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Engineering Interventions for Sustainable Agricultural Development of Bangladesh

AGRICULTURAL ENGINEERING DIVISION
THE INSTITUTION OF ENGINEERS, BANGLADESH
Head Quarters, Ramna, Dhaka-1000
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# RETRIEVING LAI OF DIFFERENT FOREST SPECIES FROM LANDSAT TM/ETM+ IMAGINARY

Nepal C Dey[1], Seiji Hayakawa[2], Yasuomi Ibaraki[3] and M. Aminul Islam[4]

**Abstract**: Information on vegetation is important for the planning of regional natural resources management, carbon cycling studies, terrestrial primary productivity, modeling of hydrology, energy and climate. In situ estimation of Leaf Area Index (LAI) is often time consuming, expensive, unfeasible for remote locations and sometimes destructive, however, remote sensing can meet the data needs in a timely and consistent manner. The values of LAI were different from year to year because the seasonal timings of image acquisition were different with the variations in phenological development of the plants. The study found that not only the three successive stages in different forest types, but they were also statistically different based on their physiologic characteristics. Separating the LAI estimation by each successive stage, there was a significant gradient in LAI through the stage and a significant difference between the stages. The lowest LAI appeared in the winter season when the trees and plants had little or no leaves. New leaves appeared in the plants during spring season and LAI started to increased. The upper values of LAI were obtained in the autumn season among the three successive stages. The linear relationships depicted that LAI increased with the increase of NDVI or SR (simple ratio). The linear relationships were significantly correlated between LAI and NDVI. However, good correlation coefficient was obtained because of the non-linear relationship between LAI and SR. The relationship was stronger in case of FPC (foliage projected cover) with NDVI than SR. The NDVI is the better spectral vegetation index for retrieving LAI from a linear relationship.

**Keywords:** ETM+, LAI, Landsat, NDVI, Remote Sensing, TM

## Introduction

The role of vegetation in sustainable development mechanisms is becoming increasingly important, as is the cost of environmental services. Therefore, there is a greater need for accurate and detailed information about biophysical characteristics (e.g., Leaf area index-LAI) among different stages of ecological succession (Kalácska et al., 2004).

The LAI is also used to predict the photosynthetical primary production and as a reference tool for crop growth. As such, LAI plays an essential role in theoretical production ecology. The characteristics of vegetation indices of different land cover species are different due to seasonal variations of plants growth (Dey and Hayakawa, 2005).

Leaf area index is a quantitative measure of foliage density used for monitoring vegetation status (Warning and Runner, 2000) and modeling fluxes of water (Nouvellon et al., 2000), energy (Sellers et al., 1994; Bonan, 1995), and greenhouse gases (Coops et al., 2001; Frank, 2002) between the atmosphere and the land surface.

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[1] Dr. Nepal C. Dey, Environmental Research Unit, Research and Evaluation Division, BRAC, 75 Moakhali, Dhaka
Email: nepal.cd@brac.net, nepal_dey@yahoo.com,
[2] Dr. Seiji Hayakawa, Professor Emeritus, Department of Biological and Environmental Sciences, Yamaguchi University, Japan
Email: hayakawa@yamaguchi-u.ac.jp
[3] Dr. Yasuomi Ibaraki, Department of Biological and Environmental Sciences, Yamaguchi University, Japan
E-mail: ibaraki@yamaguchi-u.ac.jp
[4] M. Aminul Islam, Environment and Sustainable Development, UNDP-Bangladesh, IDB Bhaban, Dhaka
Email: aminul.islam@undp.org

LAI is defined by the United Nations Food and Agriculture Organization (UN FAO, 2002) as being half the all-sided green leaf area per unit ground surface area projected on the horizontal datum. The definition has a simple modification replacing "green leaf" with "living foliage" to encompass vegetation with different photosynthetic or morphological characteristics (Fernandez, et al., 2003). Either direct or indirect approaches have been used for the estimation of in situ LAI. In situ estimation of LAI is often time consuming, expensive, unfeasible for remote locations (Wang et al., 2004) and sometimes destructive. Remote sensing products can meet these data needs in a timely and consistent manner. Optical remote sensing is an economically feasible way for retrieving information such as LAI from regional to global scales at acceptably high and temporal frequencies (Verstraete et al., 1996). There are some approaches developed for calculating LAI over large areas from remotely sensed optical imagery. Most of the LAI retrieval approaches need to be optimized for a specific location or vegetation type to be used successfully. Additionally, in situ calibration measurements of LAI over regional or global scales are impractical.

Different indices have different advantages in retrieving vegetation information. The major two-band indices included in this investigation are the Simple Ratio (SR) and the Normalized Difference Vegetation Index (NDVI). The SR is the simplest way to combine Red ($\rho_r$) and NIR ($\rho_n$) data for retrieving surface biophysical parameters, but in some cases its value increases with no bounds when $\rho_r$ is small and approaches to zero (Chen, 1996). The NDVI avoids this problem by normalizing the differences between $\rho_n$ and $\rho_r$ with the sum.

It is well documented in many studies that the NDVI has been an extremely popular spectral vegetation index (SVI) for biophysical parameter retrieval. NDVI has been used almost in all scales, from small area to research to global investigations. The fact is that it uses baseline spectral bands available from most of all remote sensing systems, including color infrared photography. Although numerous investigations have shown that NDVI is not the best solution for LAI retrieval under all circumstances (Carlson & Ripley, 1997; Colombo et al., 2003; Spanner et al., 1990). The widespread receipt of NDVI by both the application and research communities recommend that NDVI is a suitable benchmark for comparing alternative biophysical parameter retrieval algorithms and solutions (Walthall et al., 2004).

However, the NDVI and SR are fundamentally the same: one can be readily calculated from the other without additional information. The scaled normalized difference vegetation index (NDVI) method requires little or no in situ calibration measurements and is thus potential solution for global operational systems. The objectives of the study were therefore to retrieve LAI of different vegetation species from Landsat TM/ETM+ data, and to assess and evaluate LAI in successive stages of vegetation.

## Methodology

### Study site

The study was undertaken between latitudes 34°40′and 34°35′ North and between longitudes 132°15′ and 132°22′30″ East in Kake-Cho, Hiroshima Prefecture of Japan (Fig. 1). Annual precipitation amounts range from 1130 to 2506mm and annual mean temperatures ranges from 12.1 to 35.2°C. Most of the area is hills` and is covered with different types of forest species at different heights. The heights of plants, such as, $H \geq 8$m and $3 \leq H < 8$m were taken into consideration for this study.

### Data sources

The Landsat TM and ETM+ images were collected in Japan from Remote Sensing Technology Center (RESTEC) and Hiroshima Earth Environment Information Center (HEIC). The period of image acquisition, path, row and cloud characteristics of the acquired images are shown in Table 1. The actual vegetation map supplied from Department of Environmental Studies, Hiroshima University was used for the selection of species and locations of vegetation.

Table 1. Sensor type, acquisition times of the images

| Satellite | Sensor type | Path | Row | Acquisition timings |
|---|---|---|---|---|
| Landsat 5 | TM | 112 | 36 | 1985/5/2 |
| | TM | 112 | 36 | 1987/5/8 |
| | TM | 112 | 36 | 1988/5/26 |
| | TM | 112 | 36 | 1990/10/23 |
| | TM | 112 | 36 | 1992/5/21 |
| | TM | 112 | 36 | 1996/5/16 |
| | TM | 112 | 36 | 1998/5/22 |
| Landsat 7 | ETM+ | 112 | 36 | 2002/5/25 |
| | ETM+ | 112 | 36 | 2003/4/10 |

**Image processing**

The images, which were captured in the winter, spring, and autumn seasons used in this study for the retrieval of LAI. The vegetation images were rectified for geometric correction and geographic transformation using the Polynomial method. ER (Earth Resources) Mapper 6.0 software was used for geocoding by WGS84 (World Geodetic System, 1984) using the 10 GCPs (Ground control points). The same species of vegetation in different locations were selected on the actual vegetation map and a total of four species were selected and given identities (ID) (Table 2). The locations of each species in the actual vegetation map were matched with the TM and ETM+ images (Fig. 2) according to latitude and longitude using ER Mapper.

Table 2. Different land cover species, ID and their locations

| Land Cover Species | ID | Locations | Latitude | Longitude |
|---|---|---|---|---|
| *Quercetum variabili-serratae* | Q | a | 34:39 :05.28N<br>34:39 :00.41N | 132:17 :19.76E<br>132:17 :25.28E |
| | | b | 34:38 :44.55N<br>34:38 :38.27N | 132:17 :13.02E<br>132:17 :20.14E |
| | | c | 34:37 :53.38N<br>34:37 :43.52N | 132:17 :47.27E<br>132:17 :58.44E |
| *Cryptomeria japonica-Chamaecyparis obtuse* | C | a | 34:37 :23.76N<br>34:37 :18.83N | 132:17 :56.51E<br>132:18 :02.09E |
| | | b | 34:37 :37.62N<br>34:37 :23.13N | 132:19 :43.71E<br>132:20 :00.12E |
| | | c | 34:37 :05.74N<br>34:36 :59.73N | 132:18 :37.76E<br>132:18 :44.56E |

Actual Vegetation Map
Kake-Cho

Figure 1. Study area is located in the Kake-Cho, Hiroshima Prefecture of Japan

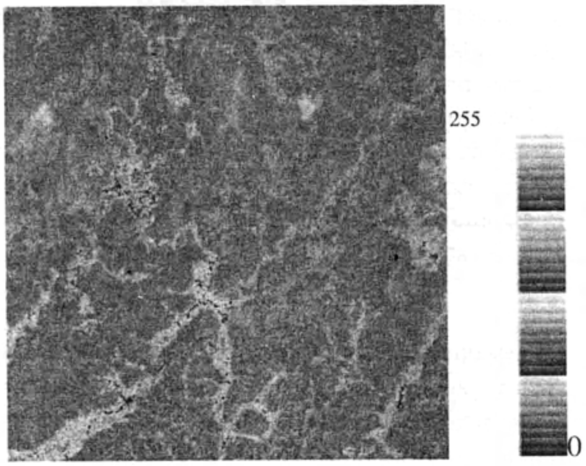

Figure 2. The Landsat Image for Band 3

## Data analysis

Two important vegetation indices, such as, the normalized difference vegetation index (NDVI) and the simple ratio (SR) were calculated from reflectance data obtained from image analysis before calculating LAI. The present study focused on to find a relationship between the remote sensed variable X (t) and biophysical variable Y(t). Here, there are two options for X (NDVI and SR), and two options for Y (LAI and FPC), producing four pair-wise relationship Y=*f* (X):

(i) LAI = *f* (NDVI);
(ii) LAI = *f* (SR);
(iii) FPC = *f* (NDVI); and
(iv) FPC = *f* (SR).

The estimation of NDVI and SR using empirical approaches used the combinations of spectral reflectance of red ® and near infrared (NIR) wavelengths. The NDVI is considered to be proxy for the status of above ground biomass at the landscape level, and it is widely used in remote sensing of the terrestrial environment (Bannari, *et al.*, 1995; Justic, *et al.*, 1985; Rasmussen, 1998; Tucker and Sellers, 1986). Rouse *et al.* (1974) developed a relationship to determine NDVI from spectral data (Eq. 1):

$$NDVI = \frac{\rho_{NIR_\lambda} - \rho_{R_\lambda}}{\rho_{NIR_\lambda} + \rho_{R_\lambda}} \quad (1)$$

and

$$SR = \frac{\rho_{NIR\lambda}}{\rho_{R\lambda}} \quad (2)$$

The near infrared and red band ranges from 0.75 to 0.90μm and 0.63 to 0.69 μm, respectively. The spectral reflectance ($\rho_\lambda$) values for near-infrared or red are calculated according to the following Equation (3):

$$\rho_\lambda = \frac{\pi . L_\lambda d^2}{ESUN_\lambda . \cos\theta_s} \quad (3)$$

Here *d* means earth sun distance and the values are derived from the handbook (IAS, 2003) using the interpolation method. Solar zenith angle ($\theta_s$) is derived from solar elevation angle ($\theta_r$) taken from image profiles in the supplied CD (compact disk). The values of solar spectral irradiances (ESUN$_\lambda$) are taken from the handbooks (IAS & RESTEC). The spectral radiance ($L_\lambda$) is calculated based on the following relationship (Eq. 4):

$$L_\lambda = \left(\frac{L_{MAX} - L_{MIN}}{Q_{CMAX} - Q_{CMIN}}\right) * (Q_{CALL} - Q_{CMIN}) + L_{MIN} \quad (4)$$

where, $Q_{CMAX}$ and $Q_{CMIN}$ are the maximum and minimum quantized calibrated pixel values, 255 and 0, respectively in both the case of TM and ETM+ data. The $L_{MAX}$ and $L_{MIN}$ are the maximum and minimum spectral radiances derived from the handbooks (IAS, 2003 & RESTEC, 1990).

The quantized calibrated ($Q_{CALL}$) pixel values are the reflectance of band 4 or 3.

## Retrieval of LAI

Choudhury et al. (1994) and Gillies and Carlson (1995) reported the scaled spectral vegetation indices (SVI) approach associates with a foliage projective cover (FPC) with an equation for LAI expressed as a function of FPC reported by Campbell & Norman (1998). LAI can be estimated as relationship (5):

$$LAI = -2 \ln \left(1 - FPC\right) \quad (5)$$

Foliage projective cover is calculated using the following relationship (6):

$$FPC = 1 - \left[\frac{NDVI_{MAX} - NDVI_i}{NDVI_{MAX} - NDVI_{MIN}}\right]^{0.6} \qquad (6)$$

Here $NDVI_{MAX}$ is the maximum NDVI value for the image, $NDVI_{MIN}$ is the minimum NDVI value of the image, and $NDVI_i$ is the NDVI of an individual pixel.

As it was important to avoid including water or spurious high value pixels when determining the minimum and maximum NDVI values, it is usually preferable to use the mean of the end 3% of the tails of the NDVI histogram for the minimum and maximum values. The scaled SVI approach assumes random orientation and distribution of leaves throughout the canopy with no clumping of elements. The relationship between FPC and LAI is the basis for algorithms used by nondestructive LAI field measurements instrumentation widely accepted by research community (Wells, 1990; Wells & Norman, 1991).

## Results and discussion

The changes of LAI of the *Q* and *C* vegetation species in different years are presented in Fig. 1. The values of LAI are different from year to year due to the fact that the seasonal timings of the image acquisition were different every year with the variations in phenological development of the plants and response to temporal variations of environmental factors.

This study also found that there was a significant gradient in LAI through the stages and a significant difference between the stages in both of the species. The smaller values of LAI were found in the years 1985, 1987, and 1996 because the image acquisition times were at the early stage of green leaf when canopy density was increasing. The smallest LAI appeared in the image acquisition time of April, 2003 which was at the end of the winter season and the beginning of the spring season, when the trees and plants had little or no leaves; the effect of background reflection can cause considerable deviations of actual LAI. The smallest LAI was shown in case of *C* species in every year.

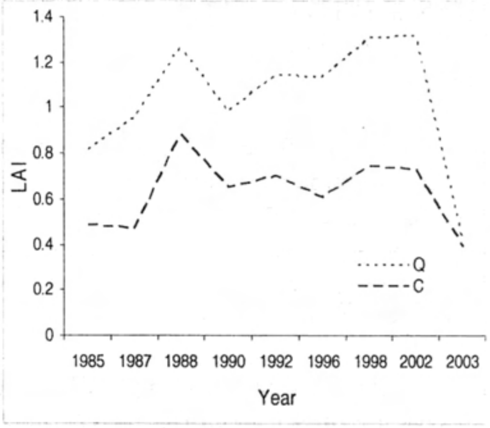

Figure 1 the changes of LAI of the two vegetation species in different years

The upper and the lower values of LAI in different successive stages of the two forest species are shown in Fig. 2 to 3. The LAI was increasing from winter to summer season in case of all species. The upper value of LAI was found highest in the summer season and lowest in the winter season. However, the lower value of LAI was greater in the autumn season in the case of *C* species. The *Q* species had the lower LAI values in the summer and relatively less value in the autumn season.

The LAI varies from 0.38 to 0.56 in the winter season. New leaves started growing in the plant during the spring season. The LAI ranged from about 0.42 to 0.96 in the spring season and 0.62 to 1.1 in the autumn season.

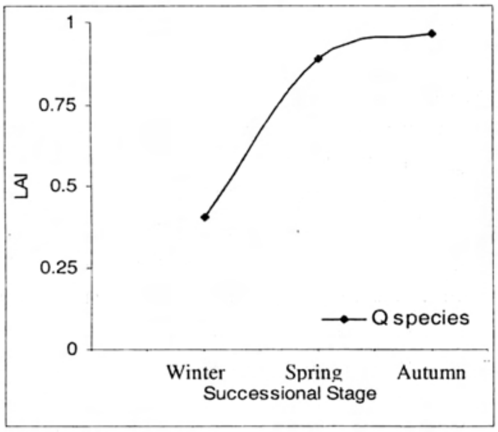

Figure 2. LAI of each successive stage for *Q* species

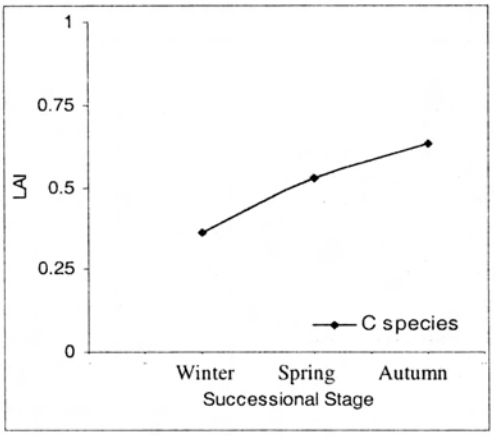

Figure 3. LAI of each successive stage for *C* species

The linear and non-linear relationships between biophysical variable (LAI and FPC) and remote sensed variable (NDVI and SR) are presented in Fig. (4 to 7). The relationships between LAI and NDVI for the two species are presented in Fig. 4. Two curve types of fitting techniques, linear and non-linear, were used for each vegetation index. The linear relationships are significantly ($R^2$=0.83) correlated between LAI and NDVI. However, non-linear relationships between LAI and NDVI were less strong ($R^2$=0.76) than the linear relationship between LAI and NDVI.

The relationships between LAI and SR for *Q* and *C* species are presented in Fig. 5. The linear relationships for *Q* and *C* species showed that LAI was directly dependent on SR. The non-linear relationships were significantly ($R^2$=82) correlated between LAI and SR. The LAI and SR were also linearly correlated ($R^2$=78) which is less strong than the non linear relationship.

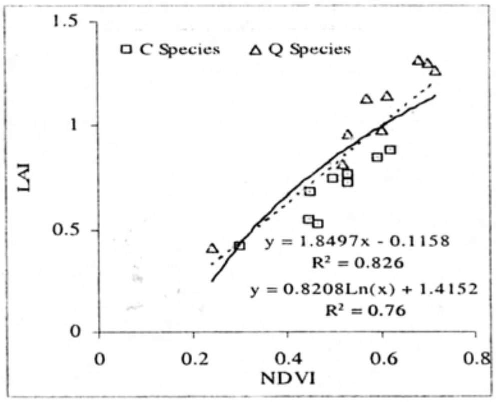

Figure 4. Relationships between LAI and NDVI

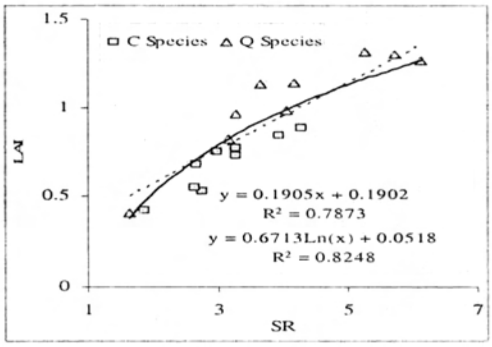

Figure 5. Relationships between LAI and SR

Fig. 6 explains the relationship between FPC and NDVI. The non-linear equation showed the better relationship between FPC and NDVI. The relationships between FPC and SR are shown in Fig. 7. The relationship is stronger in the case of FPC with NDVI than of FPC with SR. The NDVI is the better spectral vegetation index for deriving LAI as well as FPC.

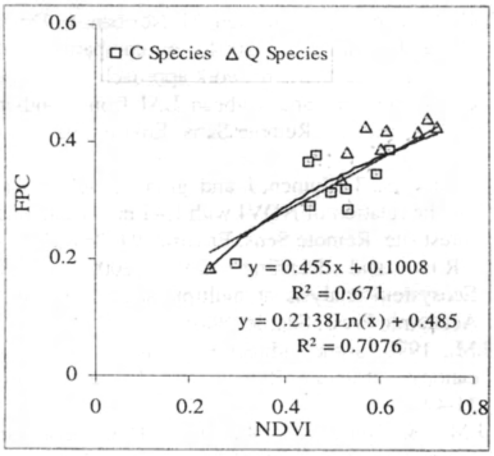

Figure 6. Relationships between FPC and NDVI

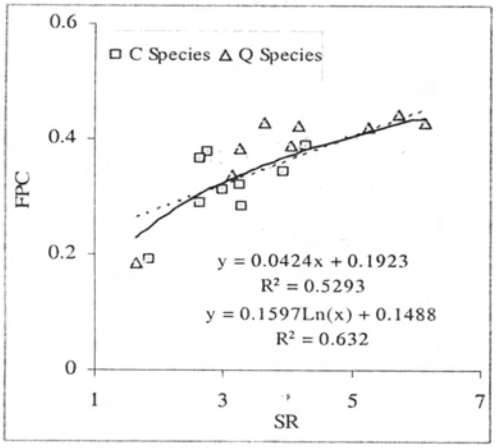

Figure 7. Relationships between FPC and SR

## Conclusion

The LAI values were different from year to year due to the fact that the seasonal timings of image acquisition were different with the variations in phonological development of the trees and response to temporal variations of environmental conditions. Here it was found that not only were the three successive stages in these different species, but they were also statistically different based on their physiognomic characteristics. Segregating the LAI estimation by successive stage, we found a significant gradient in LAI through the stages, and a significant difference between the stages. The analysis between LAI and different spectral indices were investigated using regression equations.

The LAI estimated from NDVI showed the significant linear relationship. A good relationship was obtained because of a non-linear equation between LAI and SR. FPC had a stronger relationship ($R^2$=0.70) with NDVI than it had with SR. The NDVI is the better spectral vegetation index for deriving LAI as well as FPC.

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