SPECTRAL VEGETATION INDICES AND ITS RESPONSE TO IN-SITU MEASURED LEAF AREA INDEX OF COTTON

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ABSTRACT:

The major objective of this study was to develop site-specific spectral vegetation index-LAI relationship for two cotton varieties cultivated in the Central State Farm (CSF) Hisar, using multi-date radiometric and LAI measurements as well as digital data of LISS-III onboard Indian Remote Sensing Satellite (IRS). The field-level LAI was measured using LAI-2000 Plant Canopy Analyser and Aerosol optical thickness (AOT) and water vapour content were measured using hand-held Microtops-II Sunphotometer. The radiometric measurements were carried out using Ground Truth Radiometer (GTR). The results of linear regression analysis indicated that among various SVIs, the NIR – SWIR based indices performed slightly better as compared to NIR - Red based indices. However, there was not much variation among different SVIs with relatively high R^2 in most cases. The relationship developed between LAI and NDVI of cotton varieties was used to predict LAI, which resulted in R^2 of 0.82, however most of the predicted LAI values were underestimated by 8.4 percent. This relationship was used to generate LAI map of cotton areas in the Hisar district. The results of exponential relationship between IRS LISS-III derived NDVI and yields in the farmer's fields resulted in R^2 of 0.73 and between LAI and cotton yields resulted in R^2 of 0.79. These results are encouraging in terms of their utility in retrieving LAI from IRS LISS-III derived NDVI and indirectly to estimate cotton yields at the regional scale using LAI and yield relationships.

1. INTRODUCTION

The information content of multi-spectral satellite images may be useful in large-scale quantitative assessment of biophysical attributes, such as leaf area index (LAI), which are key inputs in models describing biosphere processes. Currently, ecosystem models require either field validation of simulated LAI, or remotely sensed estimates of LAI to initiate them (Running et al., 1999). Leaf area index measurements are critical for improving the performance of such models over large areas and this has prompted investigations of the relationship between ground-measured LAI and spectral vegetation indices (SVIs) derived from satellite-measured data (Chen & Cihlar, 1996, Gower et al., 1999, Nemani et al., 1993 and Turner et al., 1999). At a regional-level LAI can be estimated with enough accuracy through SVIs, derived from Remote Sensing (RS) data. A considerable scatter in LAI- SVI relationship is usually found when the ground pixels observed by the sensor include a combination of canopy reflectance, originating from different types of vegetation with a variable amount of understory (Chen and Cihlar, 1996). The red (R: 0.63 –0.69 µm), Near Infra Red (NIR: 0.76 – 0.90 µm), Short-wave Infrared (SWIR: 1.55 – 1.75 µm) and Middle Infrared (MIR: 2.08 – 2.35 µm) are the typically used bands in SVI computation, and their response in producing LAI maps is discussed in many studies (Baret et al., 1988, Brown et al., 2000). The relationship between SVIs and LAI of different vegetation types were evaluated in a subtropical watershed using Landsat ETM^+ data (Xavier and Vettorazzi, 2004) and it was observed that LAI-NDVI showed the best fit and SAVI showed the worst fit, since it is more sensitive to NIR. A study was carried out to estimate field-scale LAI using multi-date Indian Remote Sensing Satellite (IRS) LISS-III derived spectral indices for wheat and tobacco. It was observed that exponential and power models resulted in R^2 between 0.53 and 0.65. The LAIs were estimated by inversion of empirical models, which were validated against ground measured data (Chaurasia, et. al., 2006).

The present study was conducted in the Central State Farms, Hisar where extensive LAI and radiometric measurements were carried out coinciding with Indian Remote Sensing (IRS) satellite passes on five different dates during cotton growing season. IRS LISS-III and PAN digital data were acquired to develop spectro-biological and yield relationships for two major varieties of cotton grown commercially in Haryana State. The major objective of this study was to develop farm-level spectro-biophysical and yield relationships using site-specific LAI and radiometric measurements for two cotton varieties.

2. MATERIALS AND METHODS

2.1 Study Area and its Location

The Hisar district, a part of the Indo-Gangetic alluvial plain is situated between 28°53'45" to 29°49'15"N latitudes and 75°13'15" to 76°18'15"E longitudes. The soils of the districts are conventionally referred to as alluvial and aeolian soils and fall into three orders - viz. Entisols, Inceptisols and Aridisols. The inceptisols are characterised by an ochric epipedon and cambic/calcic sub surface horizons. Most of the total irrigated area in the district is under canal irrigation. The climate is influenced by westerly winds in summer months raising temperature as high as 48°C, whereas, in winter north-westerly cold winds provide low temperature touching even 0°C. The average rainfall in the district is 334.4 mm. About 85 per cent of annual rainfall is received during the short south- western monsoon period.

The Central State Farm is located on northwest of Hisar town along the Hisar-Sirsa national highway. The total geographical area of the farm is 2710 ha out of which 2440 ha is cultivable area. The major crops grown during kharif season along with cotton are paddy, groundnut, sugarcane, pulses like green gram, black gram, cowpea and vegetables like ladies finger, guar, etc. The consolidation of the area has helped to divide area into plots of uniform size each of 25 hectares. In general, cotton is grown on two to four contiguous plots, resulting in a synthetic field size ranging from 50 to 100 ha, which is very helpful for unique identification on satellite digital data.

2.2 Data Used

2.2.1 Ground-based Measurements of LAI and Atmospheric Parameters

The LAI-2000 instrument was used in two cotton varieties to derive LAI indirectly. LAI-2000 instrument measures the gap fraction P(?) in five zenith angle (?) ranges with midpoints of 7^0, 23^0, 38^0, 53^0 and 67^0. LAI is determined by inverting simple radiative transfer model foliage information according to Welles and Norman (1991). This indirect LAI estimate specifically represents an effective leaf area index for the agricultural crops. Five large and uniform plots of each variety, sown under cotton, were selected for LAI measurements. The locations of selected plots were identified on PAN-LISS-III merged image and their precise locations were determined with the help of Global Positioning System (GPS). A total of 60 LAI measurements were carried out at randomly selected 6-sites within each plot of Desi and American cotton varieties. The measurements were made under diffuse radiation conditions or always keeping the sensor in the shadow in one sensor mode. At each site LAI was measured using one above and six below the canopy-diagonally crossing the crop rows.
Measurements were carried out on five dates (12-July, 06-August, 28-August, 19-September and 15-October-2003), which coincided with different phenological stages of cotton. LAI and atmospheric parameters were measured simultaneously on the date of satellite overpass. The aerosol optical thickness (AOT) and water vapour content were measured using hand-held Microtops-II Sunphotometer (Solar light Inc, Philadelphia, USA), which has five optical collimators working at 500, 675, 870, 936 and 1020 nm and a full field-of-view of 2.5^0.

2.2.2 Ground Truth Radiometer Data

A Ground Truth Radiometer (GTR) having similar spectral bands as that of IRS-1D LISS-III was used for radiometric measurements on Desi and American cotton varieties. A total of 60 radiometric measurements in Red and NIR spectral bands were carried out in selected five plots each of Desi and American cotton varieties. The GTR measurements were carried out simultaneously along with LAI measurements at six randomly selected locations within each plot and average values were computed.

2.2.3 Satellite Data

Cloud-free digital data from IRS-1D LISS-III of single-date 19-Sept-2003 of path/row 094/50 covering study area was available during the entire cropping season. IRS-1D PAN digital data covering Central State Farms, Hisar was also obtained for this study.

3. DATA ANALYSIS

3.1 Radiometric and Canopy Analyser Data Analysis

Radiometric and LAI measurements were carried out on five different dates. A total of 60 radiometric and LAI measurements on each date were carried out in Desi and American cotton varieties. The reflectance in each band was computed using the measurements on Barium sulphate plate and black object. The Normalized Difference Vegetation Index (NDVI) for each measurement was computed. From the 60 LAI measurements carried out at randomly selected 6-sites within each plot of cotton varieties, average LAI for each plot was computed.

3.2 Satellite Data Analysis

3.2.1 Geo-referencing and Atmospheric Correction

The Flow-chart showing procedure adopted for LAI retrieval using IRS LISS-III digital data, adapted from Pandya et al., 2003 is presented in **Figure-1.** The LISS-III sub-image covering Central State Farms (CSF), Hisar was geo-referenced using 1:50,000 scale Survey of India (SOI) topographical maps. Using 40 GCPs and second order polynomial with nearest neighbour (NN) resampling procedure LISS-III sub-image was georeferenced with Root Mean Square Error (RMSE) of 0.32, 0.26 in scan & pixel directions. The vector layer of the farm was superimposed on the registered images and cotton plots were accurately identified where LAI and radiometric measurements were carried out. The digital numbers were converted to spectral radiances (Price, 1987). These radiances were converted to at-satellite exo-atmospheric reflectance using the procedure adopted by Thenkabail, 2003.

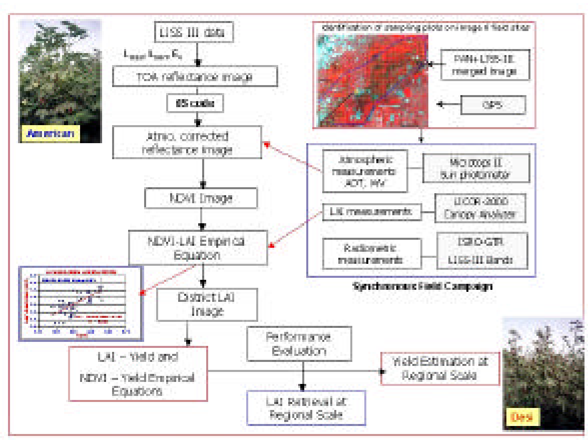


Figure-1: Flow-Chart Showing Procedure Adopted for LAI Retrieval of Cotton using IRS LISS-III data

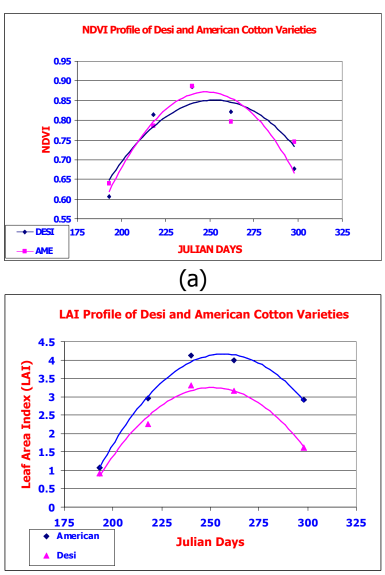
3.2.2 Computation of Spectral Vegetation Indices (SVIs)

Most SVIs use radiance, surface reflectance (ρ), or apparent reflectance (measured at the top of the atmosphere) values in the Red (R) and the Near- Infra Red (NIR) spectral bands. The indices have been proven to be well correlated with various vegetation parameters such as green biomass (Tucker, 1979), leaf area index (Asrar, et al.; 1984), and photosynthetic activity (Sellers, 1985). In the present study NIR – Red based indices like Normalized Difference Vegetation Index (NDVI), Transformed Soil-Adjusted Vegetation Index (TSAVI) and NIR – SWIR based indices like Moisture Stress Index (MSI), Three Band Ratio (TBR), Normalized Difference Moisture Index (NDMI) etc. were computed from the IRS LISS-III atmospherically corrected reflectance data. The significance of these various SVIs in vegetation studies and their computation details are described by Kalubarme et al., 2006.

4. RESULTS AND DISCUSSION

4.1 Temporal Spectral and LAI Profiles of Cotton

In-situ LAI and Radiometric measurements were carried out on five dates (12-July, 06-August, 28-August, 19-September and 15-October-2003) and average LAI and NDVI of six measurements in each site in a plot were computed for two cotton varieties for each date. The average NDVI and LAI profiles of Desi and American Cotton varieties are presented in **Figure-2.** The NDVI and LAI profiles of two varieties reveal that the NDVI of two varieties do not show significant differences on different dates even though there is significant difference in LAI. The peak LAI that occurred after 252 Julian Days of Desi cotton was around 3.1 and that of American cotton was around 4.1. During this peak LAI period the peak NDVI was around 0.87 and 0.85 for American and Desi cotton respectively.



(a)

(b)

Figure-2: NDVI (a) and LAI (b) Profile s of Cotton Varieties

4.2 Farm-level Spectro - biophysical Relationships

A linear regression between LAI and NDVI computed from field measurements of two cotton varieties pulled across five dates was carried out. This analysis was attempted in three steps of data aggregation: i) average value of six measurements on each site of 10m X 10m at five locations in each plot on five different dates (total observations ranging from 80-90 for American and 120-125 for Desi cotton), ii) average value of all five plots of each variety on five different dates (total observations ranging from 15 to 20), iii) average values of each date over five plots of two varieties (total five observations per variety). It was observed that, the linear relationship is slightly poor in the first step as compared to other two steps due to the fact that the individual sites of 10m X 10m have a lot of internal variability, which results in a large scatter in the data set. The improvement in linear relationship is due to averaging of the internal variability within individual sites, leading to less scatter in the data and higher coefficient of determination (R^2). The relationships developed using above farm-level LAI and NDVI data sets along with their $\mathbf{R^2}$ and standard errors is given in **Table-1.**

Table-1: Linear Relationships of site-specific LAI and NDVI data along with R^2 and Standard Errors.

	Model	$\mathbf{R^2}$	**Std. Error**
Step-I	American: LAI= 8.99*NDVI – 3.663	0.65	0.69
	Desi: LAI=9.043*NDVI–4.804	0.65	0.61
Step-II	American: LAI= 10.0*NDVI – 4.397	0.72	0.63
	Desi; LAI=9.813*NDVI–5.387	0.76	0.47
Step-III	American: LAI=12.077*NDVI– 5.95	0.93	0.56
	Desi: LAI=11.674*NDVI– 6.82	0.96	0.39

4.3 Spectro-Biophysical Relationships using Satellite Data

A window of 5 X 5 pixels covering each site was extracted and the average reflectance in Red, NIR and SWIR bands was extracted from the surface reflectance image of IRS-1D LISS-III data. Initially, all the LAI measurements were plotted against various SVIs and coefficients of determination (R^2) of the regression equations were computed. The regression analysis between LAI and various SVIs was performed at two levels of aggregation: i) firstly, average of all pixels at each site in each plot of both varieties, ii) and secondly, average of six sites in each plot of both the varieties.

The results of linear relationships of various Spectral Vegetation Indices (SVIs) of LISS-III digital data with farm-level LAI along with R^2 and Standard Errors are presented in **Table-2.** These results indicate that the relationships of LAI at site-specific aggregation for all SVIs attempted, shows positive correlation with low coefficient of determinations, R^2 values ranging from 0.52 to 0.57. The large scatter observed in the data set may be due to difference in growth pattern, canopy cover and shadowing effects of two varieties, which results in high amount of spatial variations. However, these relationships showed significant improvement, when the data was aggregated at plot-level (second equations for each SVIs in Table-2) with R^2 values ranging from 0.83 to 0.88. This improvement is mainly due to the fact that the internal variability at each site gets averaged out at the plot-level.

The comparison of performance of various SVIs indicate that, there is not much variation among various SVIs attempted with relatively high R^2 in most cases either using average values of six-sites in each plot or average values of five plots of both the varieties. However, NIR – SWIR based indices performed slightly better as compared to Red – NIR based indices.

Table-2: Linear Relationships of Spectral Indices of LISS-III digital data with LAI along with R^2 and SEE

Index	**Model**	R^2	SEE
NDVI	i) LAI = 11.525*X – 2.791	0.52	0.45
	ii)LAI = 11.426* NDVI– 2.748	0.83	0.23
TSAVI	i) LAI = 8.976* TSAVI + 0.203	0.53	0.45
	ii) LAI = 8.876* TSAVI + 0.234	0.84	0.23
MSI	i) LAI = - 11.123* MSI + 10.59	0.55	0.44
	ii) LAI = - 11.264* MSI + 10.663	0.85	0.22
TBR	i) LAI = 5.307*TBR - 2.241	0.57	0.44
	ii) LAI = 5.103* TBR - 2.026	0.88	0.22
NDMSI	i) LAI = 14.478* NDMSI + 0.285	0.54	0.44
	ii) LAI = 14.604* NDMSI + 0.239	0.85	0.22

i) measurements of six sites in each plot
ii) plot-level averages of both varieties

4.4 LAI Retrieval and Performance Evaluation

Six plots each of Desi and American varieties were identified in large cotton growing areas in Hisar district for conducting farm-level LAI and yield measurements. Leaf Area measurements on cotton varieties in the farmer's fields were conducted independently. The LAI was measured at six sites in each plot and five measurements were carried at each site, which resulted in 30 LAI measurements in each plot. These plots were demarcated on the IRS LISS-III digital data of 19-September-2003 and NDVI of each site was generated. The average LAI and NDVI of six plots of each variety were computed. The relationship developed between LAI and NDVI of two cotton varieties (Table – 2, equation: ii) based on measurements carried out at CSF farm was used to compute the predicted LAI of these six plots of each variety. The linear relationship between observed LAI and predicted LAI was generated which resulted in R^2 of 0.66. The scatter plot of the observed and predicted LAI along with linear regression equation is presented in **Figure-3**. The 1:1 Line is also shown in this figure, which indicates that most of the predicted LAI values are underestimated and on an average the underestimation in LAI is 8.4 percent. It was observed that except for two plots the relative deviations of predicted LAI are well within 10 per cent of the observed LAI.

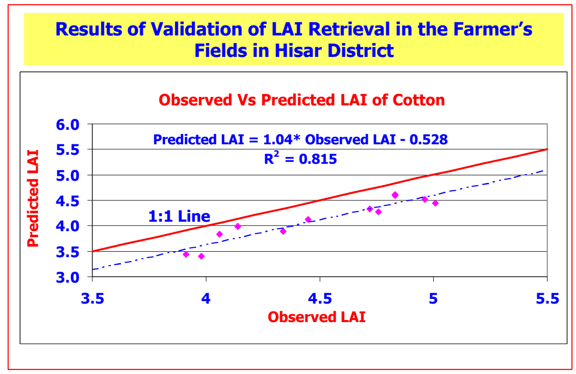


Figure-3: Results of LAI Retrieval in the Farmer's Fields

4.5 Site-Specific Spectro - LAI &Yield Relationships

The Crop Cutting Experiment (CCE) was also carried out in these farmer's fields. Cottonseed yields of each plot were determined based on four pickings conducted in each plot during the crop season. These plots were demarcated on the IRS LISS-III digital data of 19-September-2003 and NDVI of each site was generated. The average LAI and NDVI of six plots of each variety were computed. Regression analysis between LAI and NDVI of two varieties of cotton in the farmer's fields were attempted and it was observed that exponential regression resulted in highest coefficient of determination (R^2). The scatter plot of field measured LAI versus IRS LISS-III derived NDVI and LAI versus yield of two cotton varieties along with regression equations are presented in **Figure-4 & 5**. The relationship of farmer's field measured LAI at boll formation stage and CCE yields resulted in R^2 of 0.789, which shows that LAI can explain around 79 per cent variability in cotton yield. This results are encouraging in terms of their utility in retrieving LAI from IRS LISS-III derived NDVI and indirectly it would be possible to estimate cotton yields at the regional scale using LAI and yield relationships.

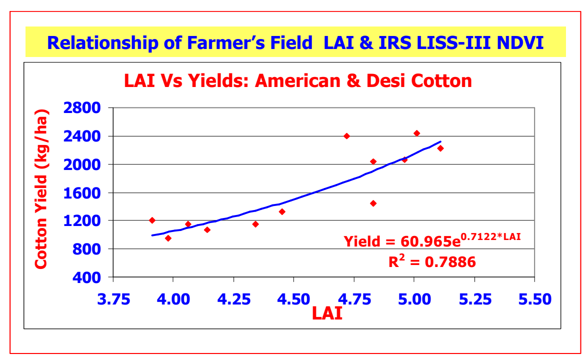


Figure-4: Relationship of Farrmer's Field LAI & IRS LISS-III derived NDVI

5. CONCLUSIONS

The study brings out that the Spectral Vegetation Indices (SVIs) derived from IRS LISS-III digital data can be successfully used in estimating LAI of cotton at the regional scale. The specific conclusions of this study are as follows:

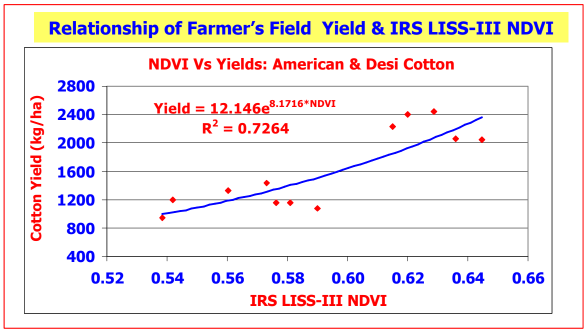


Figure-5: Relationship of Farrmer's Field Yield & IRS LISS-III derived NDVI

The relationship of farm-level cotton LAI with various Red – NIR and NIR – SWIR based Spectral Vegetation Indices (SVIs) derived from IRS LISS-III digital data indicated that NIR – SWIR based indices performed better as compared to Red – NIR based indices. However, there was not much variation among different SVIs.

The LAI – NDVI relationship derived from IRS LISS-III digital data was inverted and used to generate cotton LAI map of Hisar district. The relationship developed between LAI at boll formation stage and NDVI of two cotton varieties was also used to compute the predicted LAI and results indicated that most of the predicted LAI values were underestimated by 8.4 percent.

The relationship of farmer's field measured LAI and CCE yields resulted in R^2 of 0.789, which shows that LAI can explain around 79 per cent variability in cotton yield. These results are encouraging in terms of their utility in retrieving LAI from IRS LISS-III derived NDVI and indirectly to estimate cotton yields at the regional scale using LAI and yield relationships.

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