CROP PARAMETERS AND SPECTRAL RESPONSE OF COFFEE (*Coffea arabica* L.) AREAS WITHIN THE STATE OF MINAS GERAIS, BRAZIL[1]

Tatiana Grossi Chquiloff Vieira[2], Helena Maria Ramos Alves[3], Marilusa Pinto Coelho Lacerda[4], Ruben Delly Veiga[5], José Carlos Neves Epiphanio[6]

(Received: October 6, 2005; accepted: December 19, 2005)

ABSTRACT: This work compares coffee plantation (*Coffea arabica* L.) characteristics to their spectral responses in TM/ Landsat images to obtain identification patterns to be used in mapping and monitoring of coffee crops in 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 study 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 SPRING geographic information system. 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 plant canopies. This parameter reflects the effects of other crop variables, such as size, diameter, density, vegetative vigour and productivity. Results show 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.

Key words: Remote sensing, GIS, Landsat images, land use, land use mapping.

PARÂMETROS CULTURAIS PARA AVALIAÇÃO DO COMPORTAMENTO ESPECTRAL DA CULTURA DO CAFÉ (*Coffea arabica L.*) EM MINAS GERAIS, BRASIL

RESUMO: *Neste trabalho foi avaliada a correlação entre parâmetros culturais e respostas espectrais da cultura cafeeira (Coffea arabica L) em imagens TM/Landsat, para estabelecer padrões de identificação desta cultura por sensoriamento remoto, a serem utilizados no zoneamento e monitoramento do parque cafeeiro de Minas Gerais. Para estudo foi selecionada uma área piloto em Patrocínio, região do Alto Paranaíba, e outra em Machado, região Sul de Minas. O Sistema de Informação Geográfica SPRING foi utilizado para tratamento dos dados e criação de um banco de dados geográfico. As respostas espectrais foram avaliadas pelas reflectâncias médias, estimadas a partir dos valores de pixels de imagens TM/Landsat, para cada um dos talhões geo-referenciados em campo. Dentre as quatorze variáveis avaliadas, a melhor correlação foi observada entre a reflectância medida na zona do infravermelho próximo e a porcentagem da área coberta pelas plantas. Este parâmetro reflete outras variáveis culturais do café, tais como porte, diâmetro, densidade, vigor vegetativo e produção média. A cultura cafeeira apresenta uma resposta espectral complexa. Em função da grande variabilidade das lavouras de café e da resolução espacial das imagens TM/Landsat, a definição de um padrão de identificação para a cultura foi dificultada. Contudo, imagens TM/Landsat podem ser usadas no levantamento e monitoramento de áreas cafeeiras, particularmente nos casos de cafezais em produção e em bom estado vegetativo de regiões como Patrocínio, onde o relevo é suave a suave ondulado e as lavouras ocupam grandes extensões e são mais homogêneas.*

Palavras-chave: Sensoriamento remoto, SIG, imagens Landsat, uso da terra, mapeamento.

---

[1]The work was financially supported by CBP&D/Café (Consórcio Brasileiro de Pesquisa e Desenvolvimento do Café) and the results presented at the XX[th] Congress of the International Society of Photogrammetry and Remote Sensing.

[2]Pesquisadora da Empresa de Pesquisa Agropecuária de Minas Gerais – EPAMIG/IMA – Cx. P. 176 – 37200-000 – Lavras, MG – Brasil – tatiana@epamig.ufla.br

[3]Pesquisadora da Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA Café – Cx. P. 176 – 37200-000 – Lavras, MG – Brasil – helena@ufla.br

[4]Professora Adjunta da Universidade de Brasília – UnB/FAV – Cx. P. 04508 – 70910-970, Brasília, DF – Brasil – marilusa@unb.br

[5]Professor Adjunto da Universidade Federal de Lavras/UFLA – Departamento de Ciências Exatas/DEX – Cx. P. 3037 – 37200-000 – Lavras, MG – Brasil – delly@ufla.br

[6]Pesquisador do Instituto Nacional de Pesquisas Espaciais - INPE/DSR – Cx. P. 515 – 12227-010 – São José dos Campos, SP – Brasil – epiphani@dsr.inpe.br

1 INTRODUCTION

Remote sensing is the technology of extracting, at a distance, usually from air-borne or space platforms, information concerning targets of interest on 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 of gray or density. The remote sensors detect the differences in tone between an object and its environment (VALÉRIO FILHO & PINTO, 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, remotely-sensed satellite imagery is a potential method to obtain information on coffee production. However, coffee is a perennial crop with complex features. As observed by satellite sensor systems, coffee is very heterogeneous, since it presents variations in all the parameters that influence the vegetation spectral reflectance (EPIPHANIO et al., 1994; LEONARDI et al., 1991).

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 and organic matter content, topography, plant 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, cited by LEONARDI, 1990).

Covre (1989) 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 differences in reflectance values when comparing two different classes of Oxisol. According to the Brazilian System of Soil Classification, the soil classified as Dark Red Latosol presented higher reflectance than the Red Yellow Latosol in the bands 3, 5 and 7.

There are very few studies evaluating the complex spectral behavior of coffee fields at a remote sensing satellite view. This might be because, more than in other perennial crops, the variations of coffee crop factors such as row-spacing, shadowing, crop seasonal characteristics and substrate within fragmented agricultural systems impinge noises that are difficult to interpret at satellite level. Epiphanio et al. (1994) studied the influence of some coffee culture factors on the spectral reflectance of TM/Landsat-5 images. At farm level, 145 coffee fields were selected. Agronomic variables like plant density and age, plant diameter and height, vegetative vigour and volume of green leaves, row-spacing and direction, substrate and soil spectral characteristics, and topographic features were collected. A correlation analysis was performed for agronomic variables only, and then the correlation between TM bands and agronomic variables was analyzed. Pruning year and plant height were the most correlated parameters with bands 1, 2, 3, and 7. Those parameters seem to aggregate information related to coffee phytomass and shadowing. A few agronomic variables correlated with band 4, except vegetative vigour. Parameters related to crop characteristics are more correlated with TM bands than parameters related to substrate and terrain geometry.

There is also another problem, commented by Carvalho (2001), which is the spectral overlap that affects the use of Landsat imagery for coffee mapping because of the co-occurrence of land cover types such as forest and eucalyptus plantations.

In this work, various crop and environmental variables of the coffee crop (*Coffea arabica* L.) were evaluated, as well as the spectral response of coffee fields, surveyed and georefferenced in the field, using TM/Landsat 5 images, 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 the spectral responses of the coffee fields, in order to obtain identification patterns of the coffee crop in Landsat images.

2 MATERIAL AND METHODS

Two 520 km^2 study areas in the state of Minas Gerais were selected. The first one around the city of Patrocínio, representative of the physiographic region of Alto Paranaíba, and the second one 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 farmer associations and was important to the development of this work. The two study 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 1,100 m, favorable climate, subject to low-intensity frosts, moderate water deficiency, level to gently undulating and undulating slopes, predominance of Latosols (Oxisols), possibility of producing fine beverages and intermediate to high technology agricultural production systems. In the region of Sul de Minas, areas with altitudes varying from 780 to 1,260 m, favorable climate, subject to frost, moderate water deficiency, rolling to steep slopes, predominance of Latosols and soils with argillic B horizons, possibility of producing fine beverages and mostly production systems with medium level of technology. The pilot-area of Patrocinio was delimited by the coordinates UTM, 278 km and 304 km E and 7942 km to 7922 km N, zone 23, datum Córrego Alegre, 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 coordinates UTM 392 km and 418 km E and 7620 km to 7600 km N, zone 23, datum Córrego Alegre, 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, taken during the period from April to 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 mm) 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 mm) 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 4 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 mm), 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 (MOREIRA, 2001).

The choice of study areas was very important in the development of the work and its results. A few characteristics of the area and sampled coffee fields 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 1,000 ha, distributed in its 22 different fields.

The variables observed in the field surveys 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 the variables observed in the field, those important or possibly related to differences and/or variations in the coffee reflectance 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 plant 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 SPRING geographic information system. The images were treated with the SPRING Impima and Images modules, used to do the registration, geometric rectification, followed by the radiometric transformation (atmospheric correction and correction of the solar elevation angle) to obtain the reflectance values of the sampled fields. To obtain the reflectance values, for each of the bands analyzed (bands 3, 4 and 5), the digital values of each pixel of the image (tones of gray, varying from 0 to 255), were transformed to radiance and then to reflectance, using the equations bellow: The reflectance values used were the arithmetic average of the pixels of each coffee field surveyed. The data were transformed into percentage and attached to the electronic sheets for statistical analysis.

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

Where:
L = Radiance;
VD_i = Digital value of the pixel, in band i;
VD_{max} = Maximum digital value recorded;
$L_{max\ i}$ = Maximum radiance in band i;
$L_{min\ i}$ = Minimum radiance in band i.

$$R = \frac{L \cdot \pi \cdot D^2}{\mathrm{E}_i \cdot \cos\alpha}$$

Where:
R = Reflectance;
L = Radiance;
D = Distance Sun-Earth;
E = Irradiance on top of the atmosphere;
α = Solar zenital angle.

The analysis of the consistency of the database 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 (SAS INSTITUTE, 1999) software.

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. The data was first analyzed separately, by farms, by geomorphopedological environment and finally by production region, Alto Paranaíba and Sul de Minas.

The analysis of linear correlation of all the variables measured in the field was first carried out with reflectance measured in bands 3, 4 and 5. In a subsequent stage, only the variables that presented the highest correlation coefficients and/or the lowest significance levels were considered. The correlations between these variables and the reflectance values in band 4, which is the most important band in terms of spectral response of the vegetation, followed.

As the variable COV presented the best correlations with all other variables and with band 4 (level of significance of 0.0001 and 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% gradient, 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% 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 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, possibly 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 level of significance of the selected variables, as presented in Table 2.

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

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

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.

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)

	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
				Slope gradient > 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
				Slope gradient ≤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
				Ground cover > 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
				Ground cover < 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

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.

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 reflectance values in band 4, it is nonetheless a variable that interferes in the spectral response by orbital imaging, as other works in remote sensing show (JUSTICE et al., 1981; STOHR & WEST, 1985; STRAHLER et al., 1978). 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 (HOLBEN & 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 $\leqslant$ 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 $\leqslant$ 15% group, other variables besides COV, such as size**,** diameter and average production, also presented lower levels of significance.

4 CONCLUSIONS

The work shows that the coffee crop presents a complex spectral response which is affected by the many variables and influences its characterization by remote sensing.

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 which the ground covered by the plants is over 50%, will probably produce more accurate results.

Relief also has great influence in the coffee’s spectral response. Therefore, the use of remote sensing to map coffee fields will probably be easier in the regions where coffee is cropped over flat to gently undulating landscapes.

The results obtained, in association with the visual interpretation of the images, supported by the sound field work carried out in both regions, suggest that TM/Landsat images can be used for mapping and monitoring coffee areas of Minas Gerais. Best results will be obtained for adult coffee fields in good productive conditions, especially in areas with smoother slopes and large areas occupied by coffee. These environmental conditions occur in Patrocínio, where the Landsat images should be sufficient to monitor coffee lands. However, in the other important production regions of the state, such as the south of the state, it is advisable to use remote sensing products of satellites with better spatial resolution.

5 ACKNOWLEDGMENTS

The authors want to thank the CBP&D/Café (Consórcio Brasileiro de Pesquisa e Desenvolvimento do Café) for the financial support of the research project. Thanks are also given to EPAMIG/CTSM, EMBRAPA CAFÉ, UFLA and INPE for the technical support. Special thanks to Gilmar José Cereda for the invaluable help during field work and to the farmers for making available their coffee fields.

6 REFERENCES

CARVALHO, L. M. C. **Mapping and monitoring forest remnants**: a multiscale analysis of spatio-temporal data. 2001. 138 f. Thesis (PhD) - Wageningen University, Wagenningen, 2001.

COVRE, M. R. **Influência de parâmetros culturais de citrus sobre os dados TM/Landsat**. 1989. 241 f. Dissertação (Mestrado) - INPE, São José dos Campos, 1989.

EPIPHANIO, J. C. N.; LEONARDI, L.; FORMAGGIO, A. R. Relações entre parâmetros culturais e resposta espectral de cafezais. **Pesquisa Agropecuária Brasileira**, Brasília, v. 29, n. 3, p. 439-447, 1994.

HOLBEN, B.; JUSTICE, C. An examination of spectral band rationing to reduce the topographic effect on remotely sensed data. **International Journal of Remote Sensing**, Dundee, v. 2, n. 2, p. 115-133, 1981.

JUSTICE, C. O.; WHARTON, S. W.; HOLBEN, B. N. Application of digital terrain dato to quantify and reduce the topographic effect on Lansat data. **International Journal of Remote Sensing**, Dundee, v. 2, n. 3, p. 213-230, 1981.

LEONARDI, L. **Influência de parâmetros culturais de cafezais sobre os dados TM/Landsat-5**. 1990. 171 f. Dissertação (Mestrado) - INPE, São José dos Campos, 1990.

LEONARDI, L.; EPIPHANIO, J. C. N.; FORMAGGIO, A. R. Aspectos da relação entre parâmetros culturais do café e a resposta espectral do dossel cafeeiro. In: SIMPÓSIO LATINOAMERICANO DE PERCEPCION REMOTA, 5, 1991, Cusco. **Memórias**... Cusco: Selper, 1991. p. 55-66.

MOREIRA, M. A. **Fundamentos do sensoriamento remoto e metodologias de aplicação**. São José dos Campos: INPE, 2001. 250 p.

SAS INSTITUTE. **SAS/STAT**[a]: user's guide, release 8.2 edition. Cary, 1999.

STOHR, C. J.; WEST, T. R. Terrain and look angles effects upon multiespectral scanner response. **Photogrammetric Engeneering and Remote Sensing**, [S.l.], v. 51, n. 2, p. 229-235, 1985.

STRAHLER, A. H.; LOGAN, T. L.; BRYANT, N. A. Improving forest cover classification accuracy from Landsat by incorporating topographic information. In: INTERNATIONAL SYMPOSUIM ON REMOTE SENSING OF ENVIRONMENT, 12., 1978, Ann Arbor. **Proceedings**… Ann Arbor: [s.n.], 1978. p. 927-942.

VALERIO FILHO, M.; PINTO, S. A. F. Imagens orbitais aplicadas ao levantamento de dados do meio físico: contribuição ao planejamento de microbacias hidrográficas. In: CONGRESSO BRASILEIRO E ENCONTRO NACIONAL DE PESQUISA SOBRE CONSERVAÇÃO DO SOLO, 8., 1996, Londrina. **Anais**... Campinas: Sociedade Brasileira de Ciência do Solo, 1996. p. 77-94.