

CROP PARAMETERS FOR THE EVALUATION OF THE SPECTRAL RESPONSE OF COFFEE (*Coffea Arabica*) AREAS WITHIN THE STATE OF MINAS GERAIS, BRAZIL

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ABSTRACT:

The work relates coffee plantation characteristics with their spectral responses in TM/Landsat images to obtain identification patterns to be used in the mapping and monitoring of coffee lands of the state of Minas Gerais using remote sensing. The fieldwork involved selection of representative areas from the main coffee production regions of the state, with definition of pilot areas from where the coffee parameters and environmental data were collected. Two pilot-areas representative of the physiographic regions Alto Paranaíba and Sul de Minas were selected for the study. The field data and TM/Landsat images were treated with the geographic information system SPRING. The reflectance data, as well as the remaining data collected in the field, were organized in a statistical programme for correlation studies. The statistical analysis showed that, among the fourteen variables evaluated, the highest correlation was observed between reflectance measured in the near infrared zone and the percentage of area covered by the plants canopies. This parameter reflects the effects of other crop variables, such as size, diameter, density, vegetative vigour and productivity. The results showed that, due to the great variability of the crop and the limitations imposed by TM/Landsat products, the definition of a pattern is unlikely. Nevertheless, for productive adult coffee plants in good vegetative state, the survey and monitoring of the crop can be carried out using TM/Landsat images, particularly in regions like Alto Paranaíba, where the landscape is mostly of gently undulating slopes and the coffee fields are more extensive and homogeneous.

1. INTRODUCTION

Remote sensing can be defined as techniques that enable the extraction, at a distance, of information concerning targets of interest on the Earth's surface. This is done through detection, quantification and analysis of the electromagnetic energy that is reflected, absorbed, transmitted and/or emitted by these targets. Satellite images are tools that can be used to generate information that is obtained through the spectral behavior of the vegetation. The spectral differences are registered in the image as variations of tones, color or density. The remote sensors detect the differences in tone or color between an object and its environment (Valério Filho, 1996).

According to Leonardi (1990), due to its multi-spectral character, its repetition in time and space and relative low cost, compared to aerial photographs, remote sensing is a potential method to obtain information on coffee production. However, coffee is a perennial crop with complex features. As observed by remote sensors, coffee is very heterogeneous, since it presents variations in all the parameters that influence the spectral response (Epiphanyo *et al.*, 1994).

Agricultural crops vary in spectral complexity and work has been carried out to evaluate the relation between agricultural variables and spectral responses. The spectral response of the canopy of a given crop may be influenced by many factors, such as: humidity, vegetative vigour, canopy architecture and size, soil type, topography, plan density and spacing, variety, age and crop consortium among others.

In perennial crops, the reflectance registered in a given pixel results not only from the plant, but also from factors related to the ground, to the plant architecture and shadowing geometry. The development of these plants is usually slower and other factors, such as soil, constant use of agricultural machines, shadowing in and between the plant rows and the crop's seasonal characteristics become important.

Crops planted in rows form a complex field composed by vegetation and exposed soil, in different proportions that change during the year as the plants grow, which is captured by the sensor. In this case, the shadows of the plants in the rows, projected on the soil's surface or on other rows, become an important factor in the canopy radiation (Ranson *et al.*, 1984).

Couvre (1980) studied the relation between some parameters of citrus plantations (coverage of the terrain by citrus trees, soil type, plant rows orientation, slope gradient, slope aspect, height of the trees, substratum and uniformity of the field), and the spectral reflectance obtained from the transformation of the gray levels of the TM/Landsat-5 image. The author explains that the incoherent relation between the percentage of the terrain covered by the trees and the reflectance in the TM4 band is due, mainly, to the increase of shadows and of the covering of the ground by the trees, due to the spacing and distribution of the plants. According to the author, the increase of shadows annuls the effect of the increase of green cover over the reflectance in this band. As for the parameter soil type, the author observed higher reflectance values in the Dark Red Latosol (LE) than in the Red Yellow Latosol (LV) in the TM3, TM5 and TM7 bands.

In this work, various crop and environmental variables of the coffee crop were evaluated, as well as the spectral response of coffee fields, surveyed and georeferenced on the field, using TM/Landsat 7 images in bands 3, 4 and 5 and the SPRING software from INPE. The objective of the work was to establish the correlation between the selected variables and their spectral responses, in order to obtain identification patterns of the coffee crop in Landsat images.

2. METHODOLOGY

Two 520 km² study areas were selected, around the city of Patrocínio, representative of the physiographic region of Alto Paranaíba, and around the city of Machado, representative of the physiographic region of Sul de Minas. These areas represent two of the state's most important regions in coffee production. They are located in different environments, with different production systems, the Sul de Minas with traditional management practices and long historical information and the Alto Paranaíba with modern and entrepreneurial farming. This information is registered by the respective local associations and was important to the development of this work. The two pilot-areas were selected from previous investigations on areas that best represented the production regions of Alto Paranaíba (Patrocínio) and Sul de Minas (Machado). The Alto Paranaíba is characterized by flat plateaus with altitudes varying from 820 to 1100 m, favorable climate, subject to low-intensity frosts, moderate water deficiency, flat, gently undulating to undulating slopes, predominance of Latosols, possibility of producing fine beverages and high technology production systems. In the region of Sul de Minas, areas with altitudes varying from 780 to 1260 m, favorable climate, subject to frost, moderate water deficiency, gently to steep slopes, predominance of Latosols and soils with argillic B horizons, possibility of producing fine beverages, medium to high technology production systems. The pilot-area of Machado was delimited by the coordinates UTM 278 Km and 304 Km W and 7.942 Km and 7.922 Km S, encompassing portions of Patos de Minas and Monte Carmelo topographic maps of the Brazilian Army, at the scale of 1:100.000. The pilot-area of Machado was delimited by the coordinates UTM 392 Km and 418 Km W and 7.620 Km and 7.600 Km S, encompassing portions of the topographic maps of IBGE (Brazilian Geographic Institute), scale 1:50.000, sheets of Machado and Campestre.

TM/Landsat 5 digital images used were image orbits 220/73 (Patrocínio) and 219/75 (Machado), bands 3, 4 and 5, from April-June/1999, the period of coffee's greatest vigour and when the field surveys were carried out. Band 3 (red - 0,63 to 0,69 µm) is sensitive to green, dense and uniform vegetation. It presents great absorption, turning dark and allowing a good contrast between the areas occupied by vegetation and those unoccupied (exposed soil, roads and urban areas). It also presents good contrast between different types of vegetation (grazing fields, savanna and forest) and permits drainage mapping through visualization of the gallery forest along the rivers' courses in regions with little vegetation cover. Band 4 (near-infrared - 0,76 to 0,90 µm) allows the dense, green and uniform vegetation to reflect a lot of energy and to appear in a very light shade, and is thus recommended for studies of spectral responses of areas occupied by green vegetation. This band presents good contrast between soil and water, allowing the mapping of large rivers, lakes, reservoirs and humid areas, as well as morphology of the terrain, burned vegetation, geology and geomorphology and aquatic vegetation. Band 5 is also very sensitive to the absorption of electromagnetic

radiation by iron and titanium oxides, very common in tropical highly weathered soils. Band 5 (mid-infrared - 1,55 to 1,75 µm), allows the observation of humidity levels in the plants and the detection of possible stress due to lack of water. Band 5 is also used to obtain information on soil humidity. However, it may suffer perturbations if rain occurs just before the satellite images the area.

The choice of study area was very important in the development of the work and its results. A few characteristics of the area, desirable or not, taken into account in the study were: plantation systems; cropping practices, coffee cultivars representative of those existent today in Brazil; age, slope gradient and aspect variability and size of the fields compatible to the resolution of the TM sensor (not less than 1 ha); easy access; extension sufficient to obtain an adequate number of samples.

In all, 75 coffee fields were surveyed and georeferenced with the GPS Garmin 12. In Machado, due to the great variation of relief, of planting and cropping systems and the smaller size of the coffee fields, samples were collected in various farms to better represent the region. In Patrocínio, due to the more homogeneous conditions of the relief and the plantations, samples were collected in only one farm, which presented all the variables important to the characterization of the region, encompassing a total of 1000 ha, distributed in its 22 different fields.

The variables observed in the field surveys, carried out during the period of the coffee's greatest vigour (April to June), were: area of the field, age, height or plant size, average diameter of the plants, year of pruning, percentage of the terrain occupied by coffee plants, type and percentage of ground cover by plant canopy in the row, cultivars, plant density, spacing between plants and rows, vegetative vigour, average production, slope gradient, slope aspect and soil type.

Among these variables, a few were selected for statistical analysis, as listed below:

1. Size (SIZE): average height of coffee plants in a field in meters;
2. Plant Density (DENS): number of plants per hectare;
3. Vegetative vigour (VIG): evaluation of the coffee plants vegetative state, carried out in the field, by ranking each coffee field with marks varying from 1, for minimum vigour to 10 for maximum vigour;
4. Diameter (DIAM): average diameter of plants in a coffee field in meters;
5. Production (PROD): average plant coffee production in liters of coffee berries per plant;
6. Ground cover (COV): percentage of the ground covered by plants canopies in a coffee field. Calculated according to the average diameter and the spacing used;
7. Slope gradient (SLO): percentage of slope gradient of a coffee field.

The data was organized in electronic spreadsheets and inserted in digital databases created for each pilot-area with the aid of the geographic information system SPRING. The images were treated with the SPRING Images module, followed by registration, atmospheric correction and correction of the solar elevation angle to obtain the reflectance values of the sampled

fields. The reflectance values for each of the bands analyzed were taken from the image, through the pixel reader module. The reflectance values used were the arithmetic average of the individual values of all the pixels of each coffee field surveyed. To obtain these values, the data was transformed to radiance and then to reflectance, using the equations below:

$$L = \left(\frac{VD_i}{VD_{\max}} \right) \cdot (L_{\max i} - L_{\min i}) + L_{\min i}$$

Where:

I = band;

VD_i = digital value of the pixel, in band i;

VD_{max} = maximum digital value recorded

L_{max i} = maximum radiance registered by the detector, in band i;

L_{min i} = minimum radiance registered by the detector, in band i;

$$R = \frac{L \cdot \pi \cdot D^2}{E_i \cdot \cos \alpha}$$

Where:

L = radiance;

D = distance Sun-Earth;

E = irradiance on top of the atmosphere;

I = band;

α = solar zenithal angle.

This data was transformed into percentage and attached to the electronic sheets for statistical analysis.

Observing the nature of the data, which included a large number of uncontrollable variables, obtained in field surveys, multiple regression analysis were carried out, using models such as stepwise and backward, separating the data by farms, by geomorphopedological environment and finally by production region, Alto Paranaíba and Sul de Minas.

The analysis of the consistency of the database followed and was carried out through analysis of frequency, mediums, minimums and maximums. The results were satisfactory enough to continue with the analytic procedures, carried out through SAS (Statistical Analyses System) software.

The analyses of linear correlation of all the variables measured on the field were carried out with reflectance measured in bands 3, 4 and 5. All variables were considered. The correlations between the variables in question and the variables in band 4, band responsible for the spectral response of the vegetation and which correlated best with the variables, followed.

In a second stage, only the variables that presented the highest correlation coefficients and/or the lowest significance levels were considered. As the variable COV presented the best correlations with all the other variables and with band 4 (level of significance 0,0001/correlation coefficient 0,44753), it was decided that coffee with ground cover under 50% and over 50% would be correlated separately to homogenize the data. As the spectral response depends heavily on the conditions of relief, the data was analyzed in two groups: fields in slopes with more than 15% gradients, and field in slopes under or equal to 15% gradient. The consistency of this data was analyzed again, followed by their correlations.

3. RESULTS AND DISCUSSION

3.1 Evaluation of the spectral response of coffee

The reflectance values of the coffee fields evaluated in band 3 are low, around 3%. This value was found for the plantations with more than 50% of ground cover, as a result of one or a combination of factors such as age of the crop, size of the plants, spacing between rows, good vegetative state and vigour among others. These characteristics refer to adult coffee plants in good productive condition. The coffee still in formation (under three years of age), which usually presented ground cover lower than 50% lower presented higher reflectance values in band 3, reaching 15%, as a result of the influence of the substratum (soil and organic matter) on the spectral response. This is due to the fact that in band 3, dense, green vegetation presents great absorption, turning dark and allowing a good contrast between the areas occupied by vegetation and those unoccupied, such as exposed soil, roads and urban areas.

The reflectance results in band 4 are higher, reaching 35-40% for formed coffee crops in good production condition. In the coffee fields still in formation, again, given the great proportion of exposed substratum, the reflectance values are lower (20-25%). Band 4, which correspond to the near infrared (spectral interval 0,76 to 0,90 μm), allow the dense, green, uniform vegetation to reflect a lot of energy, appearing very bright. Therefore, this band is the most recommended for the study of spectral response in areas covered by vegetation.

The data analyzed shows that band 5 reflected more the humidity of the soil and, indirectly, the type of soil, through its greater or lesser capacity to retain water. Therefore, the reflectance values were higher in the coffee crops in formation, with great exposition of the substratum (up to 90%), reaching values up to 28%. In the areas where the soil had greater water holding capacity, such as the Latosols, the reflectance values were lower, due to the absorption of water in this band.

3.2 Results of the statistical analysis

As the objective of the work was to analyze coffee areas and the characteristics mentioned above, the analyses carried out for band 4 will be presented.

Table 1 presents the results of the descriptive analysis of all the data collected in the field, showing the crop variables evaluated and their respective average reflectance values in band 4. This analysis was carried to check the consistency of the data set and assure their reliability for the following statistical analyses.

Linear statistic analysis was carried out, to evaluate the linear correlation coefficient and the level of significance of the selected variables, as presented in Table 2.

The first analysis was carried out for all the data together. The results show that among the variables analyzed, the one that showed the lowest level of significance (0,01%) was COV, despite the low correlation, which probably reflects the nature of the data, as discussed before. This result is coherent with that expected for band 4, since the variable COV (percentage of the ground covered by the canopies of coffee plants in a coffee field) is one that includes in its response the sum of the effects of size, plant density, plants diameter, vegetative vigour and, indirectly, the average production and/or productivity of that field. It is possible to conclude, therefore, that it is the most indicated variable to evaluate the spectral response of coffee

fields in remote sensing studies. In this way, the greater the coverage of the terrain by coffee plants, the greater the spectral response in band 4. Due to these results, analyses of this parameter values, placing the data in two different groups for a better analysis, COV under 50% and COV over 50%, were carried out. These analyses can be used in the identification and survey of areas occupied by coffee by TM/Landsat images.

Although the slope gradient of the terrain does not present significant correlation with the REFB4, it is nonetheless a variable that interferes in the spectral response by orbital imaging, as other works in remote sensing show (Strahler *et al.*, 1978; Justice *et al.*, 1981; Stohr and West, 1985). The topographic effect over reflectance is defined as the variation in the spectral response of an inclined surface, compared to the spectral response of a horizontal surface and it is a function of the orientation of the surface in relation to the source of light and position of the sensor (Holbern and Justice, 1981). Therefore, the data was separated into two different groups for statistical analysis: the first composed by coffee fields with slope gradient over 15% and the second, composed by coffee fields with slope gradient under or equal to 15%. Thus the coffee fields with flat to gently undulating slopes were separated from those with undulating to steep slopes. The data presented in Table 2 show that, in the smoother landscapes (slope gradient $\leq 15\%$), the spectral response in band 4 (REFB4) was more significant (lower levels of significance) than that observed in the other types of landscapes (slope gradient $> 15\%$).

In the declivity $\leq 15\%$ group, other variables besides COV, such as size, diameter and average production, also presented lower levels of significance.

4 CONCLUSIONS

The results show that the coffee crop presents a complex spectral response that is influenced by the many variables that influence its characterization.

Statistical analysis showed that, among the variables studied, COV, which corresponds to the percentage of the terrain occupied by coffee plants, presented the best reflectance results

in band 4. COV reflects the effects of other coffee agricultural variables, such as size, diameter, plant density, vegetative vigour and average production. Therefore, the use of TM/Landsat satellite images in coffee fields, in which the ground covered by the plants is over 50%, is recommended.

Relief also has great influence in the coffee's spectral response. Therefore, it is recommended that remote sensing be used, preferably coffee is cropped over flat to gently undulating landscapes.

In formed coffee fields in good productive conditions, the spectral response allows their survey and monitoring by TM/Landsat images, especially in areas favorable to orbital imaging, that is: regions with smoother slopes, ideal atmospheric conditions and large, contiguous areas occupied by coffee fields. These conditions occur in Patrocínio. In the other regions, it is advisable to associate more precision remote sensing products of satellites with better spatial resolution.

5. REFERENCES

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Statistical Parameter	Crop variables							
	REFB4	SIZE	DENS	VIG	DIAM	PROD	COV	SLO
Average value	30.05	2.44	4305	8.10	1.99	3.64	59.87	10.40
Standard deviation	4.68	0.99	3140	1.18	0.99	3.25	28.34	11.10
Minimum value	16.86	0.80	1000	5.00	0.28	0.00	10.00	1.00
Maximum value	43.14	5.00	13333	10.0	5.00	12.0	100.0	70.00

Table 1 - Average, standard deviation, minimum and maximum values of the data set collected in the 75 coffee fields surveyed.

Where:

REFB4: average reflectance values in band 4.

SIZE: average height of coffee plants in a field in meters;

DENS: Plant Density - number of plants per hectare;

VIG: Vegetative vigour - indices from 1 to 10, according to field survey;

DIAM: Diameter - average diameter of plants in a coffee field in meters;

PROD: Production - average plant coffee production in liters of coffee berries per plant;

COV: Ground cover - percentage of the ground covered by plants canopies in a coffee field;

SLO: Slope gradient - percentage of slope gradient of a coffee field.

Crop Variables							
REFB4	SIZE	DENS	VIG	DIAM	PROD	COV	SLO
R	0.12	0.13	-0.01	0.17	0.22	0.45	0.10
α	0.31	0.25	0.93	0.15	0.05	0.0001	0.40
DECLIV > 15%							
R	- 0.37	0.38	-0.16	- 0.01	- 0.06	0.61	-0.03
α	0.22	0.19	0.59	0.97	0.85	0.02	0.93
DECLIV ≤15%							
R	0.21	0.15	0.05	0.20	0.30	0.43	0.09
α	0.10	0.23	0.72	0.12	0.01	0.0004	0.48
COBCAFE > 50%							
R	-0.29	0.13	-0.10	-0.20	0.05	0.25	0.13
α	0.04	0.38	0.49	0.16	0.75	0.07	0.35
COBCAFE < 50%							
R	0.54	-0.42	-0.21	0.59	0.43	0.61	0.15
α	0.005	0.04	0.32	0.002	0.03	0.001	0.48

Table 2 – Statistic analyses of the spectral response in band 4 (REFB4) and coffee crop variables analyzed (r = linear correlation coefficient; α = level of significance)

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