SPECTRAL INDICATORS OF VEGETATION VIGOUR OF BEAN CROP (Phaseolus vulgaris L.)

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ABSTRACT

The objective of this work was to contribute for the understanding of the relationships between agronomic and TM/Landsat-5 spectral parameters of the bean crop (Phaseolus vulgaris L.). Three agronomic descriptors were observed in 42 irrigated farmers' fields of bean: leaf area index, phytomass and percent soil cover. Spectral parameters were digital numbers of the six reflective TM/Landsat-5 bands and two derived linear vegetation indices: simple ratio (SR) and normalized difference (ND). There were curvilinear trends (logarithmic and exponential types) between agronomic and spectral relationships; there were equivalence between SR and ND. Before the beginning of the crop senescence it seems that spectral x agronomic relationships are better. Some bases for potential utilities of the studied relationships are discussed.

KEY WORDS: Leaf Area Index; Phytomass; Percent Soil Cover; Spectral Vegetation Indices; TM/Landsat

INTRODUCTION

Identification and area estimation of economically important crops perform one of the key potentialities of multispectral remote sensing.

Specific international literature has pointed out multispectral remote sensing capabilities to provide information about yield and vigour conditions of crops (Bauer, 1975; Hinzman et al., 1986).

In this direction, crop canopy attributes such as green leaf area index (GLAI), solar radiation intercep-tion, phytomass, chlorophyll density, percent of soil cover by green vegetation are usually employed as descriptors of crop condition and development. These parameters have been used alone or combined in models to simulate the response of crop canopies to their environment. GLAI, for example, is considered a key parameter to determine carbohydrate fixation and net primary productivity of vegetal communities in studies of global carbon cycle or of agricultural crop yields. It can be said that the realistic determination of these parameters in a global scale can be done only with satellite spectral data (e.g. LANDSAT, SPOT, NOAA).

Although many studies have shown relationships between spectral parameters and grain yield, it is not possible yet to conclude that crop yield can be predicted directly only from spectral measurements.

Some canopies with similar LAI and multispectral reflectance could be exposed to different environments during growth stage (e.g. moisture or temperature stress during polinization), which could cause differences in productivities but not necessarily in reflectance.

Nevertheless, results of various investigations point out that multispectral responses of canopy can be considered as a new and promising source of information related to potential yield of agricultural crops.

In this way, a lot of current efforts of this research line is devoted to combine spectral data with meteorological data and even soil productivities to foresee crop yield. The idea is to combine the high spatial resolution (but low temporal resolution) of remote sensing satellites (wich allow observation of individual field crops over extensive geographic areas) with the high temporal resolution (but low spatial resolution) of the meteorological satellites (Bauer et al., 1981).

Beans are a very important food in Brazil and several countries, but, relatively, they are not much studied with remote sensing techiniques.

In this context, the aim of this paper is to clear questions involving the relationships between the spectral and the most interesting agronomic variables of the bean plants and the trends and levels of significance of these relation-ships when satellite data (TM/Landsat) are used.

METHODS AND MATERIALS

Agronomic data were collected over 42 irrigated farmers' fields of bean crop through the 1987 winter (april-august) growing season at Sóo Paulo State-Brazil (aproximately 20^{o}S X 49^{o}W). General conditions of this study area are of smooth topograghy with very highly weathered red and yellow soils (high in free iron oxides) developed from basic and ultrabasic rocks (Oxisols).

As allowed by irrigation, there were several plant ages (LAI, height and canopy cover) and besides, there were several crop configurations (row spacings, row orientations) due to the farming commercial character. This way, it was possible an agronomical and spectral monitoring of practically all the growing season using available TM/Landsat images from only two dates (specified below). The agronomic parameters used to indicate crop conditions over the 42 bean fields were green leaf area index, dry phytomass and percent soil cover (referred to as LAI, PHY and COV, respectively).

Spectral data were collected from TM/Landsat-5 compatible computer tapes of 06/20/87 and 07/06/87. Before digital number extraction an atmospheric correction (Schowengerdt, 1983) was carried out. Sequentially, digital numbers were transformed to reflectance values (Markham and Barker, 1986) and Simple Ratio (SR) and Normalized Difference (ND) were derived.

Correlation and regression analyses using linear, logarithmic and exponencial models (ZAR, 1974) were then applied on the agronomic parameters (LAI, PHY and COV) and the eight spectral parameters (six reflective TM bands and two derived vegetation indices).

RESULTS AND DISCUSSION

Trajectories of the variables

Figure 1 shows the general development of agronomic variables which can be used as indicators of the vigour conditions through the bean growing season.

Crop canopies spectral behaviour is basically influenced by biomass volume, foliar architecture, development stage, cultural practices and geometric factors (i.e., illumination and viewing angles). Phenological behaviour of canopy elements through crop cycle affects greatly the penetration and the path scattering of incident rays over the crop (Daughtry et al., 1980); consequently, the signal received by detectors of electromagnetic radiation is affected too. So, it is necessary to have a good understanding of the behaviour of agronomic variables.

Figure 1 shows that the byophisical variables reached their respectives maxima in the third quarter of biological cycle (after an initial exponential phase due to a very rapid multiplication of leaves). The crop photosynthetic system captures then more and more radiation, with proportionally rapid increases in the primary productivity (vegetation production rate, or accumulation of photosynthetic products per terrain unit area per time unit), if there isn't stress restrictions (water, nutrients). This is the crop vegetative phase, in which the various plant components accumulate dry matter. Crop growth is decisively influenced by the length of the period during which the plant maintains its foliar surface active. This characteristic is defined by the ecophysiological parameter - Leaf Area Duration (Colwell et al., 1977; Pinter Jr. et al., 1981; Richardson et al., 1982), which is deserving increasing attention in studies involving multispectral remote sensing and crop productivity. After these maxima, the values began a decrease that was extended until the final of the cycle. After reaching maturity, plant begins a phase of senescence, which shows initially a break in the organic matter production and its transport to the grain filling.

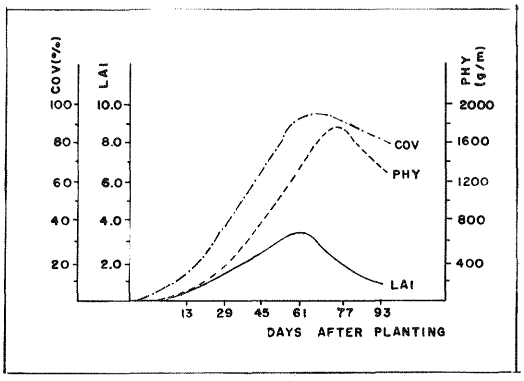

Figure 1 - General development of the three agronomic variables measured through the bean growing season.

Six reflective TM/Landsat-5 of two different dates were used as exoatmospheric reflectance (Markham & Barker, 1986). In this manner, spectral profile of bean crop (Figures 2.a and 2.b) could be studied at various ages during bean cycle.

Figures 1, 2.a and 2.b show close relationships between biophysical and spectral variables for bean crop. It can be observed that, as the plants grow, reflectances in TM4 and TM5 bands increase too, while TM3 reflectance decreases, and in the other bands (TM1, TM3 and TM7) the reflectances remain practically constant. In the three curves presented it can be verified that the points of maximum (for LAI, COV, TM4 and TM5) are nearly 60 days after planting; note that the point of minimum for TM3 reflectance (Fig. 2.b) occurs nearly 40 days after planting. In fact, this confirms that visible reflectance (red) stops answering to LAI increasings before than near infrared reflectances, as verified by Chance & Lemaster (1977), (LAI = 2.2 for the visible and LAI = 6.2 for near infrared).

Table 1 shows the correlation coefficients and the best fit models (linear, logarithmic and exponential) obtained by regression

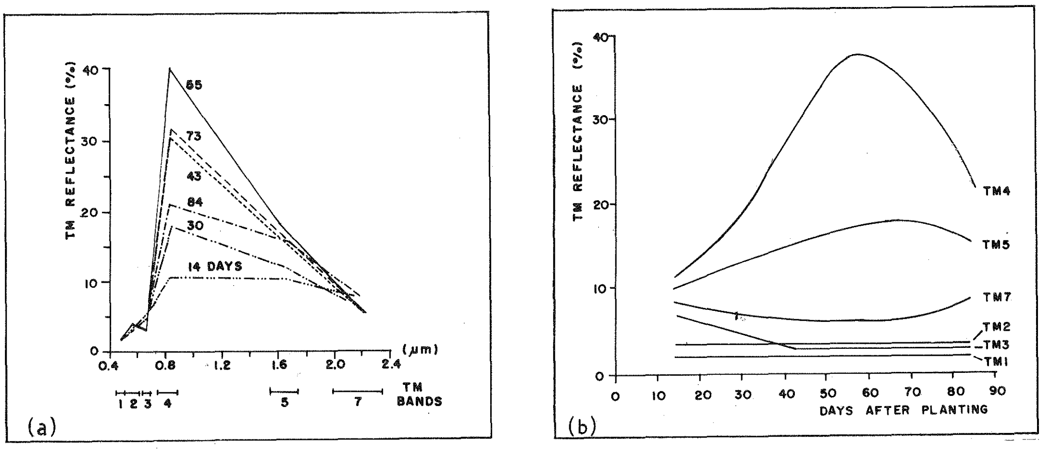

Figure 2 - TM/Landsat-5 average reflectances (a); and reflectances per band (b); for bean crop, during biologic cycle.

TABLE 1 - CORRELATION COEFFICIENTS AND LINEAR, LOGARITHMIC AND EXPONENTIAL MODELS BETWEEN AGRONOMIC AND TM/LANDSAT SPECTRAL VARIABLES, FOR BEAN CROP

PAIRS OF VAR. AGRO x SPEC	CORRELATION COEFFICIENTS LINEAR	LOGAR.	EXPON.	BEST MODEL
LAI x TM1	0.33	0.33	0.34	-
LAI x TM2	0.38	0.43	0.36	-
LAI x TM3	-0.64	-0.83**	-0.67	LOG.b<0
LAI x TM4	0.76	0.77**	0.75	LOG.b>0
LAI x TM5	0.63	0.65**	0.63	LOG.b>0
LAI x TM7	-0.27	-0.41	-0.22	-
LAI x SR	0.79**	0.78	0.76	LIN.b>0
LAI x ND	0.70	0.93**	0.64	LOG.b>0
PHY x TM1	0.20	0.31	0.21	-
PHY x TM2	0.22	0.40	0.19	-
PHY x TM3	-0.47	-0.81**	-0.51	LOG.b<0
PHY x TM4	0.61	0.79**	0.58	LOG.b>0
PHY x TM5	0.53	0.68**	0.51	LOG.b>0
PHY x TM7	0.14	0.38	0.11	-
PHY x SR	0.64	0.80**	0.58	LOG.b>0
PHY x ND	0.50	0.89**	0.45	LOG.b>0
COV x TM1	0.29	0.30	0.32	-
COV x TM2	0.37	0.41	0.38	-
COV x TM3	-0.76	-0.73	0.78**	EXP.b<0
COV x TM4	0.82	0.72	0.88**	EXP.b>0
COV x TM5	0.70	0.62	0.72**	EXP.b>0
COV x TM7	0.36	0.37	0.38	-
COV x SR	0.83	0.71	0.88**	EXP.b>0
COV x ND	0.87	0.90**	0.85	LOG.b>0

** 1% level of significance (correlation significance was verified only for the best model)

analyses for three agronomic (i.e., LAI, PHY and COV) and eight spectral variables (i.e., six reflective TM bands and two vegetation indices).

Curvilinear logarithmic models fit up in 10 cases (a spectral x agronomic pair of variables each case), while exponential models fit up in 4 cases and linear model fit up in only one pair of variables (Simple Ratio x LAI).

TM1, TM2 and TM7 didn't present any answer to phenologic variations of the crop, in the level of satellite images and agronomic variables from farm fields. It's verified that only for TM3, TM4, TM5, SR and ND occurred significative correlations and fitness at 1% level. This points out the potentiality of these spectral variables in the estimation of agronomic parameters (vigour indicators) for bean crop from satellite imagery.

However, it's necessary to emphasize some aspects of these agronomic x spectral TM relationships. Taking as an illustration the curve LAI x TM4 (Figure 3), one can verify that a reasonable point scattering occurs near the adjusted curve. One might explain this fact based on the great diversity of conditions of the 42 sampled fields, in relation to factors such as: ages, row spacings, row orientations, soil types and superficial conditions, etc. These factors, inversely to those occuring in the well controlled experiments of "scene radiation", cannot be controlled in this study (satellite x field).

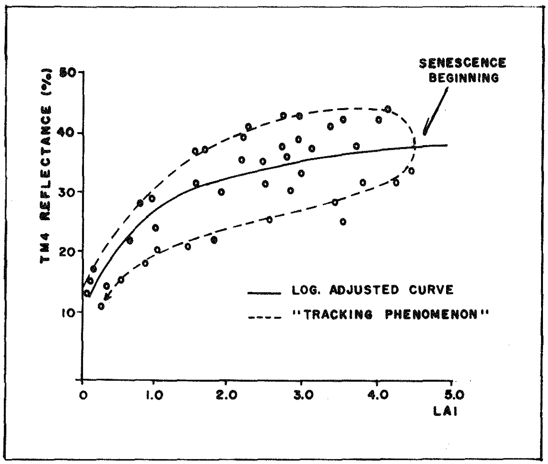

Figure 3 - Scatter diagram, logarithmic adjusted curve between TM4 and LAI, and "tracking phenomenon" illustration.

Besides, it's necessary to consider the "tracking phenomenon" (Tucker et al., 1979; Holben et al., 1980; Formaggio, 1989). I.e., as bean biological cycle progress, phytovariables values increases progressively until a plateau or a maximum (which indicates the beginning of the senescence) (Figure 4); then these phytovariables decrease assuming similar values than those observed before the referred plateau. This way, same values of phytovariables (for example one value pre- and another post-plateau) will produce different values of spectral variables, because the phenological conditions pre- and post-plateau are different.

This also remarks that there is a period (before the senescence beginning), during plant growth and development, in which the correlations and the fitness between agronomic and satellite spectral variables are better than in other phases for bean crop.

CONCLUSIONS

There is a strong necessity for a better understanding of the complex interactions between spectral and biophysical variables of agricultural crops.

The physical and physiological foundations for the behaviours observed (relationships between spectral and agronomic variables) constitute a chapter of particular interest for many agricultural remote sensing scientific groups concerning to studies of scene radiation.

In this research it was verified, for bean crop, a preferential curvilinear relationship (exponential or logarithmic types) between TM3, TM4, SR and ND spectral variables and LAI, PHY and COV agronomic variables, resulting in highly significative correlation coefficients.

Before crop senescence it seems that these relationships are better, i.e., in this phase of beans biologic cycle, green vegetation density may be considered the most important factor influencing TM reflectances.

There were high correlation and equivalence between the used TM vegetation indices (SR and ND) suggesting the use of orthogonal indices (e.g. Kauth & Thomas (1976) greenness and Richardson & Wiegand (1977) perpendicular vegetation index/PVI) in conjunction with linear vegetation indices.

Satellite spectral data, as TM/Landsat-5, are potential sources of agronomic information for the bean crops (large-area) and of yield considerations, but more researches and development related with the study are needed, so as better understanding of sampling questions, use of ancillary data (e.g. thermal and meteorological) and simulation models.

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