A GEOMETRICAL MODEL OF PLANT BIDIRECTIONAL REFLECTANCE

MICHEL VERBRUGGHE
I.N.R.A. Bioclimatologie, site agroparc, 84914 Avignon cedex 9 (France)
JERZY CIERNIEWSKI
Adam Mickiewicz University, Institute of Physical Geography.
Fredy 10, 61-701 Poznan, (Poland)

ABSTRACT

A model, based on the assumption that the bidirectional reflectance of a crop is strongly correlated with its general shape (macrostructure) and the specular-diffuse character of the radiance, is presented. A collection of spheroidal cylinders placed over an horizontal plane simulate the cultivated surface. The superficial surface of the plant canopy is divided into elementaries facets. The shaded and sunlit facets of a given cylinder, the adjoining cylinders are observed within the field of view of a radiometer. The relative reflectance factor of the structure is calculated using the geometrical parameters of the crop and of its illumination and observations conditions. The specular-diffuse features of the reflected energy is determined using Fresnel equations. The model was tested using bidirectional reflectance data acquired on a field of soybean in south of France (Avignon). The spectral data were measured with a field radiometer in the three SPOT (HRV) bands for 18 solar zenith angles variing from 33 to70 degrees. The reflectance distribution is characterised by a large specular effect. The relative reflectance factor can vary from 0.8 to 2.7 during a day. A quite good adequation between the experimental measurements and the results predicted by the geometrical model, taking into account the macrostructure and the specular-diffuse characteristics of the soybean crop has been found.

KEY WORDS : Bidirectional reflectance, Radiometry, Visible, Near-infrared, Modeling, Soybean, SPOT.

INTRODUCTION

The use of remote sensing data for the estimating of the activity of the phytomass in relation with agricultural or forest production need to take into account the component of data which only depend on the biological characteristics of the analysed surfaces. It is only possible if the remote sensing data are corrected from atmospheric effects, sensor characteristics and conditions of measurements. This latter which includes crops properties and the Sun and view geometries, is particulary important for using data of multiangles sensors satellites as the SPOT (HRV), NOAA (AVHRR) or ERS1 (ATSR). As the detailed properties and geometries of plant canopies are generally difficult to acquire at regional scale investigations, the analysis which is presented has been centered on the modeling of the general shape (macrostructure) of the crop and the illumination and view conditions.

Results from previous researches show that there is a substantial discrepancy between nadir and off-nadir radiances of soil and vegetation targets observed in different conditions of illuminations (Huete et al.,1992; Rondeaux,1991; Jackson et al.,1990, Moran et al., 1990, Vanderbilt; 1985). The approach taking into account the bulk reflectance and the geometric properties of the canopy has been more particulary by Jasinski (1992).

The aim of this paper is to present a modeling of the effects of view and Sun geometries on the bidirectional reflectance of a vegetation canopy in SPOT (HRV) spectral bands. The model is valided on ground bidirectional reflectance measurements of a soybean field in the south of France (Avignon).

Taking into account the specular energy leaving crop canopy, the model presented improved the previous model prepared for simulation of bidirectional reflectance of a cotton canopy in the visible and the near-infrared range (Verbrugghe and Cierniewski, 1995).

METHODOLOGY

The bidirectional reflectance factor (BRF) of the soybean canopy was measured with a CIMEL SPOT (HRV) simulation radiometer (XS1: 0.50-0.59μm, XS2: 0.61-0.68μm, XS3: 0.79-0.89μm) fixed on a goniometric support. The radiometer was situated at 2.9 m over the top of the crop and was moved along an arc of circle centered on the middle of the soybean row (Fig. 1). The field of view of the radiometer is 12 degrees and the

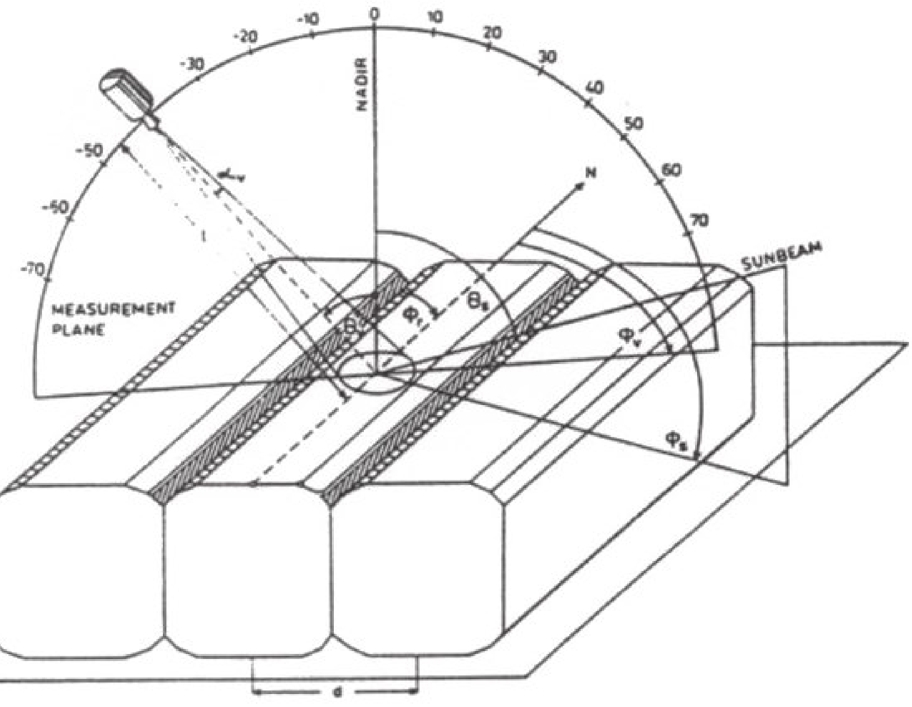

Figure 1. Schema of the crop, view and sun geometries.

solar zenith angles variing from 33 to 70 degrees. The view angles variing from -60 degrees (forwardscattering direction) to +60 degrees (backscattering direction). For each sun position the nadir radiance is measured at the beginning, the middle and the end of each sequence which lasted about 4 minutes for the15 view angles situations.The relative reflectance factor of each bands was obtained by computing the ratio between off nadir measurements and the mean value of the three nadir measurements of each sequence. The ratio of diffuse and global atmospheric radiations in the 3 HRV SPOT spectral bands was measured for each sequence by a CIMEL radiometer looking on the sky and ponctually shaded. The experiment was performed on a soybean field, before the clove growth stage on 21 and 22 July 1993 in south of France on an experimental field of INRA, Avignon. The rows were oriented in the North-South direction and spaced 0.65m apart.The soybean rows had the shape illustrated in Figure 1, their height was 0.75m.

THE MODEL

Surface of soybean field is described by a collection of opaque spheroidal cylinders. The cylinders, simulating the plant rows are parallel and (d) is the distance between rows centers. The angle ϕr is the azimuth angle of the rows with respect to the North. Slopes of the cylinders create a given number of flate plane (facets). Position of the planes in the section perpendicular to the longitdinal axis of the cylinders are defined in xy system with the originate in the center on the top of the cylinder above which the radiometer is exactly at the nadir view position. The distance of the radiometer to the top of the cylinder is (l). The angles θv and ϕv, respectively, describe the zenithal and azimuthal positions of the aparatus. The field of view (FOV) of the radiometer is αv. The geometrical structure is illuminated by sunbeams of given zenith angle θs and azimuth angle ϕs, and by diffuse skylight.

In the first step the model calculates the area of illuminated (I) and shaded (S) facets of the given and the adjoining cylinders, visible by the radiometer FOV at its given view zenith (θv) and azimuth (ϕv) angles. The area is determined analytically using trigonometrical equations.

In the second step the model computes electromagnetic energy coming to the geometrical structure. The zenith and azimuth position of each of the facets, and with the Sun zenith (θs) and azimuth (ϕs) angles, determine the amount of energy reaching the sunlit surface using the factor (E_{fa}), defined as:

$$E_{fa} = \cos\theta s \cos\beta + \sin\beta \sin\theta s (\sin\phi s \sin\phi r + \cos\phi s \cos\phi r). \qquad (1)$$

The factor E_{fa} express the cosine of the sunbeams incidence angle (γ) to the facet.

The model assumes that the energy leaving a given sunlit facet of the geometrical structures is proportional to the energy coming to them and has a specular-diffuse character. A part of the direct energy is reflected like from a near-perfect specular object and a part like from a perfect diffuse one.

Energy reflected from a given facet in the near-perfect specular way is dispersed into many vectors (v_{sp}) creating an spheroidal shape. Position of the major axis of the spheroid is into direction of the sunbeams reflection. The elongation of the spheroid (el), defined as the proportion of its major radius (ae) to its minor radius (be), depend on intensity of polarization ($Fp_{(\gamma)}$) of reflected energy E_{fa} at the γ angle, as:

$$el = ae/be = 1/(1 - Fp_{(\gamma)});\ Fp_{(\gamma)} = (r_{\perp} + r_{=})/2\ , \qquad (2)$$

where $r_{\perp}$ and $r_{=}$ are respectively the perpendicular and parallel Fresnel reflection coefficients given by:

$$r_{\perp}(\gamma) = (n\,\mu_T - \mu_I) / (n\,\mu_T + \mu_I) \text{ and } r_{=}(\gamma) = (n\,\mu_I - \mu_T) / (n\,\mu_I + \mu_T) \qquad (3)$$
$$\text{with } \mu_I = \cos\gamma = E_{fa} \text{ and } \mu_T = (1 - \sin^2\gamma / n^2)^{0.5}\ ,$$

where n is the refractive index of the reflective surface.
We assume that the n coefficients equals 1.51, 1,50, and 1.48 for, respectively, XS1, XS2 and XS3. (Gausman,1973).
The volume of the spheroid (V_{sp}) is expressed by:

$$V_{sp} = 4/3\ \pi\ ae\ be^2. \qquad (4)$$

It defines the reflected energy reflected in the near-perfect specular way, and is constant.
Knowing values of the spheroidal volume and the proportion between its major axis we can calculate the length of the vector (v_{sp}).

The component of energy leaving a given facet in the perfect diffuse way is dispersed into equal-size vectors (v_{di}) creating the ideal shape of a sphere of volume (V_{di}):

$$V_{di} = 4/3\ \pi\ (v_{odi}/2)^3, \qquad (5)$$

where v_{odi} is the vector perpendicular to the facet.

The length of the (v_{di}) vector is calculated using the same assumption as for (v_{sp}) vectors, but for a sphere.

The proportion between the near-perfect specular and the perfect diffuse energy expresses the specular-diffuse coefficient (SDC):

$$SDC = V_{sp}/(V_{di} + V_{sp}). \qquad (6)$$

The energy outgoing from a given sunlit facet (Ei_{fa}), sensed by the sensor from the given direction (θv) defined as:

$$Ei_{fa} = E_{fa}\,[SDC^{1/3}\, v_{sp} + (1 - SDC^{1/3})\, v_{di}\,] + f_{di}, \qquad (7)$$

where f_{di} is the fraction of the skylight to the direct light for the given wavelength (channel of a radiometer). This energy is proportional to the area of a given sunlit facet (Ai_{fa}).

The energy leaving the shaded facet (Es_{fa}), expressed by the f_{di} fraction having an isotropic distribution, is proportional to the area of shaded facet (As_{fa}). The factor of proportionality of the radiance of the simulated field surface (L) visible to the radiometer from the given direction (θv) can be formulated as:

$$L_{(\theta_v)} = \frac{\sum_{i=1}^{j} Ei_{fai} Ai_{fai} + \sum_{i=1}^{j} Es_{fai} As_{fai}}{\sum_{i=1}^{j} Ai_{fai} + As_{fai}} \qquad (8)$$

where i is i^{th} facet o the geometrical structure visible inside of the FOV radiometer at θv angle.

The relative reflectance factor is then calculated, as the ratio of $L_{(\theta v)}$ measured from off-nadir and the nadir directions.

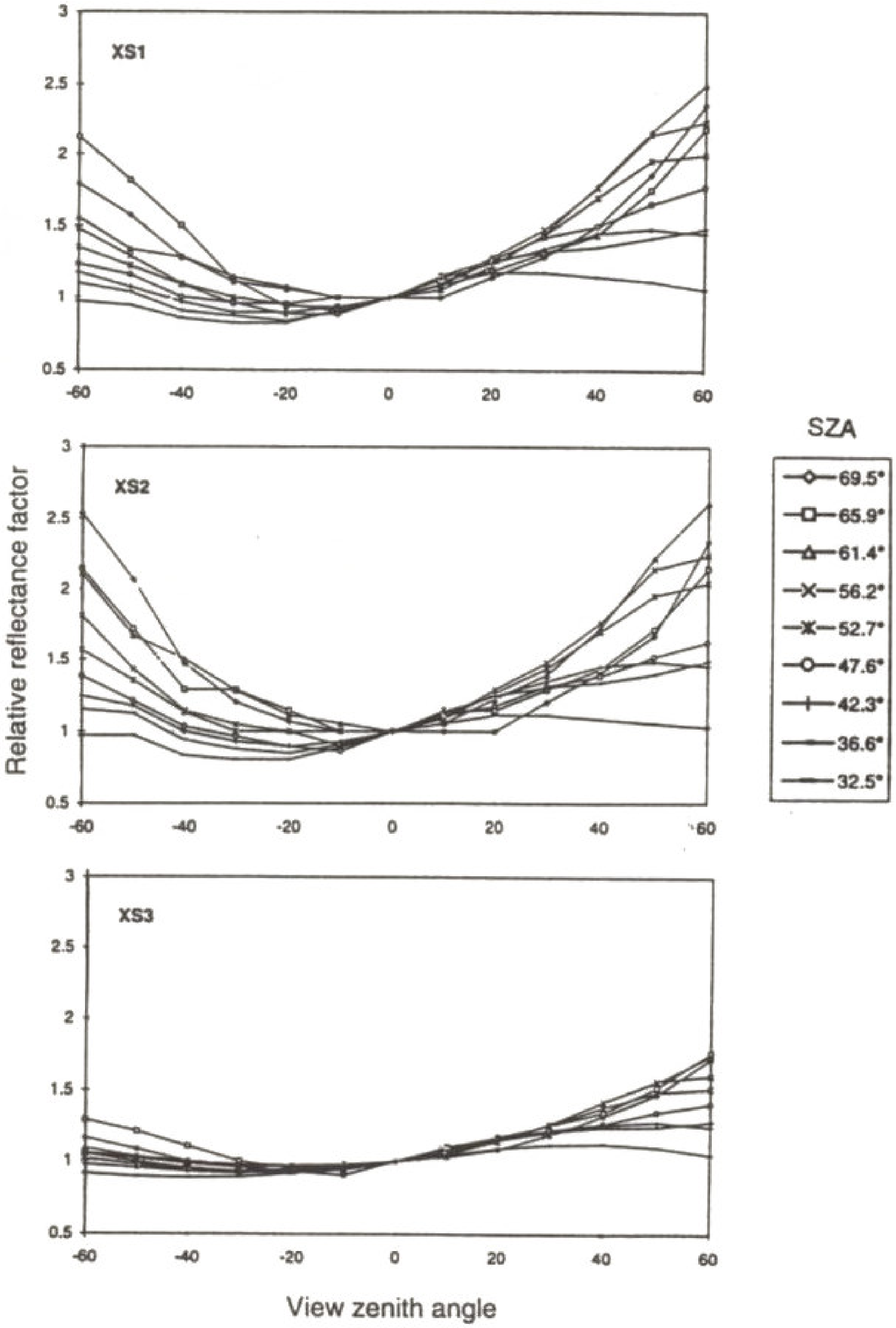

Figure 2. Distribution of the relative reflectance factor in function of view zenith angles for the SPOT XS1, XS2, and XS3 bands for solar zenith angles (SZA). Negative view angles correspond to forwarscattering direction and positive angles to backscattering direction.

RESULTS AND DISCUSSION

The distribution of the soybean reflectance in the view zenith angle function in variable illumination conditions has a clear non-Lambertian character, more pronounced in the visible channels than for the near-infrared one (Fig. 2). The soybean relative reflectance factor varies during a day from 0.8 to 2.7 for the XS1 and XS2 channels and from 0.9 to 1.8 for the XS3. When the solar zenith angle becomes higher, the reflectance increases for forwardscattering, as well for the backscattering range.

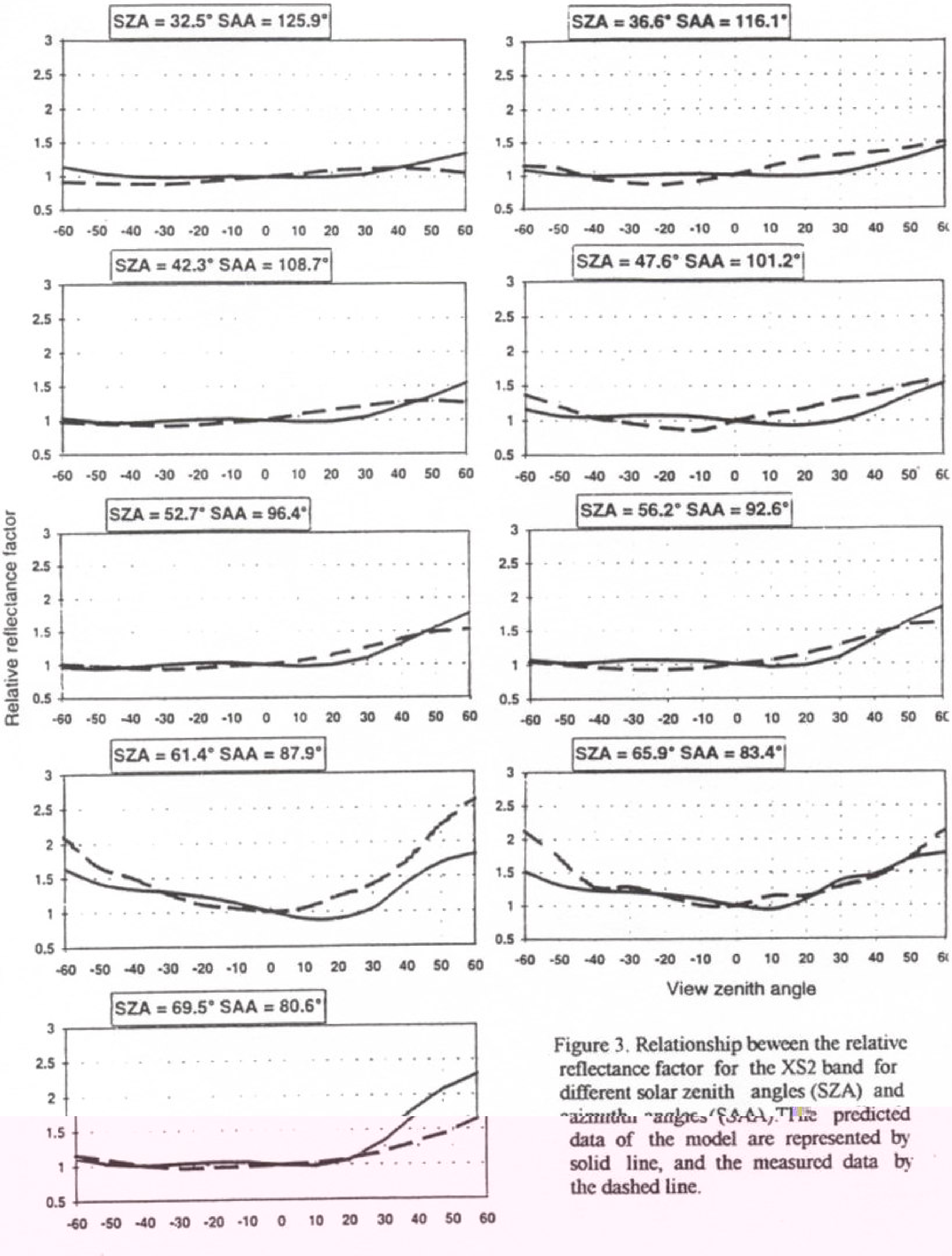

Figure 3. Relationship beween the relative reflectance factor for the XS2 band for different solar zenith angles (SZA) and azimuth angles (SAA). The predicted data of the model are represented by solid line, and the measured data by the dashed line.

The specular-diffuse coefficient (SDC) was estimated by substituting of different values to the model and looking for the values which give the highest coefficient of determination and the lowest root mean square between the model-generated and measured crop canopy reflectance data. The best SDC for the XS1 and XS2 was 0.61 for solar zenith angles (θs) higher than 50°, and 0.13 for the θs lower than 50°. The best SDC for XS3 was 0.06 for the θs higher than 50° and 0.03 for the θs lower the θs than 50°.

We found a similar pattern of the reflectance distribution in the view zenith angle between the measured and predicted data for each analysed illumination conditions (Fig. 3).

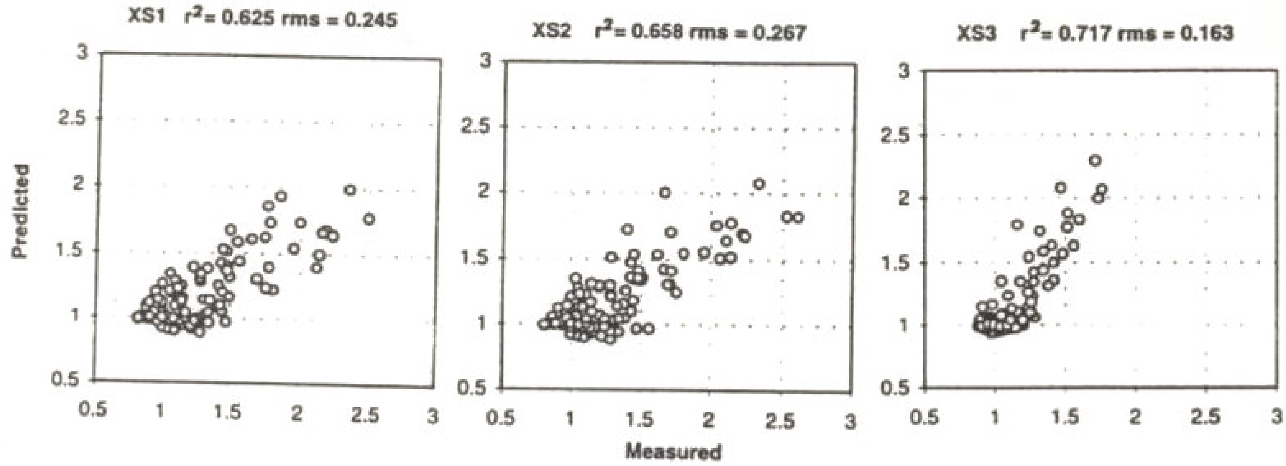

Figure 4. Relationship between measured and predicted soybean reflectance factor for the SPOT XS1, XS2, and XS3 bands.

The regression analysis was performed separately for the three channels, using 234 pairs of data representing the soybean canopy under different illumination conditions. The analysis yielded the highest coefficient of determination $r^2 = 0.72$ for the XS3 channel and the lowest one , $r^2 = 0.63$. for the XS1 channel (Fig. 4). The relative reflectance factor may be predicted for the channels XS1 and XS2 with a mean deviation (rms) from the measured reflectance data of about 0.24 - 0.27 and of 0.16 for the channel XS3.

CONCLUSIONS

This study emphasis the importance to take into account the directional properties of a crop canopy before interpretation of remote sensing data. On a soybean crop a large specular effect is observed and the relative factor of reflectance can vary from 0.8 to 2.7 during a day.

There is a quite good adequation between the experimental measurements and the results of the geometrical model taking into account the macrostructure and the specular-diffuse properties of the soybean crop.

REFERENCES

Brakke, T. W., Smith. J. A., Harnden, J. M. 1989. Bidirectional scattering of light from trees leaves. *Remote Sens. Environ.*, 29: 175-183.

Gausman, H. W., Allen. W. A., Wiegand. C. L., Escobar, D. E., Rodriguez, R. R.. Richardson, A. J. 1973. The leaf mesophylls of twenty crops, their light spectra. and optical and geometrical parameters. *Technical Bulletin No. 1465.* Agricultural Research Service. United States Department of Agriculture in Cooperation with Texas Agricultural Experiment, 1-59.

Huete. A. R., Hua, G., Qi, J., Cheboni, A. and Van Leeuwen, W. J. D. 1992. Normalization of multidirectional red and NIR reflectances with the SAVI. *Remote Sens. Environ.*, 41: 143-454.

Jackson, R. D., Teillet, P. N., Fedosejevs, G., Jasinski. M., Aase, J. K.. Moran. M. S. 1990. Bidirectional measurements of surface reflectance for view angles correction of oblique imagery. *Remote Sens. Environ.*, 32: 189-202.

Jasinski, M. 1990. Sensitivity of normalized difference vegetation index to subpixel canopy cover. soil albedo. and pixel scale. *Remote Sens. Environ.*, 32: 169-187.

Moran, M. S.. Jackson. R. D., Hart. G. F., Slater. P. N., Bartell. R. J.. Biggar. S. F.. Gellman, D., and Santer, R. 1990. Obtaining surface reflectance factors from atmospheric and view angle corrected SPOT-1 HRV data. *Remote Sens. Environ.*, 32: 203-214.

Mulders, M. A. 1987. *Remote Sensing in Soil Science.* 15. Elsevier. Amsterdam. Oxford, New York, Tokyo.

Rondeaux, G., Herman, M. 1991. Polarization of light reflected by crop canopies. *Remote Sens. Environ.*, 38: 63-75.

Vanderbilt, V. C.. Grant. L. 1985. Plant canopy specular reflectance model. *IEEE Trans. Geosci. Rem. Sens., GE-23*, 5: 722-730.

Verbrugghe, M., Cierniewski, J. 1995. Effects of sun and view geometries on cotton bidirectional reflectance test of a geometrical model. *Remote Sens. Environ.*, in press.