CHARACTERIZATION OF COFFEE AGROECOSYSTEMS OF THE STATE OF MINAS GERAIS IN BRAZIL

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ABSTRACT:

Coffee is one of Brazil's most important cash crops and the state of Minas Gerais is responsible for approximately 50% of the national production. However, in spite of its importance, updated information about the areas occupied by the crop in the state is scarce. This work presents the characterization of coffee agroecosystems of Minas Gerais and evaluates the relationships between the crop and the environment. The study was carried out in three 520 km^2 pilot areas, representative of the production regions of Alto Paranaíba (Patrocínio) and Sul de Minas (São Sebastião do Paraíso and Machado). The data was obtained from secondary information, interpretation of satellite images and complementary field surveys. GIS and remote sensing were used to integrate and model the data from different sources, to map coffee areas and produce thematic maps from each environment. A geomorphopedological model was used to map the main soil classes. The relationships between environment and coffee production in the selected areas were assessed and quantified. The results showed the main soil, slope and altitude classes in which the crop is cultivated, emphasizing the relations between crop management practices and limitations imposed by the environment. The use of Landsat images in the mapping of coffee areas, although presenting problems to be solved, constituted an advance over the traditional methodologies, especially for the gently undulating landscape of the *cerrado* ecosystem of the western region of the state, where the coffee fields are more extensive and homogeneous. The information obtained can subsidize regional land use planning.

1 INTRODUCTION

Coffee is one of Brazil's most important crops, due to the incomes generated by exportation and the social benefits the coffee agribusiness propitiates. However, in spite of its importance, updated information about the areas occupied by the crop is scarce and when available, normally at high levels of aggregation and/or small scales. The state of Minas Gerais is responsible for approximately half of the national production, concentrated mainly in its southern region, which accounts for approximately 50% of the state's total production. Nevertheless, the greatest expansion of coffee fields in Minas Gerais has been observed in the regions of Alto Paranaiba and Triangulo Mineiro, both in the region now known as *coffee of the cerrado.* This region presents today the highest area and productivity growth rates observed in the state. Since 1984/85, the number of coffee producing properties increased 40% and the increase in the area occupied by the crop and the number of productive coffee plants was even more expressive, reaching 150% (MINAS GERAIS, 1995).

Sound agricultural planning requires, first, the knowledge of the environment in which the activity is inserted. The characterization of complex environments such agroecosystems usually required their subdivision into more homogeneous segments, which, after the characterization, were reintegrated into the whole ecosystem. Information systems however, have modified the methodology used in the survey of natural resources. Combining the advances of digital cartography, database management systems and remote sensing with the development of geographical analysis, GIS offers a new way for assessing and updating environmental information (Burrough & Mcdonnell, 1998).

Due to the constant changes observed in the state's coffee production sector during the last decades and as a requirement for future planning, it is important to characterize these areas and establish efficient methodologies to map and monitor these fields, with the possibility of an easier periodical updating of the information.

This work is part of a project to characterize coffee agroecosystems of the state of Minas Gerais using geotecnologies to evaluate the relationships between the physical environment, emphasizing soils and relief, and local coffee production systems. It is expected that the quantitative and spatial information obtained can subsidize better regional land use planning.

2 METHODOLOGY

To characterize the main coffee agroecosystems of Minas Gerais, two of the most important production regions where selected, the physiographic regions of Sul de Minas and Alto Paranaíba. Due to differences observed in the environment and coffee management practices, within the Sul de Minas region two representative pilot areas of 520 km2 were chosen, one around the city of Machado and the other around the city of São Sebastião do Paraíso. To represent the region of Alto Paranaíba, another 520 square kilometers study area around the city of Patrocínio was selected.

The available secondary data on natural resources and characteristics of coffee production systems of these regions was reviewed. To complement this information, field surveys were carried out in each area, in order to assess the relationships between coffee and the environment and collect georeferenced data from coffee fields, soils and geomorphology. Topographic maps from the Brazilian Institute of Geography and Statistics (IBGE), at the scale of 1:50.000 were used as a cartographic basis. Published soil surveys, geologic and geomorphic maps were also used, as well as aerial photographs, at the scale of 1:25.000, and images from the TM Landsat 7 satellite, from 1999 and 2000. The implementation of a digital database for the pilot areas and the treatment of the satellite images were carried out using the geographic information system SPRING. Thematic layers of different physiographic aspects of the study regions, such as urban areas, roads and drainage networks, contours and spot heights information, were obtained from the topographic maps by digitizing. The areas occupied by coffee, surveyed and georeferenced during field surveys, were also digitized to create the correspondent digital overlay in the database.

The TM Landsat images were treated in the SPRING's IMAGE module. Only three spectral bands were used for the classification of the image, viz. band 3 (red), band 4 (near infrared) and band 5 (mid infrared), since these bands represent more than 80% of the spectral information. Controlled samples of the main land cover types were used to train the classifier. These samples were obtained from areas identified and georeferenced during the field surveys. The segmentation of the images was performed using a region growing method and a supervised classification was carried out using the Maxver classifier (maximum likelihood algorithm available in the SPRING) on band 4. The thematic maps generated from the classified images identified the following land cover classes: **Productive coffee**: coffee fields with plants with more than 4 years of age, 2 meters or more of height, and canopies covering more than 50% of the ground; **Forest**: correspondent to areas occupied by natural vegetation from "*cerradão*" (Brazilian savanna woodlands) to remnants of semi deciduous Atlantic forest; **Other uses**: correspondent to areas occupied by small size natural vegetation (bush trees and other types of *cerrado*), natural and cultivated pastures, annual crops and even coffee fields still in formation, *i.e.* recently planted coffee areas which covered less than 50% of the ground*;* **Bare Soil**: comprehending areas prepared for cultivation and urban areas. These classes were chosen taking into account the main interest of the project, which was the coffee and the difficulty to distinguish this crop among natural forest and other land cover classes that spectrally overlap with it when sensed at the coarse spectral resolution of the TM Landsat. The thematic layer *Actual Land Use* was generated from the classified images.

The Delaunay triangulation was used to construct a TIN and create a digital elevation model (DEM) and a digital terrain model (DTM) for each area, based on the digital contours and spot heights data obtained from the topographic maps. Slope, aspect and hypsometry class maps were derived from these models. The slope classes used in the segmentation of the DTM were selected based on the relations between geomorphology and the soils distribution, according to the field observations of the regional landscapes studied (Andrade *et al* 1998). The geomorpho-pedologic model, validated for the regions of São Sebastião do Paraíso and Machado in field campaigns, is presented in Table 1.

According to the Brazilian Soil Classification system, the main soil classes occurring in these regions are Latosols (soils with oxic B horizons), Argisols (soils with argillic B horizons), Cambisols (soils with cambic B horizons) Neosols (soils without diagnostic B horizons – Litholic and Alluvial soils) and Gleysols (Hidromorphic soils). As shown in table 1, Latosols occur predominantly where the slope gradient is lower than 12%, although Hidromorphic and Alluvial soils might occur at flooded plains where the slope gradient is lower than 3%. Argisols occur where the slope gradient is higher than 12% and lower than 45%, although Cambisols and Lithosols might occur locally where the slope gradient is higher than 24%. For the area of São Sebstião do Paraíso the soil map was obtained from the overlay of the slope classes map and the geology domains map, according to the criteria established in Table 2. At the region of Machado however, the geology was more homogeneous and geomorphology and altitude were the primary factors determining the distribution of soil types over the local landscape. Therefore the model used the criteria shown in Table 3. The soil map of the pilot area of Patrocínio was obtained from an unpublished pedological survey carried out by the soil research center of EMBRAPA. The mapping units delimited were checked in the field and adjusted to the scale of the work.

The maps generated were crossed using the LEGAL/SPRING program. The thematic layers *Land Use Classes* x *Soil Classes* and *Land Use Classes* x *Slope Classes*, for each pilot area, were overlayed and the quantitative relations were evaluated.

3 RESULTS

3.1 Study area of Patrocínio

The results of the crossed tabulations (*Land Use Classes* x *Soil Classes* and *Land Use Classes* x *Slope Classes*) of the study area of Patrocínio are presented in tables 4 and 5, respectively.

The geomorphology of the pilot area of Patrocínio is represented, predominantly, by flat to gently sloping surfaces of great extensions. In these areas Red Latosols and Yellow Red Latosols occur and are discriminated according to the content of iron of the parent material. Coffee is cropped in this environment, occupying 13, 86% of the lands of the pilot area, distributed mainly in the areas with plain and gently undulated relief. In this region the crop is characterized by large fields, generally in contiguous areas of great dimensions, where Latosols, correspondent mainly to the Ld1 + Lea9 and Led16 + Ld1 mapping units occur. Due to climactic conditions, irrigation is a frequent agricultural practice and mechanic harvest is also favored by the geomorphologic characteristics. These practices condition the management of the crop in the region and influence many of its parameters, such as maximum plant high (2.2 m) and planting density (3.8 m x 0.6 m). These parameters influence the percentage of soil cover by the coffee plants canopies, favoring the interpretation and survey of coffee fields in TM/Landsat satellite images, as well as propitiating the automatic classification and mapping of land use classes.

3.2 Study area of Machado

According to the geological maps available (DNPM/CPRM, 1979), the pilot area of the region of Machado presents homogeneous geology, corresponding to the Complexo Varginha, constituted basically by ophthalmic gneiss and migmatites, whose mineral and chemical compositions do not

Slope Gradient (%)	Slope Classes	Soil Class
0 - 3	Plain	Latosols
3 – 12	Gently undulated	Latosols
12 – 24	Undulated	Argisols
24 – 45	Strongly undulated	Argisols and Cambisols
> 45	Mountainous	Cambisols and Neosols

Table 1. Correlation between slope gradient, relief type and soil class used to model the soils distribution over the landscapes of Machado and São Sebastião do Paraíso regions.

Slope Class	Geological Domain*	Soil Mapping Unit
0-12%	Qa	Association of Haplic Gleisol (GX) + Fluvic Neosol (RU)**
	KJsg	Ferric Red Latosol (LVf)
	TQi, Kb, KJb	Association of Red-Yellow Latosol (LVA) + Sandy-Loamy Red-Yellow Latosol (LVAp)
	PCi	Association of Red-Yellow Latosol (LVA) + Red Latosol (LV)
20-45%	KJsg	Association of Ferric Red Nitosol (NVf) + Haplic Cambisol (CX)
	TQi, Kb, KJb	Association of Red-Yellow Argisol (PVA) + Sandy Red-Yellow Argisol (PVAa) + Haplic Cambisol (CX)
	PCi	Association of Red-Yellow Argisol (PVA) + Red Argisol (PV)
>45%	KJsg, TQi, Kb, KJsg, KJb, PCi	Association of Haplic Cambisol (CX) + Litholic Neosol (RL)

Table 2. Correlation between slope class, geological domain and soil mapping units for the pilot area of São Sebstião do Paraíso

** Geological domains obtained from DNPM/CPRM (1978), where:*
Qa: Quaternary sedimentary deposits, mainly aluvial.
TQi: Undifferentiated covers, involving Latosols with paleopavings.
Kb: Bauru Formation – sandstones with medium granules, clayey, reddish pink and whitish to reddish, quartzons, locally with coarse sandstones, with crossed and plain stratification having small to medium portment.
KJsg: São Bento Group - Serra Geral Formation – basaltic flows with sandier lenses and layers (Botucatu sandstone type).
KJb: São Bento Group - Botucatu Formation – sandstones with fine to medium granules, well selected, whitish to reddish, quartzons; locally with coarse sandstones beds, with tangential, crossed stratification, having large portment at the base.
Pci: Tubarão Super Group – Undifferentiated Itararé Group – coarse to fine sandstones, yellowish to reddish color, with development linked to red-brick color diamictites, grading to sandier and silty pellitic material; present crossed and plain stratification having small to medium portment.
*** This soil class was mapped by photo interpretation.*

Slope Class	Altitude Class	Soil Mapping Units
0 –3%	700 – 950 m	Association of Red-Yellow Latosol (LVA1) + Red Latosol (LV1)
	> 950 m	Association of Humic A Red-Yellow Latosol (LVA1 humic A) + Humic A Red Latosol (LV1 humic A)
0 –12%	700 – 950 m	Association of Red-Yellow Latosol (LVA2) + Red Latosol (LVA2)
	> 950 m	Association of Humic A Red-Yellow Latosol (LVA2 humic A) + Humic A Red Latosol (LV2 humic A)
12-24%	700 – 950 m	Association of Red-Yellow Argisol (PVA) + Red Argisol (PV)
	> 950 m	Association of Umbric A Red-Yellow Argisol (PVA umbric A) + Umbric A Red Argisol (PV umbric A)
24-45%	700 – 950 m	Association of Red-Yellow Argisol (PVA) + Red Argisol (PV) + Haplic Cambisol (CX)
	> 950 m	Association of Umbric A Red-Yellow Argisol (PVA umbric A) + Umbric A Red Argisol (PV umbric A) + Umbric A Haplic Cambisol (CX umbric A)
> 45%	700 – 950 m	Association of Haplic Cambisol (CX) + Litholic Neosols (RL)
	> 950 m	Association of Umbric A Haplic Cambisol (CX umbric A) + Umbric A Litholic Neosol (RL umbric A)

Table 3. Correlation between slope class, altitude class and soil mapping units for the pilot area of Machado

reflect in variations in soil classes. Therefore, the soil map was obtained from geomorpho-pedological correlations, based on the model established by Andrade *et al* (1998) that, after field evaluation, proved valid for the region of Machado. During the fieldwork, soils with humic/umbric epipedons were observed, distributed in altitudes over 950m. So, another correlation between slope classes and altitude classes was used to separate these soil-mapping units and representative soil profiles were described and sampled to confirm their occurrence.

Tables 6 and 7 show the results from the cross tabulations between *Land Use Classes* x *Soil Classes* and *Land Use Classes* x *Slope Classes*, respectively, for the pilot area of Machado.

Productive coffee occupies 26,44% of the pilot area of Machado, distributed in practically all the types of relief (plain, gently undulated, undulated and strongly undulated) predominating in the undulated class, where it represents 9,19%. This distribution reflects the geomorphology of the region. The geomorpho-pedologic zoning of the pilot area of Machado divided the region into two large environments:

- Geomorpho-pedological environment N-NE-E: with predominance of Latosols, in predominantly flat to undulated landscapes, occurring in the north, northeast and eastern regions in relation to the urban area of Machado; and

- Geomorpho-pedological environment W-NW: with predominance of soils with argillic B-horizons, as well as Cambisols, in predominantly undulated to mountainous landscapes, occurring in the western and northwestern parts of the study region.

Coffee is distributed over both environments, with greater concentration in the W-NW environment, despite the harder conditions imposed by the relief. The soils cropped with coffee belong to the mapping units Red Argisols + Red Yellow Argisols and Red Latosols + Red Yellow Latosols, with Humic/Umbric epipedons when above 950 m. The occurrence of the latter, however, corresponds to a small percentage of the W-WN environment. The results showed that coffee production is directly related to the distribution of soils in the landscape.

3.3 Study area of São Sebastião do Paraíso

Geoprocessing analysis together with field observations led to the understanding of soil distribution in the landscape of the pilot area of São Sebastião do Paraíso and to the establishment of a model correlating geomorphology and geology to map them. The checking of the mapping units and the description of representative soil profiles for its characterization were carried out in the Ribeirão Fundo watershed, representative of the regional landscape. The main soil classes were established and described according to Lemos and Santos (1996) and EMBRAPA (1999).

Tables 8 and 9 present the results of the cross tabulations between *Land Use Classes* x *Soil Classes* and *Land Use Classes* x *Slope Classes*, respectively. Productive Coffee occupies 25,96% of the pilot area and 23,07% of this total is distributed in areas of flat to undulated slopes. The soils used for coffee production belong to the mapping units LVf (Ferric Red Latosol) and NVf (Ferric Red Nitosol), totalizing 13,33%. They are followed by the LVAp (Sandy-Loamy Red-Yellow Latosol) and PVAa (Sandy Red-Yellow Argisol) units, which represent, together, 7,69% of the area. In the remaining soil classes coffee occupies less than 2,5%. The predominance of coffee production in the LVf and NVf units is justified, as both originate from basalt from the Serra Geral Formation (KJsg) and are naturally more fertile. The LVAp and PVAa, derived from sandstones (Kb, Kjb and PCI), are soils that present good physical characteristics and with adequate fertility management become suitable for coffee production.

After the interpretation of the data the region of São Sebastião do Paraíso was divided into two main environments:

- Geo-pedological environment W: domain of basalts of the Serra Geral Formation, with slope gradients up to 12%, where Ferric Red Latosols e Loamy Red Latosols at the intertrapped portions of basalts and sandstones of the Botucatu Formation and Itararé Group are found. At the slopes with more than 12% gradient Ferric Red Nitosols are formed;

- Geo-pedological environment E: domain of sandstones of the Itararé Group, where Loamy to Sandy-Loamy Red Yellow Latosols are found on the slopes with less than 12% of gradient and after that Loamy to Sandy Red Yellow Argisols are formed.

Coffee production in the region is located, predominantly, in the environment W, especially in the portion located between the cities of São Sebastião do Paraíso and São Tomás de Aquino, where the soils, especially the Ferric Red Latosols are more suitable for production.

4. CONCLUSION

Satellite imagery has been acknowledge as the most promising way for detailed mapping and monitoring of land agricultural use and cover, over large geographical areas, although there are theoretical and practical challenges that must be met in order to realise its potential. In this work geoprocessing, allied to field activities, proved efficient in the characterization of coffee agroecosystems of Minas Gerais, especially in the evaluation of the areas occupied by coffee in relation to units that characterize the physical environment and reflect the regional landscape.

Land Use Classes (%)	**Soil Classes (%)**								
	Ca17	Ld1 + LEa9	Ra5 + AR	Ca31	LEd16 + Ld1	LEa9	LEd4	Ca6+Ra2	**Total**
Productive coffee	0,24	8,29	0,01	0,27	2,85	0,59	0,00	1,61	**13,86**
Forest	1,78	3,42	0,35	2,33	1,99	1,02	0,00	9,21	**20,09**
Other uses	4,51	13,36	0,23	3,14	6,64	2,18	0,00	12,71	**42,77**
Bare soil	0,28	8,65	0,00	0,26	2,27	3,35	0,88	7,83	**23,28**
Total	**6,80**	**33,71**	**0,59**	**5,99**	**13,55**	**7,12**	**0,88**	**31,35**	**100,00**

Table 4. Results of the cross tabulation between Soil Classes and Land Use Classes for the study area of Patrocínio

Land Use Classes (%)	**Slope Classes (%)**					
	Plain	Gently Undulated	Undulated	Strongly Undulated	Mountainous	**Total**
Productive Coffee	7,61	4,87	0,90	0,39	0,09	**13,86**
Forest	7,90	4,32	4,22	3,05	0,59	**20,08**
Other uses	27,73	16,11	9,36	4,42	0,73	**58,35**
Bare soil	5,16	2,24	0,24	0,06	0,01	**7,71**
Total	**48,40**	**27,54**	**14,73**	**7,91**	**1,42**	**100,00**

Table 5. Results of the cross tabulation between Land Use Classes and Slope Classes for the study area of Patrocínio

Land Use Classes (%)	Soil Mapping Units (%)										
	LVA1 + LV1	LVA1 + LV1 Humic A	LVA2 + LV2	LVA2 + LV2 Humic A	PVA + PV	PVA + PV Umbric A	PVA + PV + CX	PVA + PV + CX Umbric A	CX + RL	CX + RL Umbric A	Total
Productive Coffee	3,71	0,57	6,24	1,97	7,14	2,05	2,38	2,34	0,3	0,68	**26,44**
Forest	1,80	0,14	3,66	0,16	3,62	0,76	1,40	1,12	0,14	0,26	**13,07**
Other Uses	8,09	0,71	14,00	0,72	16,33	2,39	4,54	2,52	0,35	0,49	**50,13**
Bare Soil	2,21	0,16	3,30	0,18	3015	0,38	0,60	0,30	0,04	0,04	**10,36**
Total	**15,81**	**1,57**	**27,21**	**1,58**	**30,24**	**5,59**	**9,43**	**6,28**	**0,84**	**1,46**	**100,00**

Table 6. Results of the cross tabulation between Soil Classes and Land Use Classes for the study area of Machado

Land Use Classes (%)	Slope Classes (%)					
	Plain	Gently Undulated	Undulated	Strongly Undulated	Mountainous	Total
Productive Coffee	4,25	6,79	9,19	5,22	0,99	**26,44**
Forest	1,93	3,83	4,38	2,52	0,41	**13,07**
Other Uses	8,76	14,74	18,73	7,06	0,84	**50,13**
Bare Soil	2,37	3,48	3,53	0,90	0,08	**10,36**
Total	**17,31**	**28,84**	**35,83**	**15,70**	**2,32**	**100,00**

Table 7. Results of the cross tabulation between Land Use Classes and Slope Classes for the study area of Machado

Land Use Classes (%)	Soil Mapping Units (%)										
	LVf	NVf	CX + RL	LVA + LV	PVA + PV	PVAa	LVAp	LVA	PVA	RU	Total
Productive Coffee	7,05	6,28	0,27	0,69	0,87	2,97	4,72	2,48	0,51	0,12	**25,96**
Forest	1,21	1,74	0,16	0,17	0,43	1,20	1,38	0,38	0,10	0,01	**6,78**
Other Uses	11,06	8,25	0,15	1,80	1,73	5,30	14,35	3,74	0,71	0,13	**47,21**
Bare Soil	4,20	2,14	0,04	0,28	0,27	2,52	8,53	1,78	0,27	0,03	**20,04**
Total	**23,52**	**18,40**	**0,63**	**2,94**	**3,29**	**11,99**	**28,98**	**8,37**	**1,59**	**0,29**	**100,00**

Table 8. Results of the cross tabulation between Soil Classes and Land Use Classes for the study area of São Sebastião do Paraíso. (where a: arênico = sandy and p: psamítico = sandy-loamy)

Land Use Classes (%)	Types of Relief (%)					
	Plain	Gently Undulated	Undulated	Strongly Undulated	Mountainous	Total
Forest	1,56	1,59	2,13	1,33	0,16	**6,78**
Productive Coffee	6,27	8,77	8,03	2,61	0,28	**25,96**
Other Uses	11,00	20,06	13,31	2,68	0,16	**47,21**
Bare Soil	5,29	9,51	4,40	0,80	0,04	**20,04**
Total	**24,13**	**39,93**	**27,88**	**7,42**	**0,64**	**100,00**

Table 9. Results of the cross tabulation between Land Use Classes and Slope Classes for the study area of São Sebastião do Paraíso

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