# MONITORING THE RELATIONSHIPS BETWEEN ENVIRONMENT AND COFFEE PRODUCTION IN AGROECOSYSTEMS OF THE STATE OF MINAS GERAIS IN BRAZIL

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**ABSTRACT:**

Satellite imagery has been acknowledged as the most promising way for detailed mapping and monitoring of land agricultural use, although there are challenges that must be met in order to fulfil its potential. Coffee is one of Brazil's most important cash crops and the state of Minas Gerais responds for approximately half of the national production. Nevertheless, in spite of its importance, updated detailed information about the areas occupied by the crop is scarce. In this work data obtained from secondary information, interpretation of Landsat images of the years 2000 and 2003 and modelling, complemented by field surveys, were used to characterize coffee lands of Minas Gerais and evaluate the relationships between the crop and the environment. Two of the most important production regions where chosen, Sul de Minas and Alto Paranaíba, and 520 $km^2$ representative study areas were selected. Models relating geology, geomorphology and-pedology were 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 management practices and limitations imposed by the environment. The use of Landsat images in the mapping of coffee areas constituted an advance over the traditional methodologies, especially for the gently undulating landscape of the western region of the state, where the coffee fields are more extensive and homogeneous. The information obtained can subsidize better regional land use planning.

## 1. INTRODUCTION

When mankind explores natural resources, introducing in them changes to suite its needs, the environmental impact is usually negative. An understanding of these changes is necessary to prevent the degradation of natural resources and should form the basis for any sustainable agricultural activity. Land use planning based on sound studies of the physical environment and its evolution dynamics becomes essential. These studies should be fundamental to a region's development planning in order to reduce socio-economic losses and make it a sustainable process through time (Assad et al., 1998).

Remote sensing, integrated to the Geographic Information Systems (GIS), are useful tools in research applied to land use planning. GIS are computerized systems used to store, analyze and manipulate geographic data, i.e. data that represent objects and phenomena whose geographic location is a characteristic inherent to their formation and therefore indispensable to their analysis. They constitute a modern way of storing and manipulating information of the physical environment, integrating data from heterogeneous sources such as soils, geology, topography, land use and land cover, which are organized in spatially referenced digital databases in a transparent way (Câmara Neto et al., 1996). With this technology, spatial information for land evaluation and other environmental studies can be generated and analyzed more efficiently.

Remote sensing is the combination of processes and techniques used to measure a surface or object's electromagnetic properties, without physical contact between the object and the sensor equipment. In other words, it is the technology that gathers images and other types of data from earthly surfaces by registering the energy reflected or emitted by them (Moreira, 2001). It is an important relative of GIS and undoubtedly, the largest primary source of digital data for use in GIS is created by remote sensing technology on board satellites and other aircraft. In fact, satellite imagery has been acknowledged as the most promising way for detailed mapping and monitoring of land agricultural use, although there are challenges that must be met in order to fulfil its potential. It is therefore essential for environmental applications that remote sensing and GIS be closely linked (Jones, 1997; Carvalho, 2001).

The state of Minas Gerais has very different environments in terms of relief, geology, soils and climate. Detailed mapping in the state is difficult due to its vast extension, the complexity of the physical environment and the accelerated dynamics of its land use. Inserted in this context, coffee cropping is socially and economically important to the state and the whole country. However, despite its importance, the coffee crop lacks precise quantitative data, relating to the extension and distribution of the fields as well as to the characteristics of the environments in which the crop is cultivated (MINAS GERAIS, 1995). The use of Landsat images in the mapping of coffee areas, although presenting problems to be solved, constitutes an advance over traditional methodologies.

This work is part of a project to characterize coffee agroecosystems of the state of Minas Gerais using geotechnologies to evaluate the relationships between the physical environment and local coffee production systems. The objective, in this case, was to use remote sensing and GIS technology to map and monitor the evolution of coffee areas in relation to the environment in the regions of Patrocínio (within the physiographic region of Alto do Paranaíba), São Sebastião do Paraíso and Machado (both in the physiographic region of Sul de Minas), between the years 2000 and 2003.

## 2. MATERIAL METHODS

The study areas were selected within two of the main coffee producing regions of the state of Minas Gerais. Three representative study areas, in terms of characteristics of the crop and its relation to the physical environment, were chosen, each one with 520 $km^2$: Machado, representative of the southern region of the state with hilly relief; São Sebastião do Paraíso, also within the southern region of the state but with a different environment, smother relief and soils rich in iron; and Patrocínio, representative of the Alto Paranaíba region, with smoother landscapes within the cerrado (Brazilian savanna) environment.

To characterize each area all the secondary information available on the natural resources and characteristics of the coffee crop of each region was gathered. Field surveys were carried out in each area to assess the relationships between coffee and the environment and to collect referenced data from coffee fields, soils and geomorphology in order to establish ground truth samples. Topographic maps from the Brazilian Geography and Statistic Institute (IBGE), scale 1:50,000, were used as cartographic basis. For Machado, the sheets Machado and Campestre (UTM coordinates E 392 000 to 418 000 m and N 7620 000 to 7600 000 m). For São Sebastião do Paraíso sheets São Sebastião do Paraíso and São Tomás de Aquino (UTM coordinates E 274 000 to 300 000 and N 7700 000 to 7680 000 m) were used. For the region of Patrocínio the maps of the Army Ministry, scale 1:100,000, sheets Patos de Minas and Monte Carmelo (UTM coordinates E 278 000 to 304 000m and N 7942 000 to 7922 000m) were used. To map land use the TM-Landsat 7 images, from 2000 and 2003, corresponding to the regions of Machado (219 /75), São Sebastião do Paraíso (220/74) and Patrocínio (220/73), as well as the IKONOS Image of 11/08/2002 of São Sebastião do Paraíso, were used.

Through secondary information, field surveys and satellite image interpretation, data on soils, relief, hydrologic resources and land use were generated with emphasis on the coffee crop. This information was incorporated through the geographic information system SPRING (SPRING, 2003) to generate a digital database for each study area. From this database thematic environment characterization maps were generated, among which are maps of land use, slope gradient, slope aspect and soil classes. The soils maps were generated using geologic-geomorphic-pedologic models (according to Andrade et al., 1998) and the relief maps were based on each region's contours and DTM obtained from the digitized topographic maps.

The areas occupied by coffee were mapped using the Landsat images 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/use types obtained during the field survey were used to classify the images. 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. This classification was corrected by photointerpretation, checked in the field and by comparison with the Ikonos image and edited to obtain the final map of coffee lands.

The maps generated and stored in the database were overlayed through the computer language LEGAL (SPRING`s Spatial Language for Algebric Processing). The relations between environment and the coffee crop for the years 2000 and 2003 were assessed and quantified. The results obtained for the two years were compared and the changes observed in these relationships during this period were then evaluated.

## 3. RESULTS AND DISCUSSION

Due to the alterations observed in the areas occupied by coffee, a study of the dynamics of the crop in relation to the environment was necessary. According to the results obtained by overlaying the land use and environment maps, it was observed that, in São Sebastião do Paraíso, the coffee areas changed most in relation to the soils classes on which they are cultivated. In Patrocínio, the change occurred in relation to the classes of slope aspect and in Machado, in relation to slope gradient classes.

The analysis carried out through geoprocessing techniques, the generation and manipulation of thematic maps of distribution of natural resources, especially geology and geomorpholgy, allied to the field observations, lead to a better understanding of soil distribution in São Sebastião do Paraíso. The analysis also established a correlation model between relief and geology, which allowed the mapping of the main soil units. The soils map of the study area of São Sebastião do Paraíso was obtained using the LEGAL program, through the overlaying of thematic maps of slope classes and geologic domains, as presented in Table 1. This correlation model was developed and field checked in the Ribeirão Fundo watershed, which is an environmental unit representative of the model of soil distribution in the regional landscape. The soil profiles, representatives of the main mapping units, were described and sampled for chemical and physical analysis according to the methodology suggested by EMBRAPA (1999) and Lemos (1996). The main soil classes were defined and mapped according to the Brazilian System of Soil Classification (EMBRAPA, 1999). This model was applied to the study area and in this way, by generalization, the map of soil classes of São Sebastião do Paraíso was created.

Analysing the distribution of coffee lands in relation to the soil map it was observed that, in the year 2000, 38% of the coffee fields were located on Ferric Red Latosols (LVf) and, in 2003, this area decreased to 32%. The coffee planted on Ferric Red Nitosols remained practically in the same proportion, 22% in 2000 and 21% in 2003. In the Red Yellow Latosols there was an increase of 3%, as the coffee area increased from 33% in 2000 to 36% in 2003 (Figures 1 and 2).

In Patrocínio the digitized contours and elevation points of the topographic maps were used to model and sample the terrain, generating the digital terrain model (DTM) and to generate a thematic map of slope aspect. The slope aspect map was divided in the directions $1^{\circ}$ to $45^{\circ}$ (N-NE), $45^{\circ}$ to $90^{\circ}$ (NE-E), $90^{\circ}$ to $135^{\circ}$

(E-SE), 135° to 180° (SE-S), 180° to 225° (S-SW), 225° to 270° (SW-W), 270° to 315° (W-NW), 315° to 360° (NW-N) and flat areas that have no angle inclination.

| 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 1. Correlation model between slope gradient, geological domain and soil classes of the Ribeirão Fundo watershed used to map the soils of the pilot area of São Sebstião do Paraíso

** Geological domains obtained from DNPM/CPRM (1979), 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.*

Overlaying the coffee lands map of the two years onto the slope aspect thematic map it was observed that in the region of Patrocínio the crop is cultivated mainly on the flat surfaces. However, in 2000, 4% of the coffee was planted in the SE-S slopes (Southwest-South) and 11% was planted in the W-NW slopes (West-Northeast). In 2003 however, 10% of the coffee

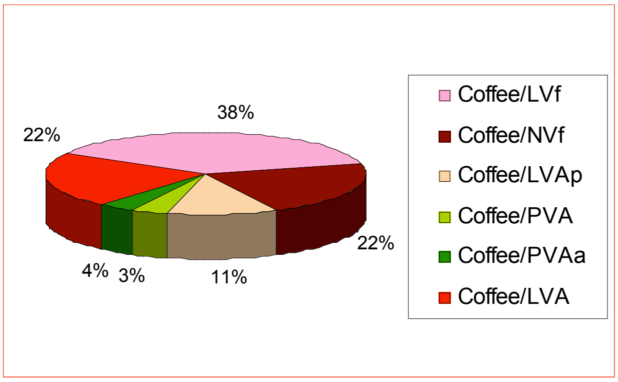


Figure 1. Distribution of coffee lands of São Sebastião do Paraíso by soil class in the year 2000

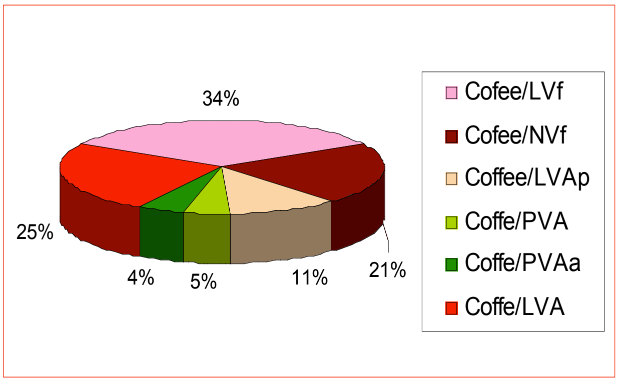


Figure 2. Distribution of coffee lands of São Sebastião do Paraíso by soil class in the year 2003

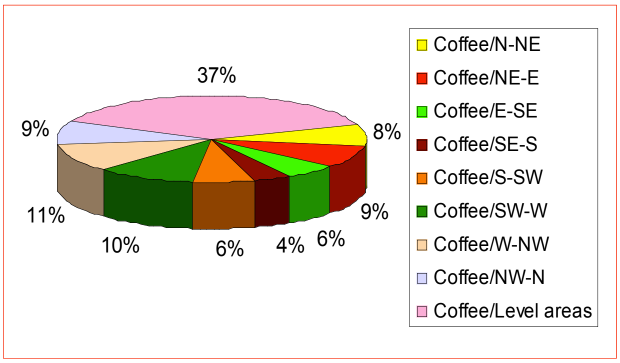


Figure 3. Distribution of coffee lands of Patrocínio by slope aspect in the year 2000

was planted in the SE-S surfaces and 4% in the W-NW, showing that there was an inversion of the localization of coffee areas in relation to the slope aspect (Figures 3 and 4). This has implications in the physiology of the plants and also in the use of satellite images to map and monitor the crop.

In Machado, the slope gradient map was generated using SPRING modules, from the contours digitized from the topographic maps of IBGE. Five slope classes were defined and related to various types of relief and soil classes according to Table 2: 0-3% – flat or level areas; 3-12% – Gently undulated surfaces; 12-24% – Rolling to Strongly undulated; 20-45% – Hilly to Steeply dissected surfaces; and >45% – Mountainous relief.

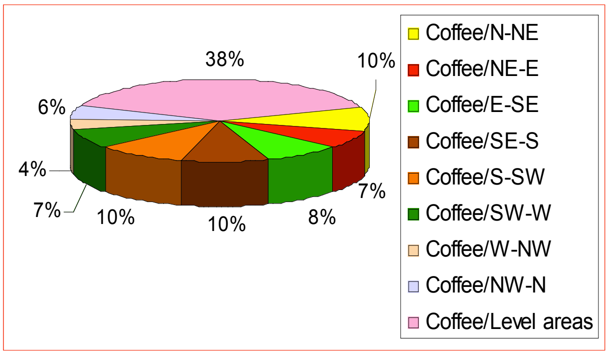


Figure 4. Distribution of coffee lands of Patrocínio by slope aspect in the year 2003

| Slope Gradient (%) | Slope Classes | Soil Class |
|---|---|---|
| 0 – 3 | Flat | Latosols |
| 3 – 12 | Gently undulated | Latosols |
| 12 – 24 | Rolling to Strongly undulated | Argisols and Nitosols |
| 24 – 45 | Hilly to Steeply dissected | Argisols, Nitosols and Cambisols |
| > 45 | Mountainous | Cambisols and Neosols |

Table 2. Correlation between slope gradient, relief type and soil class used to model the landscape of Machado

Also using SPRING's computer spatial language processing LEGAL, the land use maps of the years 2000 and 2003 were overlayed with the environment maps. Through these overlayings the evolution of the coffee crop's distribution in the study area and the changes in relation to its occupation over the landscape were quantitatively evaluated.

In Machado it was observed that, in 2000, 34% of the coffee was planted on gently undulating relief and 13% on hilly to steep relief (Figure 5).

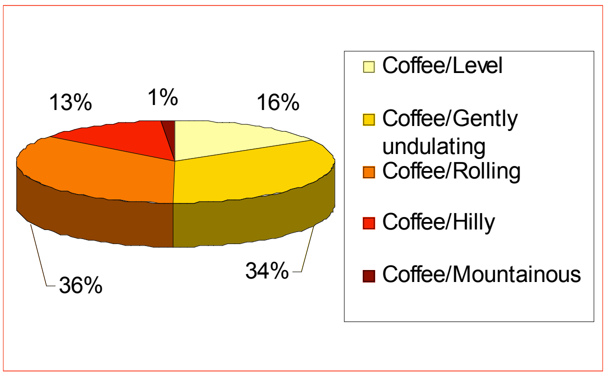


Figure 5. Distribution of coffee lands of Machado by relief classes in the year 2000

In 2003, the area of coffee planted on gently undulating relief decreased 4% and the area planted on hilly to steep relief increased 3%, showing that there was a decrease of the coffee areas planted on the smoother areas occupied preferably by Latosols (Figures 5 and 6). This could indicate that the farmers are moving the coffee to areas with richer soils and leaving the smother areas to annual crops. This tendency must be better investigated through time and taking into account other socio-economic factors.

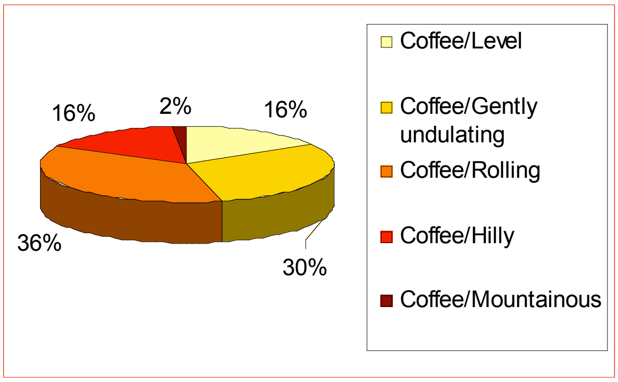


Figure 6. Distribution of coffee lands of Machado by relief classes in the year 2003

## 4. CONCLUSIONS

The results showed that using the methodology applied in the work it was possible to observe the distribution and the dynamics of coffee occupation in relation to the surrounding environment, as well as to monitoring these changes, providing relevant information for land use planning. The behavior of the crop was different in each region studied and the changes are probably closely related to the local production systems characteristics.

Remote sensing and GIS were useful in the characterization and mapping of the coffee agroecosystems of the selected regions, proving to be an efficient methodology in terms of both speed and resources. Through the geotechnologies used, spaced information on the coffee crop of each study area was generated faster, with lower costs and higher precision, subsidizing rational management and planning of the crop in these regions.

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