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Spectral Reflectance Anisotropy of Wheat Canopy in Assessing Biophysical Parameters

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ABSTRACT

Reflectance anisotropy of objects arises in a variety of ways, important being viewing and illuminating angles. Remote sensors possessing wide swath have variation in view angle across scenes. Besides, assuming that the earth is a lambertian surface will introduce significant errors in measurement. To study the problem of dependence of crop reflectance on source-target-view geometry, a field experiment was conducted on wheat using Li-1800 spectroradiometer with a field of view of $20^0 16'$. For a fixed sun position, sensor azimuth angles were varied as 65^0, 155^0, 245^0, 335^0 and sensor zenith angles were changed as 0^0, 10^0, 20^0, 30^0, 40^0, 50^0, 60^0. Specially made $BaSO_4$ plate with 95-99% isotropic reflecting surface was used as standard. The bidirectional reflectance was found to increase with the view zenith angle in all the four azimuth positions studied. For any fixed view angle, the reflectance was found to be more in the direction when the difference between the sensor and sun azimuth angle was the least which is the hot spot direction. The crop biophysical parameters like leaf area index (LAI) and dry biomass (g/m^2) were correlated with the ratio vegetation index (RVI) obtained from the bidirectional reflectance and a maximum R^2 value of about 0.88 with LAI and 0.86 with the biomass were obtained in the hot spot direction (azimuth angle155^0) and at 50^0 view zenith angle. The study clearly shows that the relation between crop biophysical parameters and reflectance is significantly dependent on source-target-view geometry.

Key words: Bidirectional reflectance, sensor geometry, biophysical parameters, hot spot, reflectance anisotropy.

Introduction

Remote Sensing of the earth's natural resources, specifically its application in studies and monitoring of crops, derives its legitimacy from the established relationship between the crop parameters and spectral signatures of the crop (Ashcroft *et al.* 1990; Jensen *et al.* 1990; Anderson, 1992; Price, 1992). Parameterization of these relationships have made possible the application of remote sensing for identification and discrimination of crops, and in assessment of crop biophysical parameters. Vegetation canopies and atmospheric constituents are not isotropic scatterers of photons as large dependence of reflectance on source incident angle and wavelength was found (Breece and Holmes, 1971). So multi-view angle observations of the earth will significantly improve our ability to quantify structural and functional changes of vegetation over spectral scales. There are several vegetation indices, which are derived from reflectance at red and near infrared (NIR) broad spectral intervals, hence referred to as broadband indices. Many of these indices have been used to estimate several vegetation parameters such as leaf area index (Baret and Guyot, 1991), absorbed photosynthetically active radiation (Asrar *et al.* 1984), green biomass, and indirectly to estimate photosynthetic capacity and net primary productivity (Seller, 1987). However, it was found that the relationship between IR/Red and LAI to be dependent on the solar angle Pinter *et al.* (1983). Wardley (1984) investigation was also carried out to find out the variability of various vegetation indices on viewing geometry. Certain off nadir view geometry are best suited for estimating different canopy parameters (Goel and Thomson, 1983). Different biophysical parameter like LAI and biomass are very important input for any crop growth model but its ground measurement is very cumbersome and time consuming and it is impossible to obtain at global scale or regional scale. So it is very important to study the reflectance behaviour of a plant canopy like wheat at different sensor viewing position and to find out the best viewing position for estimation of its biophysical properties as correctly as possible.

Materials and Methods

A field experiment was conducted at the Research Farm of Indian Agricultural Research Institute, New Delhi, latitudes 28°38'22" N, longitudes 77°09'28" E, above a mean sea level of 228.6 m. Wheat (*Triticum aestivum* L.) crop (Variety HD 2329) was raised during the *rabi* season of 2001-2002 in a sandy loam soil. The field was divided into blocks of size 6×5 m^2 with proper irrigation channel. Six nitrogen treatments namely 0, 30, 60, 90, 120 and 150 kg/ha were given and replicated twice to achieve a wide range of values of biophysical parameters. Other inputs were given as per agronomic recommendation.

Biophysical parameters

Wheat leaf area index (LAI) and dry biomass was recorded along with the reflectance measurements at different stages during the crop season. For LAI measurement, a plant sample from 0.5 m row length was cut and its green leaf area was measured using LI 3100 leaf area meter. The area displayed was recorded and from its reading LAI was calculated as LAI = [leaf area (m^2)]/ (0.225 × 0.50) because the row-to-row distance of the wheat was 0.225 m. The same plant samples were dried to a constant weight in oven at 70°C for 72 hrs and weighed to get total above ground dry biomass.

Spectral reflectance

The spectral reflectance measurements of the crop canopy were recorded by using LICOR-1800 portable spectroradiometer, which continuously scans from 330 to 1100 nm at 5 nm intervals. The remote cosine sensor of the spectroradiometer is embedded on a metal plate (Fig. 1a) and connected to the instrument through an optical fiber cable. The canopy spectral reflectance, expressed in fraction, was ratio of the target reflected radiation (numerator) and the radiation reflected from standard lambertian surface (denominator). Reflected radiation is obtained by holding the sensor facing the crop canopy and radiation measurements from standard were taken by holding the sensor horizontally facing it a barium sulphate plate, which is 95-99% isotropic reflecting surface. Reflectance measurements were taken under clear sky conditions between 1100 to 1300 hours, from 1 m above the crop canopy. While taking the observations, care was taken not to cast shadow over the area being scanned. The data so collected was integrated to obtain reflectance corresponding to standard multi spectral scanner (MSS) bands of landsat for further use in calculating different indices.

The sensor, which gives the hemispherical reflectance, is modified to measure the directional reflectance by changing the geometry of the set up. The sensor of the instrument is attached to a square shaped steel platform (Fig. 1a), which receives reflections from all directions. In order to measure the directional reflectance, that is, to receive reflections only from a particular direction, the reflections from all other directions are to be cut. This was achieved first by fixing a perspex plate to the steel platform, as shown in Fig. 1b and then a central groove was cut in the perspex plate so that

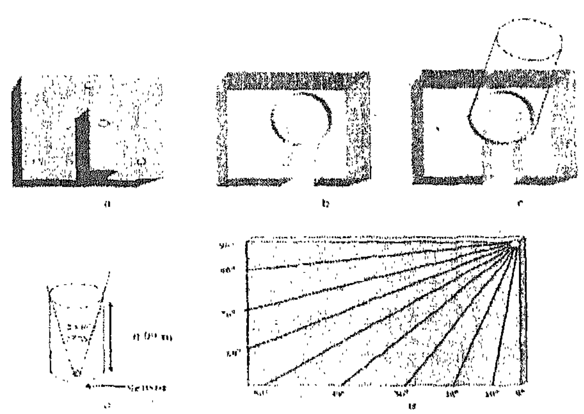

Fig. 1. (a) sensor impregnated on the steel basement in spectroradiometer. (b) perspex plate with a central groove for the attachment to the base of the sensor of spectroradiometer. (c) perspex assembly attached to the base of sensor of spectroradiometer to create field of view. (d) field of view created by Perspex assembly. (e) plastic sheet marked with the help of protractor to get different angles

a perspex cylinder can be tightly fitted into it (Fig. 1c). The length of the cylinder can be chosen depending on the area to be sensed, subtending a specific solid angle at the center of the sensor. The entire setup was covered with black tape so that the stray solar radiation cannot enter except through the open end of the cylinder. The length of the tube will determine the field of view of the sensor and in the present study, the length of 0.09 m was chosen, which gave a field of view of $20^{0}16'$ (Fig. 1d). A tripod stand was fabricated with galvanized iron pipe such that the height of the stand can be adjusted as the crop grows. The sensor setup was attached to the tripod stand by a clamp, such that it could be rotated in the vertical plane. A square shaped plastic sheet was taken and with protractor different angles from 0^{0} to 90^{0} at 10^{0} intervals were marked distinctly on it (Figure 1e). This plastic sheet was also attached with the tripod stand along with the sensor in such a way so that the plastic sheet can give the indication of view zenith angle (Fig. 2a). A wooden board of the size 4 ft x 6 ft was painted with the barium sulphate powder, thoroughly mixed in water and adding little amount of white adhesive. Several coatings of the $BaSO_4$ paste were given, each time scrubbing with a sand paper, so as to get a 95-99% isotropic standard reflecting surface. This was used as the standard reflection for calculating the reflectance percentage for both hemispherical and bidirectional measurements (Fig. 2b). For bidirectional reflectance, four azimuthal positions were chosen at the centre of the four sides of the plot. Taking north direction as 0^{0} azimuth, the four azimuthal positions were 65, 155, 245, 335 (Fig. 2c). For each azimuthal position, crop reflectance was measured at seven-view zenith angles from 0^{0} to 60^{0} at 10^{0} intervals, making a total of 28 readings for each plot. Sun azimuth and zenith were calculated using ENVI-IDL software by giving day, month, year, GMT time, latitude and longitude as an inputs. Similarly, the reflectance measurements from standard $BaSO_4$ plate were recorded at four azimuthal and seven zenith angles as was done for wheat plots.

Results and Discussion

To study the sun-target-view geometry effects, a setup was fabricated as shown earlier, with a field of view (FOV) of $20^{0}16'$ which measured reflectance at seven different view angles. Such

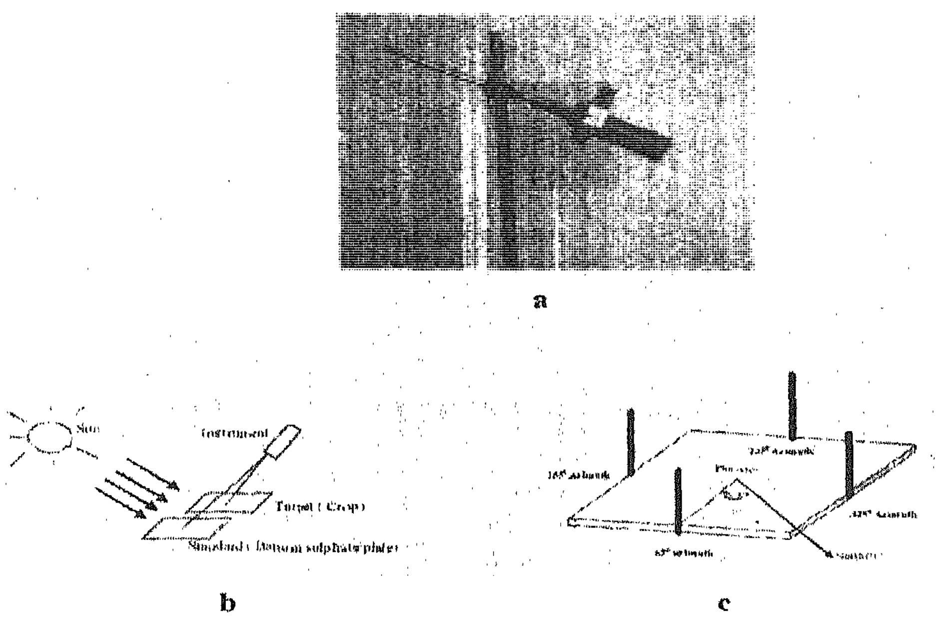

Fig. 2. (a) total set up attached to a stand with the help of a clamp, movable vertically to take radiation from different view angles (b) reflectance calibration of the Spectroradiometer with the help of $BaSO_4$ plate (c) representative plot with there respective azimuth positions

measurements were made at four azimuth angles as described earlier for each experimental plot. The time taken for making the bidirectional reflectance measurements at different view geometry was about 15 minutes during which it was assumed that the sun's position did not change much. It was observed from the hemispherical reflectance measurements that the ratio vegetation index (IR/Red) attained a maximum value around maximum vegetation stage that is around 90-94 days after sowing. So most of the results on bidirectional reflectance measurements around maximum vegetation stage are presented. The reflectance at near infrared region (800-1100 nm) for fixed sun position (solar zenith angle 53^0 and solar azimuth angle between 178^0-183^0) is shown in Fig. 3. The different tone of gray scale is depicting the percentage reflectance at near infrared region. The darker tone represents low reflectance and brighter tone represents high reflectance values. Fig. 3 clearly shows that as the sensor zenith angle increases, the reflectance at near infrared region increases simultaneously. Same trend was observed for every fixed sensor azimuth angle. Norman *et al.* (1985) who included view angles outside the principal plane, also found that the reflectance increased with view zenith angle for most azimuth angles. The probable reason of this may be the sensor is exposed to more vegetation within the canopy as the sensor zenith increased. Also more diffused radiation got entry to the sensor in higher sensor zenith angle. Among different sensor azimuthal position, the angle 155^0 showed higher reflectance than any other sensor azimuthal position. The important fact to be noted is that the sensor azimuth 155^0 has least difference with sun azimuth. This kind of effect is called hot spot effect (Suit, 1972). The intensity of hot spot effect also changed with the viewing angle. The intensity of hot spot effect is found to be low at view zenith 0^0 i.e., nadir view and it increased with the increase in view zenith angle. The intensity of hot spot effect is maximum between view angle 50 and 60^0. This clearly shows that the reflectance taken in all directions is not the same and it is affected by the sensor position with respect to the position of the sun. So plant canopy is not isotropic scatterer of photon rather it reflects preferentially in hot spot direction where the difference between senor and sun azimuth is least. Therefore, from that particular direction the canopy appears brighter than any other direction. Likewise Fig. 4 depicts the reflectance anisotropy in visible region (400-700 nm) at different sensor position with fixed sun geometry. Here also same trend was found as shown in Fig. 3 i.e., with the increase of sensor zenith angle reflectance increases and among different sensor azimuth angles, highest reflectance was observed at 155^0.

Among the widely used transforms (vegetation indices), the most widely used index (termed as Ratio Vegetation Index or IR/Red, Ratio Index) which involves reflectance in the near infrared region (800-1100 nm) and the reflectance in the red region (600-700 nm) of the vegetation was calculated from the reflectance data taken at different position of the sensor represented by its view zenith and azimuth angles. Scatter plot diagrams were made with RVI & LAI and RVI & dry biomass. Straight trend lines were drawn with their fitted equation and R^2 values shown as example in the Fig. 5 and 6. In the present study we have taken four azimuth and at each azimuth seven zenith angles for the sensor. Therefore, total 28 sensor positions were taken into account along with hemispherical reflectance. For each angle combination linear fitted equation with their R^2 values are shown in the Table 1 for RVI and LAI and Table 2 for RVI and dry biomass. It was found that RVI is highly correlated with LAI and biomass at all position of the sensor. However, consistently higher R^2 values were obtained for the 155^0 azimuth position irrespective of view zenith angles both for LAI and biomass. Interestingly, this 155^0 azimuth is the hot spot position in our experiment. Therefore, hot spot direction is the best position of sensor for measuring the biophysical parameters. For 155^0 azimuth, view zenith 50^0 exhibited highest R^2 value both for LAI (0.88) and dry biomass (0.86). For better understanding, the R^2 values relating LAI and RVI are depicted in different tones of gray scale at different sensor zenith and azimuth angles in Fig. 6. Clear circular contour was observed with highest R^2 value at 155^0 sensor azimuth and 50^0 sensor zenith angle. Similarly R^2 values relating dry biomass and RVI are represented with different tones of gray scale at different sensor geometry in

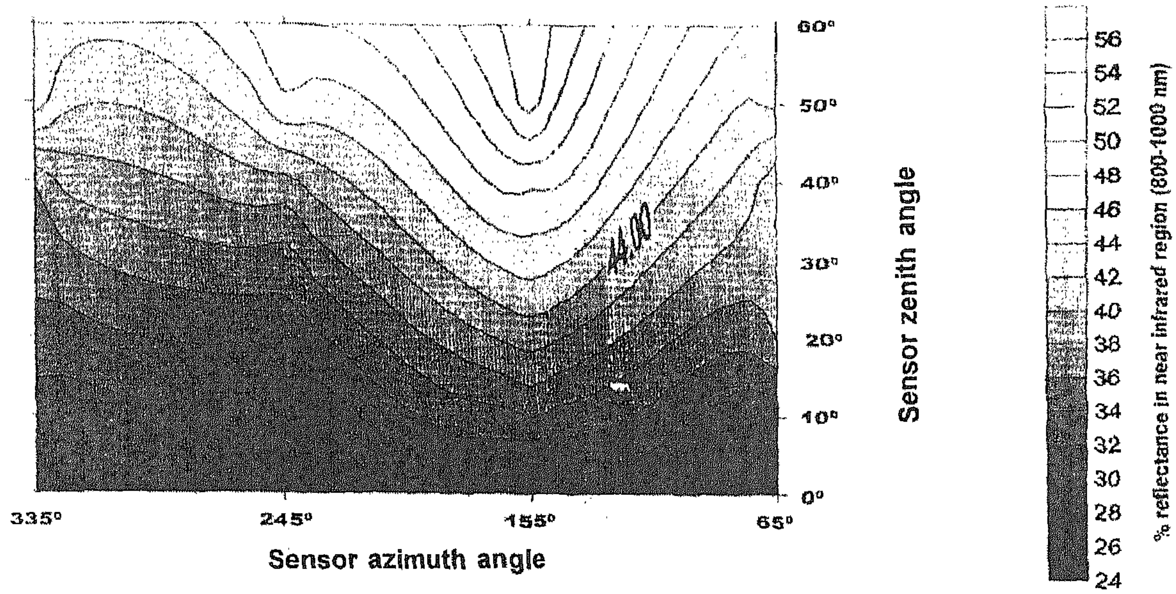

Fig. 3

Fig. 3. Bidirectional reflectance pattern of wheat canopy in near infrared region (800-1100 nm) at different sensor geometry for a fixed sun position

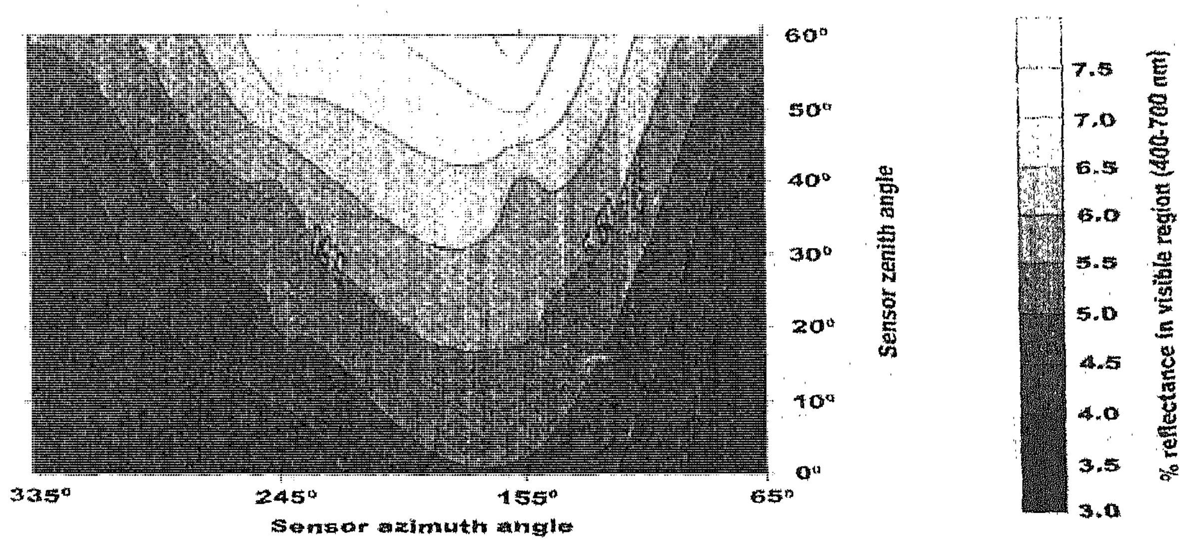

Fig. 4

Fig. 4. Bidirectional reflectance pattern of wheat canopy in visible region (400-700 nm) at different sensor geometry for a fixed sun position

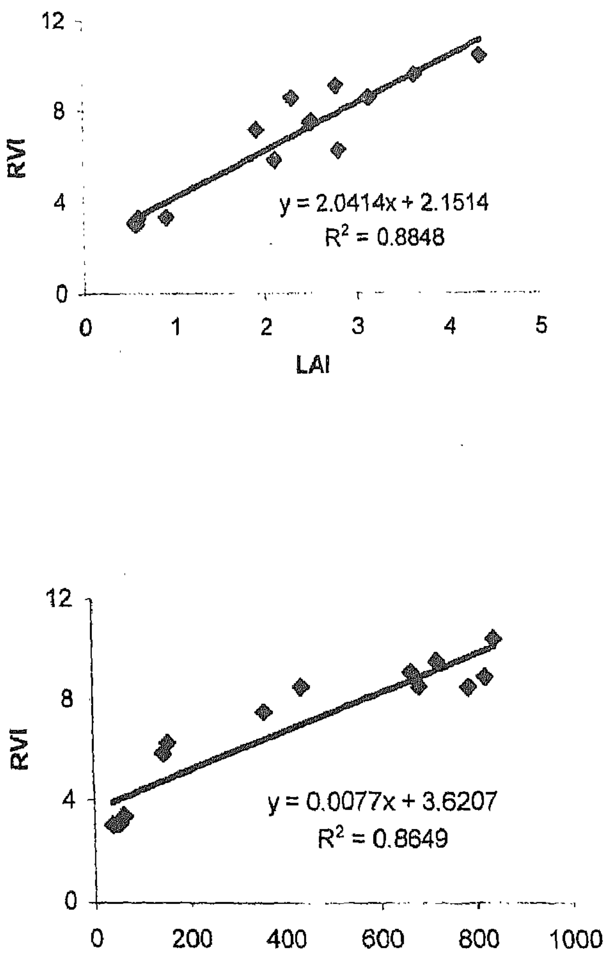

Fig. 5. Scatter plot diagrams with the linear fitted equation and R^2 value for RVI and LAI (a) and RVI and dry biomass (b)

Fig. 7. Several circular contours were observed in this figure but the brightest with highest R^2 value was obtained again at sensor azimuth 155^0 and sensor zenith 50^0 angle combination. Therefore, it may be considered the most suitable angle combination for measurement of biophysical parameters crop canopy. This finding can be supported by the worked done by Bunnik *et al.* (1983) who used the crop reflectance data in the hot spot direction to relate IR/Red ratio to LAI at five different leaf inclination angle distributions for a view zenith angle of 52^0, which was chosen on the basis of simulations using SAIL models. Their results showed that for a view angle of about 52^0 the crop reflectance are practically independent of leaf angle distribution. They obtained a good relationship between IR/Red and LAI in the hot spot direction, which was validated using bidirectional measurements on winter wheat canopies.

So the present experiment clearly showed that the plant canopy is not an isotropic scatter of photon. It reflects preferentially in the hot spot direction, where the difference between sensor and sun azimuth is least. With the increase of sensor zenith, the reflectance of wheat canopy increased simultaneously. RVI was found to be highly correlated with LAI and above ground dry biomass. But the sensor zenith 50^0 from hot spot direction was found be the best to monitor biophysical parameters of wheat crop. These finding can be further used to study the bidirectional reflectance behaviour of different plant canopy and validation of canopy reflectance model.

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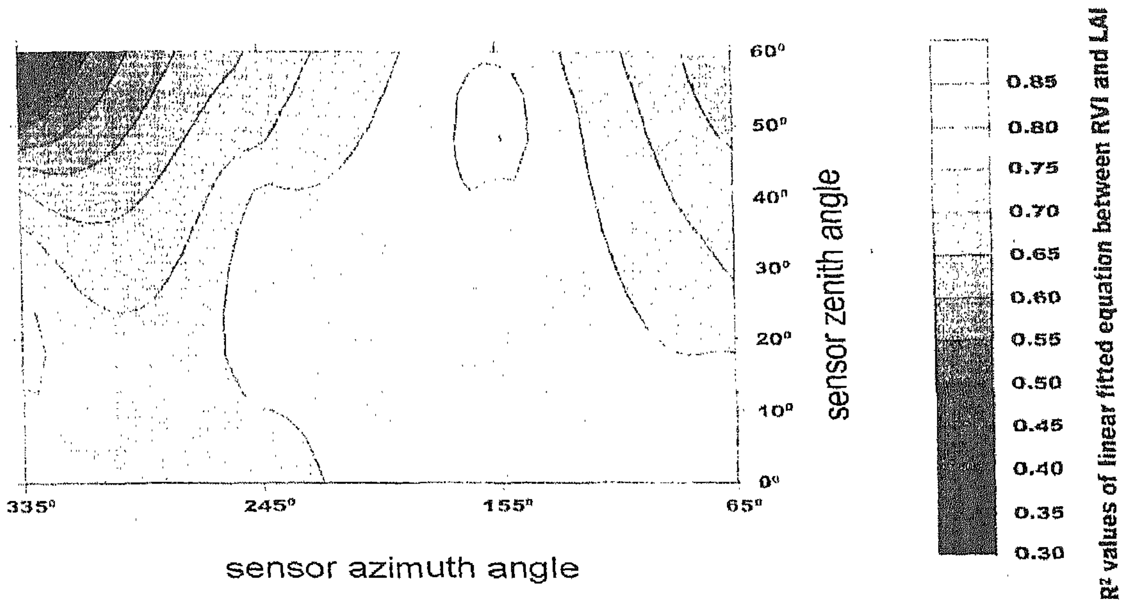

Fig 6

Fig. 6. R^2 values of linear fitted equation between LAI and RVI as found from different sensor geometry

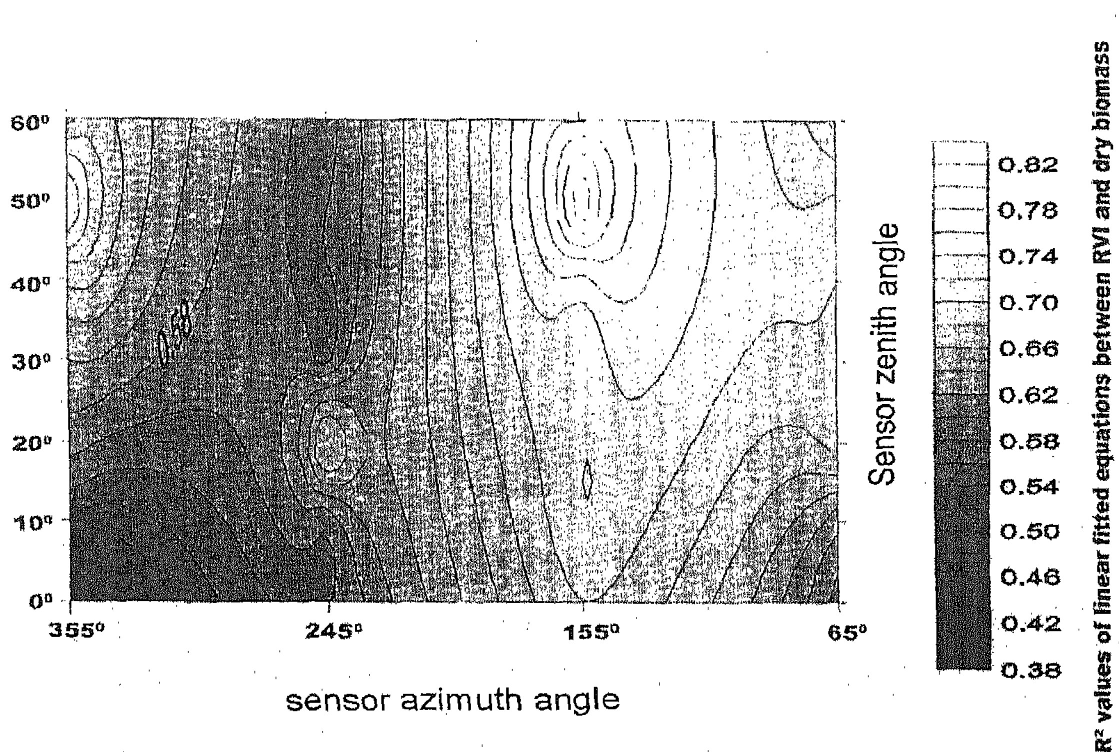

Fig 7

Fig. 7. R^2 values of linear fitted equation between dry biomass and RVI as found from different sensor geometry

Table 1. Linear statistical relationships developed between the leaf area index (X) and ratio vegetation Index (Y) for different view azimuth and view zenith angles

Sensor Azimuth	View Angles	Equation	R^2 Value	Pr>t for regression coefficient
65°	0°	Y = 1.5246X + 3.2603	0.76	.00004**
	10°	Y = 1.7411X + 3.5321	0.79	.00002**
	20°	Y = 1.6777X + 4.4462	0.74	.00007**
	30°	Y = 1.7060X + 4.6806	0.69	.00024**
	40°	Y = 1.6998X + 4.6314	0.67	.00034**
	50°	Y = 1.5471X + 4.7195	0.64	.00059**
	60°	Y = 1.0736X + 5.1242	0.60	.00111**
155°	0°	Y = 1.9486X + 2.2540	0.78	.00002**
	10°	Y = 2.0851X + 2.3696	0.79	.00001**
	20°	Y = 2.0441X + 2.4605	0.77	.00003**
	30°	Y = 2.0685X + 2.4277	0.79	.00001**
	40°	Y = 1.9269X + 2.7888	0.77	.00003**
	50°	**Y = 2.0414X + 2.1514**	**0.88**	**.0000005****
	60°	Y = 1.5140x + 3.0452	0.78	.00003**
245°	0°	Y = 1.6838X + 2.8428	0.70	.00017**
	10°	Y = 1.8462X + 2.9996	0.75	.00006**
	20°	Y = 1.9147X + 3.2242	0.79	.00002**
	30°	Y = 1.9952X + 3.4044	0.78	.00002**
	40°	Y = 1.8868X + 3.7369	0.77	.00003**
	50°	Y = 1.6160X + 4.1837	0.67	.00036**
	60°	Y = 1.3140X + 4.1059	0.66	.00044**
335°	0°	Y = 1.8057X + 2.8307	0.73	.00009**
	10°	Y = 1.8159X + 3.4268	0.74	.00008**
	20°	Y = 1.9488X + 3.6684	0.77	.00003**
	30°	Y = 1.8693X + 3.9145	0.73	.00011**
	40°	Y = 1.5928X + 4.3221	0.68	.00028**
	50°	Y = 1.3376X + 4.6162	0.49	.00564**
	60°	Y = 0.8134X + 4.6537	0.32	.03671*
Hemispherical		Y = 2.1255x + 3.0888	0.72	2×10^{-9}**

** Significant at 1% level; * Significant at 5% level.

Table 2. Linear statistical relationships developed between the above ground dry biomass (X) and ratio vegetation Index (Y) for different view azimuth and view zenith angles

Sensor Azimuth	View Angles	Equation	R^2 Value	Pr>t for regression coefficient
65^0	0^0	Y = 0.0051X + 4.5346	0.57	.00186**
	10^0	Y = 0.0059X + 4.8131	0.60	.00106**
	20^0	Y = 0.0065X + 5.2452	0.70	.00018**
	30^0	Y = 0.0068X + 5.4435	0.69	.00023**
	40^0	Y = 0.0069X + 5.3257	0.70	.00019**
	50^0	Y = 0.0066X + 5.1316	0.71	.00015**
	60^0	Y = 0.0051X + 5.0299	0.65	.00046**
155^0	0^0	Y = 0.0059X + 3.4922	0.70	.00018**
	10^0	Y = 0.0076X + 3.8175	0.72	.00012**
	20^0	Y = 0.0076X + 3.9182	0.72	.00012**
	30^0	Y = 0.0074X + 3.9743	0.70	.00017**
	40^0	Y = 0.0069X + 3.8036	0.72	.00011**
	50^0	**Y = 0.0077X + 3.6207**	**0.86**	**.000001****
	60^0	Y = 0.0054X + 4.1193	0.75	.000006**
245^0	0^0	Y = 0.0059X + 3.9173	0.56	.00203**
	10^0	Y = 0.0061X + 4.3767	0.55	.00231**
	20^0	Y = 0.0058X + 4.9163	0.70	.00502*
	30^0	Y = 0.0063X + 5.0541	0.54	.00285**
	40^0	Y = 0.0062X + 5.2023	0.56	.00198**
	50^0	Y = 0.0058X + 5.1758	0.56	.00211**
	60^0	Y = 0.0047X + 4.9089	0.55	.00227**
335^0	0^0	Y = 0.0052X + 4.4134	0.40	.01494*
	10^0	Y = 0.0061X + 4.6255	0.52	.00352**
	20^0	Y = 0.0068X + 4.8546	0.57	.00185**
	30^0	Y = 0.0069X + 4.8856	0.60	.00117**
	40^0	Y = 0.0064X + 4.9041	0.64	.00059**
	50^0	Y = 0.0069X + 4.3828	0.74	.00007**
	60^0	Y = 0.0049X + 4.1173	0.63	.00067**
Hemispherical		Y = 0.0108x + 4.1667	0.72	3.64×10^{-7}**

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