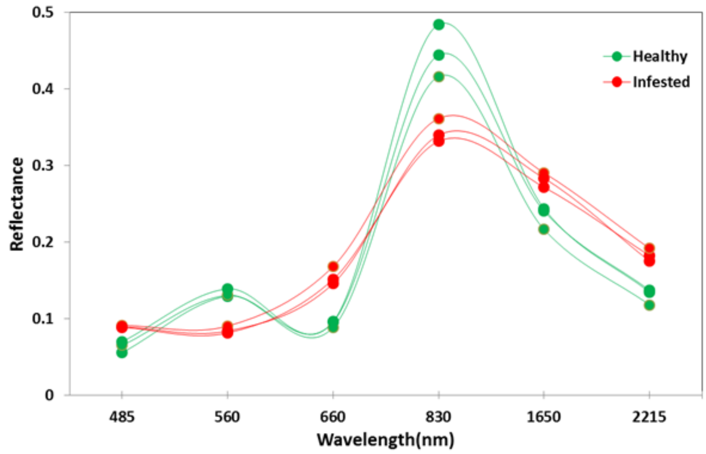

Fig.3 Spectral reflectance profile of healthy and mealybug infested cotton crop

Reflectance from the mealybug-infested and noninfested cotton crop is shown in Fig 3. It is evident that the spectral response of the mealybug-infested cotton crop was significantly affected by mealybug (Fig. 3). The reflectance of cotton crop in the NIR region was significantly lower in contrast to a significant increase in the visible spectrum due to mealybug feeding (Fig. 3). In SWIR region also, spectral response of the mealybug-infested cotton crop showed significant difference compared to non-infested cotton crop which attributed to changes in leaf water content. Mealybug-infested cotton crop captured less or reflected more light than the noninfested cotton crop in NIR and Visible region.

Relationship between Severity Index (SI) and Remote Sensing Derived Index

Correlation coefficients between mealybug severity and spectral indices varied considerably amongst indices (r^2 = 0.21–0.59).LST showed the highest correlation coefficient (r^2= 0.59) with mealybug severity, followed by MSI-1(r^2=0.51). LSWI also shows a negative correlation with severity index (r^2=0.36). Substantially lower correlation coefficient could be observed for the TVDI(r^2= 0.21).

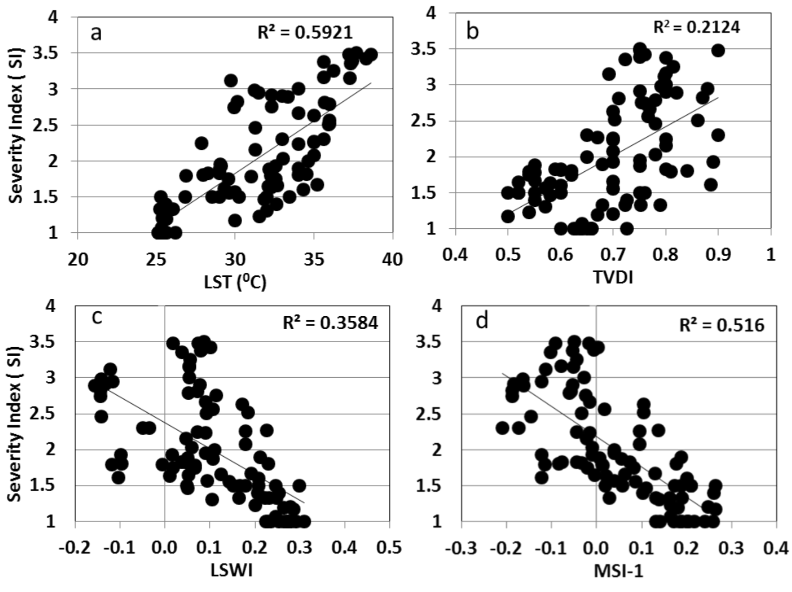

Fig.4 Relationship between Severity Index (SI) and (a) LST (b) TVDI (c) LSWI (d) MSI-1 at different sites

Remote Sensing based model development formealybug damage assessment

Remote sensing based model was developed by using, Land surface temperature (LST), Temperature Vegetation Dryness Index (TVDI), Land Surface water Index (LSWI) and Mealybug Stress Index-1 (MSI-1) as independent variable and Severity Index (SI), dependent variable.

The developed model shows significant relationship with severity index (r^2=0.825). F-ratio is 104.684, which is very unlikely to have happened by chance (p<0.001). The standard error of estimate (SEOE) was 0.319.

Multiple regression analysis based model development

Y = -2.603+0.118*LST+1.247*TVDI+1.665*LSWI - 3.188*MSI1

r= **0.908** $\mathbf{r^2 = 0.825}$ **Adj.** $\mathbf{r^2 = 0.817}$ **n = 93 ---------(4)**

Sig. at 0.001, SEOE = 0.319, F=104.684

Where, Y = Severity Index

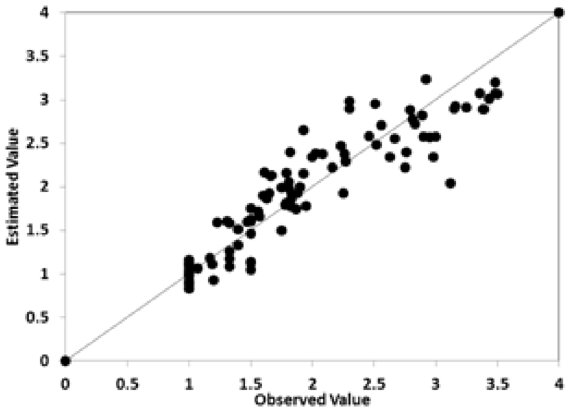

Fig.5 1:1 relationship between estimated and observed value by model

Fig.5 demonstrates the scatter plot of estimated and observed value along the 1:1 line. This 1:1 line demonstrates the anticipating limit of the model with SEOE of 0.319. In this model, the majority of the anticipated qualities are concentrated close to the 1:1 line which shows great precision as it matches with the observed values.

TVDI, which represent soil moisture, makes it appropriate for use in soil moisture evaluation furthermore coefficient value greater than 1, also reveals the significance of TVDI in anticipating the severity of mealybug. LSWI which is sensitive to leaf water content and soil moisture and the negative relationship with severity index demonstrates that mealybug infestation causesthe water stress in the crop (Fig.4c)MSI-1, yield negative relationship with mealybug severity, reveals loss of chlorophyll and leaf green area leads to negative MSI-1 value.

Utilizing the Equation 4, applied on 21stSeptember 2009 and 24thSeptember 2010, utilizing the Erdas Imagine software's Modeller Module, Spatial conveyance of mealybug impact on cottonappears in Fig. 6a and 6b.

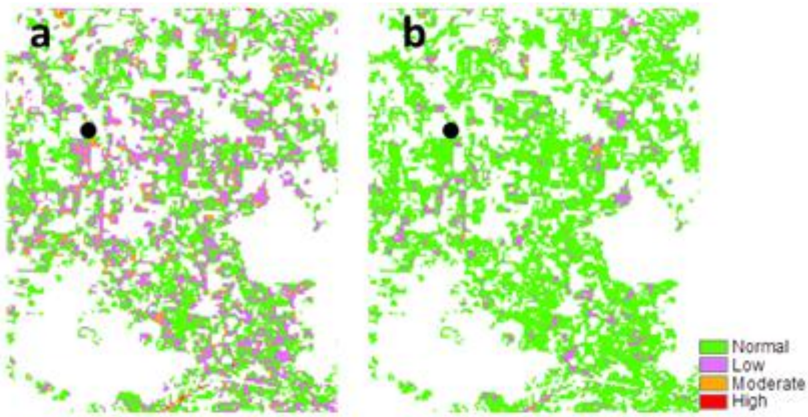

Fig.6 (a) Spatial variation of severity of mealybug surrounding of Madhosinghana village, Sirsa district (21st Sept. 2009) (b) Spatial variation of severity of mealybug surrounding of Madhosinghana village, Sirsa district (24thSept. 2010)

The severity of the mealybug was low & moderate, covers a large area (Fig.6a) while low severity of mealybug was observed in (Fig.6b) compared to year 2009. Predicted severity of the mealybug was in accordance to ground observation. The severity of mealybug was high in the year 2009 and reduced in 2010(Fig.6b).

Essentially, the high reflectance of light energy in the blue and red region of visible spectra from the infested crop contrasted with a healthy crop (Fig.3) recommends that the mealybug infestation decreased photosynthetic pigment concentration inside the leaf structure. The spectral changes in reflectance because of mealybug infestation in cotton saw in this study are like those found because of brown plant hopper in rice [20], cotton aphid in cotton [13], leafhopper in cotton [15], late blight in potato [21], yellow rust in wheat[22], greenbug in wheat [23-25] and cotton mealybug in cotton[26,27]. Loss of chlorophyll due to infestation by sap-feeding insects like aphids [28,29], leafhoppers [30] have been reported earlier.

The noteworthy contrast in green band reflectance was seen in the healthy and mealybug invaded cotton crop. Subsequent to the green reflectance is ascribed because of green leaf area of the crop because of which reflectance in the green region reduces. These distinctions in spectral reflectance of the healthy and the mealybug infested cotton crop could be expected because the green band is described by generally higher reflectance because of a chlorophyll substance in the healthy crop [31].

The outcomes show huge contrasts between mealybug-infested and healthy cotton crop in Near Infra-Red (NIR) region. Decrease in the NIR reflectance of mealybug-infested cotton crop could be the development of dirty mold fungus on the honeydew discharged by the mealybug on infested plants which damage the leave's inside structure. The changes in NIR reflectance because of mealybug infestation found in this study are similar to dirty mold growth from scale insect-plagued citrus leaves [29,32]. High reflectance in the SWIR band could be ascribed to the loss of water from the mealybug-infested cotton crop (Fig.3) is similar to infestation of brown plant hopper on rice and increased reflectance in the SWIR region [20] and Solenopsis mealybug in cotton that causes water stress and increase the reflectance in the SWIR band [18,33].

Atmospheric differences could have influenced the results, as could variations in edaphic factors such as exposed soil, soil type, and soil moisture, and biotic variability such as plant height and health, concentrations of moisture, chemicals and pigments, vegetative growth stages, differences in cotton variety, and damage severity. It was not possible to control these types of factors in this study, and, in fact, it would not be feasible to control them for an operational pest monitoring system. It is clear evident in Fig.4 that the sensitivity of a spectral index is affected by variability differing from one place to another.

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Thus, reflectance responses of the mealybug-infested cotton crop show that remote sensing have the potential to detect the damage caused by mealybug. Mealybug infestation on cotton significantly increased the visible reflectance and decreased the NIR reflectance when compared with noninfested cotton. The relationships between severity index and spectral indices showed that remotely sensed data transformed into spectral indices provides a method for detecting mealybug and differentiate damaged and healthy cotton crop. In addition, the model developed in this study, applied to the satellite data produced mealybug severity zone maps. These maps provide detailed temporal and spatial information on mealybug severity zone, which can be a very useful tool for mealybug management.

V. Conclusion

Continuously scientific development in the field of remote sensing provides high spectral, spatial and temporal resolution data from airborne or satellite platforms, it is necessary to evaluate and develop methodology that could be useful in pest/disease management. The integration of remote sensing and GIS techniques for the integrated pest management programs is essential. This research is an effort in that direction and shows the potential of remote sensing indices for mealybug damage assessment in cotton. Since the spectral vegetation indices used in the study capture all the input that favors the development of mealybug, LST, surface temperature indicator which shows warm and cold zone for mealybug developmet,TDVI represent soil moisture and could be mapped for identification of probable zone for mealubug, LSWI, sensitive to leaf water content and soil moisture depicts mealybug infested zone. Furthermore, validation of these SVIs with independent data sets showed that they are capable of detecting the mealybug damage, and hence their potential use in the management of the exotic mealybug pest.

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