Indian Journal of Agricultural Sciences **83** (4): 380–5, April 2013/Article

Retrieval of Leaf Area Index using IRS-P6, LISS-III data and validation of MODIS LAI product (MOD15 V5) over trans Gangetic Plains of India

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Received: 12 November 2012; Revised accepted: 5 Februaruy 2013

ABSTRACT

The mapping of leaf area index (LAI) in large geographic area may be impossible when we rely on the field measurement. To solve this problem, there have been continuing efforts to develop methodologies to estimate LAI using remote sensor data. Different methods to estimate LAI from reflectance data have been developed and can be grouped into two approaches such as (1) statistical approach and (2) physical process based approach. In this study, statistical approach has been used to retrieve the LAI of a part of north western part of the country using LISS-III, IRS P6 sensor. Using physical process based approach (i e radiative transfer model) MODIS on-board Earth Observing System (EOS) Terra/Aqua platforms, now provide LAI as a standard product (MOD15) to the scientific community at 1 km resolution, every eight days. The validation of LAI products by comparison to reference field LAI values is necessary and has been carried out for many sites over USA, Africa but very few results are available over India, hence MOD 15 LAI products have been validated using the derived LAI of LISS-III which was aggregated to 1 km resolution. Results revealed positive correlation ($R^2 = 0.62$) between MODIS LAI product and aggregated LISS-III LAI but MODIS LAI values were found to be underestimated compared to the measured values. The overall RMSE of MODIS LAI is higher (ie 2.74) compared to LISS-III LAI (0.65).

Key words: Leaf area index, LISS-III , MODIS, NDVI, Trans Gangetic Plain, Wheat

Leaf Area Index (LAI) has been an important parameter that is directly related to the photosynthesis, evapotranspiration, and the productivity of plant ecosystem (Bonan *et al*. 1993). Measurement of LAI in the field is very difficult, and requires a great amount of time and efforts (Gower *et al*. 1999). The mapping of LAI in large geographic area may be impossible when we rely on the field measurement. To solve this problem, there have been continuing efforts to develop methodologies to estimate LAI using remote sensor data. The normalized difference vegetation index (NDVI) was the most commonly used (Chen and Cihlar 1996). Although empirical modeling is relatively easy and useful method for relating field measured LAI to remote sensor data, several factors have certain influence on empirical model (Cohen *et al*. 2003). Accurate estimates of leaf area index is essential in agricultural and forestry applications as LAI exhibits a major control on transpiration and uptake of CO_2 by the canopy. Remotely sensed data acts as a unique cost-effective source for a detailed knowledge of the spatial and temporal variations LAI. Different methods to estimate LAI from reflectance data have been developed and can be grouped into two approaches such as (1) statistical approach and (2) physical process based approach (using radiative transfer models) (Tripathi *et al.* 2012). Using statistical approach, many researchers have developed empirical relationships between vegetation indices (VIs) and canopy biophysical variables (Tripathi *et al.* 2013). All the existing VIs are based on the large contrast existing between vegetation reflectance observed in the red wavebands and the infrared wavebands. Such a contrast is not observed on other earth surfaces (bare soil, rocks, water bodies). As a consequence, this contrast is an indicator of vegetation presence and status. The potential of VIs for the determination of crop parameters have been demonstrated in numerous

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studies (e g Broge and Leblanc 2001, Chen and Cihlar 1996, Colombo *et al.* 2003, Gitelson *et al.* 2005, Tucker 1980) and the simplicity and computational efficiency of the approach makes it highly desirable for large-scale remote sensing applications. MODIS on-board Earth Observing System (EOS) Terra/Aqua platforms, now provide LAI as a standard product (MOD15) to the scientific community at 1 km resolution, every eight days. The MODIS LAI product is defined as the one-sided green leaf area per unit ground area (Myneni *et al.* 2002, Privette *et al.* 2002). An algorithm based on three-dimensional radiative transfer theory is used in the production of MODIS LAI products (Myneni *et al*. 2002). Model inversion technique using a look-up-table approach was used for its production (Knyazikhin *et al.* 1998a,b; Tian *et al*. 2004). A back-up method based on the relationship between NDVI and LAI (Knyazikhin *et al*. 1998a, Myneni *et al*. 1997) was employed where this main algorithm failed (Myneni *et al*. 2002). The MODIS LAI products are available to the scientific community and can be ordered through the EOS Data Gateway or directly via FTP through Data Pool at the Land Processes Distributed Active Archive Center (https://wist.echo.nasa.gov/api/). The LAI products were projected on a Sinusoidal 10° grid with 36×18 tiles spanning the globe (Myneni *et al*. 2002) and are distributed in HDF (Hierarchical Data Format)-EOS format. Extensive quality control information regarding cloud and data processing conditions is also included in the data. Wang *et al*. 2004 found that the accuracy of MODIS LAI (version 4) for needle leaf forest is within 50%, whereas for agricultural area (accuracy was within 30% (Tan *et al.* 2005) as found from ground base validations. The validation of LAI global fields, i e assessment of uncertainty of remote sensing-derived products by analytical comparison to reference data which are presumed to represent the target values is necessary and has been carried out for many sites over USA, Africa and elsewhere, but very few results are available over India. Pandya *et al*. (2003) who used MOD 15 version 003 found significant positive correlation between LAI derived from LISS-III and MODIS data, with an overestimation in the MODIS product. Keeping all these in view, a study was proposed with the objective to retrieve the LAI using IRS-P6, LISS-III data and validation of MOD 15 LAI product for a part of North West region of the country.

MATERIALS AND METHODS

The study area lies between 72°38’54.44"E to 77°36’11.74"E and 27°39’19.38"N to 32°30’26.85"N, with altitude varies 180 metres to 1200 metres above sea level, which covers whole states of Punjab and Haryana, Delhi and two districts of Rajasthan in India which is commonly known as Trans Gangetic Plain.Ground sampling is done for whole of the above mentioned area. But the present study of validation of MODIS LAI product is carried out of only a part of the above study area (covering district Karnal,

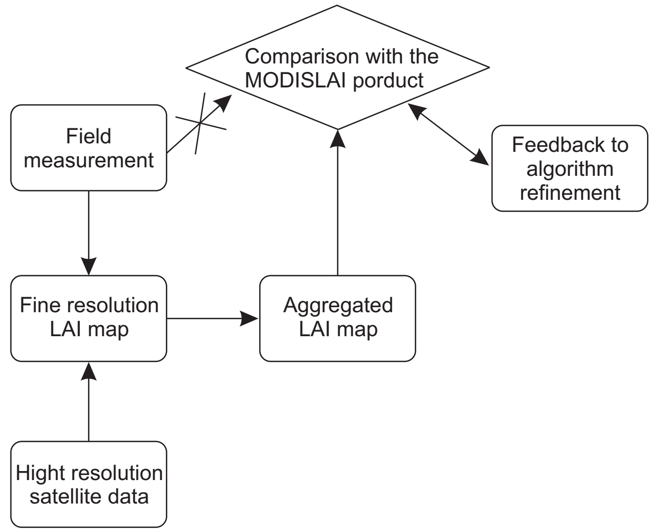

Fig 1 Methodology for validation of MODIS LAI product (MODIS V5)

Kurukshetra, Panipat, Jind, Kaithal in Haryana state and Patiala and Ambala districts in Punjab state of India), which is shown in the Fig 1. The study was carried out in wheat growing regions of the study area only.

The level-4 MODIS global Leaf Area Index product is composited every 8 days at 1-kilometer resolution on a Sinusoidal grid. These science data sets provided in the MOD15 include LAI, (also Fraction of Photosynthetically Active Radiation, FPAR), a quality rating, and standard deviation for each variable**.** They are provided in HDF-EOS data format (Knyazikhin *et al*. 1999).

IRS LISS III image covering part of study area was used for generation of LAI product and validation of MODIS LAI product (MOD 09). The details of the LISS III image used is given as below (Table 1).

A field visit was conducted in the early February in the

Table 1 Specification of IRS P6, LISS-III sensor

Satellite and sensor	IRS-P6, LISS-III
Path and row of LISS-III image tile used in the study	Path-094 Row-050
Date of pass	7 Feb, 2008
Spatial resolution	24 m
Spectral bands	0.52 to 0.59 microns (Green (Band 2)) 0.62 to 0.68 microns (Red (Band 3)) 0.76 to 0.86 microns (NIR (Band 4)) 1.55 to 1.7 microns (SWIR (band 5)
Lmin (mW/cm^2/sr/μm)	0 for all the bands
Lmax (mW/cm^2/sr/μm)	B2-12.064 B3-15.1310 B4-15.757 B5-3.397

wheat growing regions of the study area with the purpose of *in-situ* measurement of LAI of wheat in farmers' field using canopy analyzer (LICOR-2000). The ground truth was conducted using handheld GPS and locations (latitude and longitude) of the sample collection were noted down.

In situ LAI measurement was done in various farmers' field of the study area using canopy analyzer (LICOR-2000). The instrument was set to take three below canopy measurements and one above canopy measurements to estimate the LAI. LAI-2000 measures the gap fraction P(θ) in five zenith angle (θ) ranges with midpoints of 7°, 23°, 38°, 53° and 67°. LAI is determined by inverting simple radiative transfer model foliage information (Welles and Norman 1991). This indirect LAI estimate specifically represents an effective leaf area index for the agricultural crops and an effective plant area index, including branch components, for deciduous forests. The assumption of a random spatial distribution of the leaves as made in the model inversion is generally satisfied for these crops. Where a nonrandom spatial distribution of canopy foliage is observed, an accurate description of gap size is essential to avoid large errors in LAI estimation (Chen *et al*. 1997, Gower *et al*. 1999).

LAI is calculated according to Gower and Norman (1991) from the LAI-2000 gap fraction measurements:

$$\mathrm{LAI} = 2\int_0^{\pi/2} \ln[1/P(\theta)]\cos\theta\sin\theta\, d\theta$$

LAI measurement was done in 190 locations of whole Trans-Gangetic plain having two measurements in each field, out of which 80 locations were in the coverage region of LISS-III data.

Optimum detection of object requires that data be expressed in physical units, such as radiance or reflectance. Therefore, understanding of the spectral reflectance characteristics is necessary for proper interpretation of satellite images.

Spectral radiance from a pixel in each band, denoted by L with the units of mW cm^{-2} sr^{-1} μm^{-1}, is proportional to its digital number (DN) and can be derived by using the minimum (Lmin) and maximum (Lmax) radiance values of a sensor band.

$$L_{rad} = (DN/\text{max gray}) * (L_{max} - L_{min}) + L_{min}$$

Where,

L_{rad} : radiance for a given DN value,

DN : Digital Count,

Max gray : 255 for LISS – III

L_{min}/ L_{max} = minimum/maximum radiance value for a given band

Lmax and Lmin for each band, corresponding to a current gain setting of a satellite sensor, can be obtained from the satellite header information. The typical values for the LISS-III sensor of IRS-1D satellite, dated march 7 February 2008, are given in Table 1.

Top of atmosphere reflectance of a pixel in each band can be estimated from the computed spectral radiance and the mean solar exo-atmospheric spectral irradiance (Esun; mW/cm^2/μm), by using the equation given by Markham and Barker (1986 and 1987).

$$\rho_\lambda = \frac{\pi L d^2}{E_{\sin\lambda}\cos\theta}$$

where, ρ_λ = spectral reflectance of a pixel; $E_{\sin\lambda}$, mean solar exo-atmospheric spectral irradiance; θ, solar zenith angle; *d,* distance between earth and sun.

The computed values of mean solar exoatmospheric spectral irradiances for LISS-III channels as reported by Pandya *et al.* 2002.

Top of atmosphere reflectance was converted to surface reflectance using Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) module of ENVI 4.4. FLAASH incorporates the MODTRAN 4 radiation transfer code.

The reflectance image was registered to corresponding geo rectified images using nearest-neighbour resampling.

The traditional approach for LAI estimation using vegetation indices is based on the combination of a chlorophyll sensitive band (typically the red band) and a band located in the high reflectance plateau of vegetation canopies (NIR band).

$$\mathrm{NDVI} = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

The LAI measurement locations were identified and demarcated carefully on the corresponding LISS-III data. The empirical approach based on NDVI with a linear, exponential and polynomial models were used to relate remote sensing observation data to field LAI in the present study. But exponential model was found to be highly significant and hence this was used to establish an empirical model based on which LAI map of high resolution was generated. Ground measured 40 locations were used for developing regression model with NDVI and rest 40 LAI values were used for its validation.

LISS-III LAI image having resolution 24 m, could not be compared with the MODIS LAI product having resolution of 1 km. Hence LISS-III derived LAI was aggregated to moderate resolution (1 km) with the help of ArcGIS software (ver 9.2) through averaging. The comparison was carried out between aggregated LAI product and MODIS LAI product by deriving regression relationship. Leaf area index validation results of other sites in the different parts of the world can be used to further refine the algorithm used in developing MODIS LAI product. Complete procedure of validation is explained in the flow diagram (Fig 1).

RESULTS AND DISCUSSIONS

Comparison between MODIS LAI product and LISS-III derived LAI

A regression analysis was performed between LISS-III NDVI image generated from the LISS-III surface reflectance

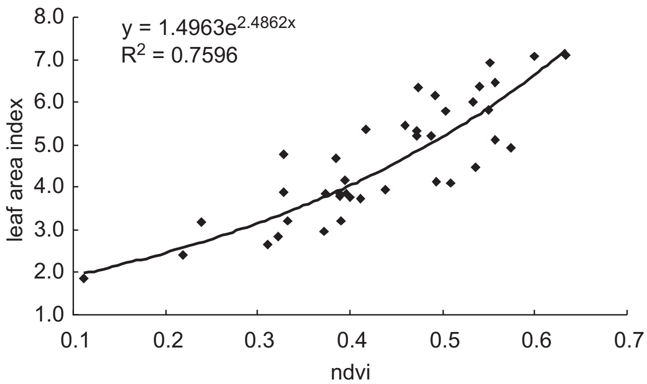

Fig 2 Empirical relationship between measure wheat LAI and NDVI values calculated from surface reflectance image of LISS-III

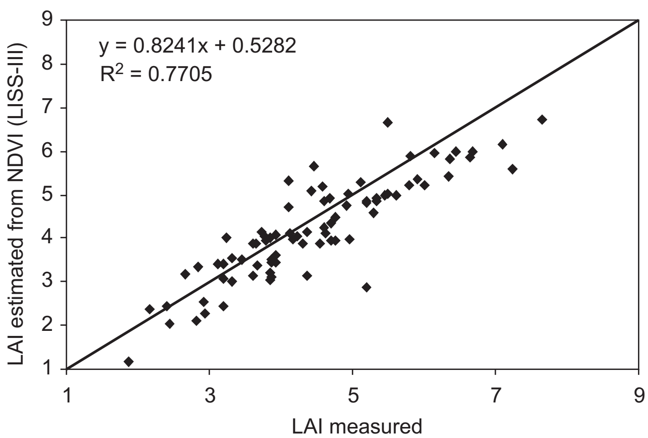

Fig 3 Comparison between estimated LAI from LISS-III NDVI and measured LAI of wheat (with 1:1 line)

data and ground measured LAI (Fig 2) Three empirical relations, ie linear, exponential and polynomial were examined for the NDVI-LAI relation. The exponential model fit was found to have higher R^2 (0.76) than other models. A fine resolution LAI map was generated from IRS LISS-III data by using the exponential NDVI_LAI relationship. A good

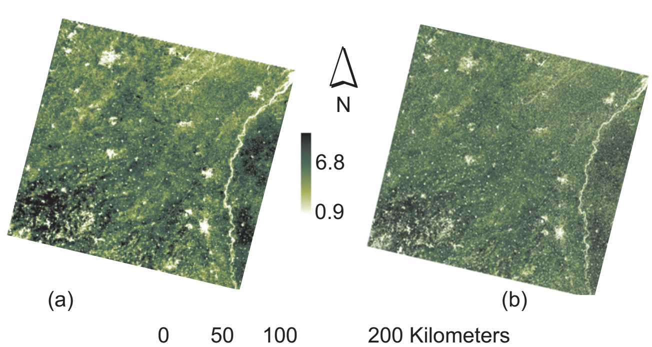

Fig 4 (a) LAI map (of 1 km) aggregated from (b) LAI product of LISS-III, IRS P6 (24 m) generated from its NDVI image using regression model

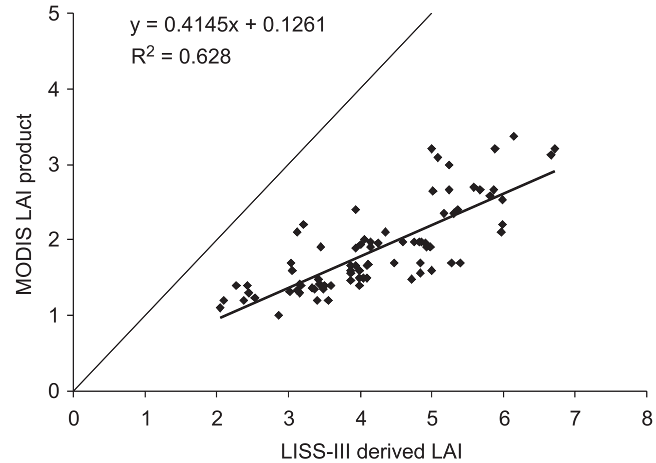

Fig 5 Comparison of MODIS LAI product with the aggregated LAI of LISS-III

correlation (R^2 =0.77) between ground measured LAI and LAI retrieved through exponential regression model was found (Fig 3). LAI retrieved through regression analysis between LISS-III NDVI and LAI, was aggregated to 1 km resolution (Fig 4). A regression analysis was performed between Aggregated LISS-III- LAI (independent variable) and MODIS LAI (dependent variable) for camparison (Fig 5). A significant positive correlation was found between LISS-III-derived LAI and MODIS LAI (with R^2 value 0.63). The analysis indicated under-estimation in MODIS LAI compared to LISS-III LAI. Underestimation of LAI values was higher for higher LISS-III LAI estimates (Fig 5). The overall RMSE of MODIS LAI is higher (i e 2.74) compared to LISS-III LAI (0.65). MODIS LAI was corrected using the linear regression model developed between LISS-III and MODIS LAI. During the analysis it was also observed that many pixels of MODIS LAI product were having very low LAI which was very much contrary to that of ground observations. Leaf area index is a spatially heterogeneous quantity and it is associated with high uncertainty in field observations and other procedures. Additional studies covering more sites and vegetation types are underway which may bring better realistic MODIS LAI product for its operational use (Knyazikhin *et al.* 1999).

Leaf area index estimation for large geographic areas is difficult when relying on the field measurements. Hence remote sensing data is used to estimate LAI using statistical and physical process based approaches. In this study, statistical approach was used to retrieve the LAI for the parts of Haryana and Punjab states of north western part of the India using LISS–III, IRS P6 sensor. MODIS on-board Earth Observing System (EOS) Terra/Aqua platforms, provide LAI as a standard product (MOD 15) to the scientific community at 1 km resolution, every eight days. But these MODIS LAI products are validated for very few areas over India. In the present study MOD 15 LAI products were validated using the LISS–III derived LAI aggregated to 1 km resolution. Results revealed positive correlation (R^2 = 0.62) between MODIS LAI product and Aggregated LISS-III LAI but MODIS LAI values were found to be underestimated compared to the measured values. The overall RMSE of MODIS LAI was found to be higher (i.e. 2.74) compared to LISS-III LAI (0.65). The extrapolation of source field data from sampling points to a large area is the biggest challenge for validation of moderate and coarse resolution LAI products. Further studies over more sites and vegetation coverage has to be conducted and necessary correction may be recommended for algorithm refinement (of MOD 15 V5) before its operational use.

ACKNOWLEDGEMENTS

Authors thank the Indian Agricultural Research Institute, New Delhi, India, for providing financial help for completing this project.

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