GEOTHECNOLOGIES IN THE ASSESSMENT OF LAND USE CHANGES IN COFFEE REGIONS OF THE STATE OF MINAS GERAIS IN BRAZIL

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ABSTRACT: Coffee is one of Brazilian most important cash crops due to the incomes generated by exportation. Southern Minas Gerais State represents approximately half of the total national production, although the greatest expansion of the crop has been observed in the western part of the state ("Triângulo Mineiro" and "Alto Paranaíba" regions). As a requirement for future planning, it is important to establish efficient methodologies to map and monitor these lands, with the possibility of an easier periodical updating of the information. In this work geotechnologies were used to evaluate changes, in space and time, of areas occupied by coffee plantations in Minas Gerais. Land use maps of study areas selected in the main producing regions of the state were generated for the years 2000 and 2003 using the GIS SPRING and Landsat images. The results of the quantitative comparison of these maps indicated different behaviours for the regions evaluated. In São Sebastião do Paraíso and Machado, countries (south of Minas Gerais), a decrease of the areas occupied by coffee was observed, whereas in Três Pontas, increased. In Patrocínio, western part of the state, the area occupied by the crop remained unaltered. Remote sensing and GIS were efficient in the evaluation of the spatial-temporal dynamics of coffee lands of Minas Gerais, providing a greater understanding of the different environments and information that can support regional land use planning.

Key words: Remote sensing, GIS, Land Use, Crop Mapping, Coffee Production, *Coffea arabica*.

GEOTECNOLOGIAS NA AVALIAÇÃO DAS MUDANÇAS NO USO DA TERRA DE REGIÕES CAFEEIRAS DO ESTADO DE MINAS GERAIS, BRASIL

RESUMO: *O café é uma das principais culturas de exportação do Brasil. A produção de café do estado de Minas Gerais, que representa aproximadamente metade da produção nacional, concentra-se principalmente na região Sul de Minas, apesar da maior expansão da cultura verificar-se na região oeste do Estado (regiões do Triângulo Mineiro e Alto Paranaíba). O planejamento agrícola requer metodologias eficientes para mapear e monitorar estas terras, que possibilitem, mais facilmente, a atualização periódica da informação. Neste trabalho, geotecnologias foram utilizadas para avaliar mudanças, no tempo e espaço, de áreas ocupadas pela cafeicultura (Coffea arabica L.) em Minas Gerais. Mapas de uso da terra dos anos 2000 e 2003 de áreas de estudo selecionadas nas principais regiões cafeeiras do estado foram gerados com o sistema de informações geográficas SPRING e imagens Landsat. Os resultados da comparação quantitativa destes mapas indicaram comportamentos diferenciados nas regiões avaliadas. Em São Sebastião do Paraíso e Machado, região Sul de Minas observou-se um decréscimo nas áreas ocupadas pela cafeicultura, enquanto que em Três Pontas houve um acréscimo nas áreas cultivadas com café. Em Patrocínio, região Alto Paranaíba, a área ocupada pela cultura permaneceu inalterada. O Sensoriamento remoto e o sistema de informações geográficas foram eficientes na avaliação espaço-temporal da dinâmica de áreas de café do Estado, propiciando uma melhor compreensão dos ambientes cafeeiros e fornecendo informação que pode subsidiar o planejamento agrícola regional.*

Palavras-chave: Sensoriamento Remoto, Sistema de Informação Geográfica, Uso da Terra, Mapeamento Agrícola, Cafeicultura, Coffea arabica.

1 INTRODUCTION

Land use and land cover information are fundamental to sound agricultural planning and the proposition of solutions to the problems of unregulated agricultural development and environmental degradation. The analysis and mapping of land and its uses are based on studies of the physical environment and its evolution dynamics. These studies should be important in regional development planning to reduce socio-economic losses and to make this a sustainable process in time (FORMAGGIO et al., 1992).

The traditional methodologies for surveying land use are costly and present difficulties in obtaining data in a short period of time, which constitutes a limitation

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to their application. In Brazil, land use data is limited to small areas surveyed for specific purposes.

Updated spatial information of land use and land cover are useful for the survey of natural resources, flooding control, identification of areas under advanced erosion process, environmental impact evaluation, formulation of economic policies and others . With the advent and popularization of remote sensing and orbital imagery it became possible to map land use efficiently with a relatively low cost and a frequency that makes the monitoring of this occupation easier.

Remote Sensing and Geographic Information System are technologies that can be used to map and characterize coffee areas, providing valuable information for agricultural zoning and planning and for the establishment of evaluation models of land use and occupation (NOVO, 1989). Together, they can integrate information from different sources and, in this way, facilitate the study of these dynamics (ASSAD & SANO, 1998; VIEIRA et al., 2006).

Contrary to other regions of the country, the State of Minas Gerais comprehends environments very different in relief, geology, soils and climate. Due to this environmental complexity, associated to the contrasts between regional socio-economic problems and the dynamics of land use and occupation, mapping becomes very complicated.

The coffee crop of Minas Gerais is socially and economically important for the whole country. There are different production systems, varying from small holding farmers, employing technologies that range from intermediate to high level input systems, to the large entrepreneurial farms which employ the most recent technical recommendations. Agriculture planning has to manage this complex scenario, in which the alternatives for land use are multiple and varied.

Specifically in coffee production, geotechnologies can be used for surveying, characterization and identification of cropped areas and estimates of annual production. In order to do this two types of data can be produced by orbital remote sensing: the characteristics of the coffee lands and the area occupied by the crop.

The objective of this work was to evaluate, in space and time, the coffee (*Coffea arabica* L.) areas of the main producing regions of Minas Gerais using Remote Sensing and GIS. These geotechnologies offer greater speed and precision in the gathering of data. They are useful tools to analyze tendencies, which in turn help delineate alternatives of action and future scenarios, generating geodatabases that convey valuable information to farmers and decision makers.

Characterization of the study areas

The study areas were selected according to their importance in terms of coffee production for the state and differences in the environment in which they are located. Four areas, representative of the main coffee producing regions of Minas Gerais, were chosen: Machado, São Sebastião do Paraíso and Três Pontas, in the South region, and Patrocínio, representative of the region of Alto Paranaiba, in the western part of the state, within the cerrado environment.

The areas were selected first based on secondary information regarding the importance of coffee production for the region and aspects of the physical environment. Census data from IBGE (Brazilian Institute of Geography and Statistics) and the available secondary information on the regions' natural resources, particularly geology, geomorphology, soils, as well as topographic maps, were analyzed. Then field surveys were carried out to define the study areas. In each place, an area of approximately 520 square kilometers was chosen. Figure 1 shows aspects of the landscape and coffee lands of the study regions selected.

Machado is one of the main coffee producing regions of the state. Its environment is characterized by altitudes ranging from 780 to 1260 meters, mild climate subject to frost, moderate water deficiency, gently to steep slope surfaces, with the predominance of Latosols and soils with argillic horizons. Coffee farmers are predominantly small holders, but with intermediate to high level technology production systems, *i.e.*, farmers use updated technologies that have been recently developed by research in order to produce quality coffees. The study region was delimited by geographic coordinates 45°47'33" to 46°02'34" of longitude west and 21° 31'09" to 21°42'05" of latitude south, according to the topographic maps of the Brazilian Institute of Geography and Statistics (IBGE), scale 1:50,000, sheets Machado and Campestre.

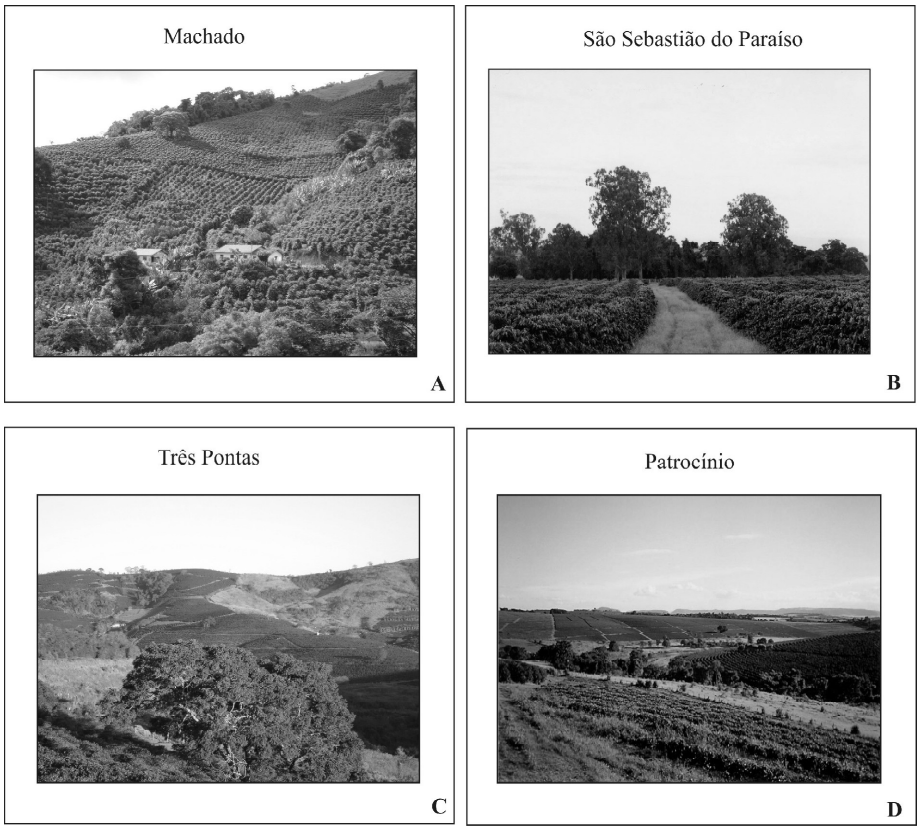

Figure 1 – Aspects of the landscape and coffee lands of the study regions of Machado (A), São Sebastião do Paraíso (B) and Três Pontas (C) in the South region of Minas Gerais and Patrocínio in the region of Alto Paranaíba.

In São Sebastião do Paraíso, the selected study area was outlined by geographic coordinates 46°55'17" to 47°10'25" of longitude West and 20°47'20" to 20°570'59" of latitude South, encompassing portions of the IBGE topographic maps, scale 1:50,000, sheets São Sebastião do Paraíso and São Tomás de Aquino. The environment is characterized by altitudes ranging from 850 to 1100 meters, mesothermic climate, moderate to high water availability, and undulated to gently undulated landscape with a predominance of Red Latosols and Nitosols with high iron content. These environmental characteristics, allied to high technology production systems, can produce quality coffees.

Três Pontas is one of the main coffee producing regions of the state and remained for a long time the largest coffee cultivated area of the country. Coffee production represents 70% of the agricultural income. The area chosen for this study was outlined by geographic coordinates 45°30'04" to 45°45'10" of longitude West and 21°17'13" to 21°28'00" of latitude South, encompassing portions of the IBGE topographic sheet Três Pontas, scale 1:50,000. Its environment is characterized by altitudes that range from 700 to 1150 meters, mild climate and predominance of gently undulated relief, with Dark Red Latosols, Dark Red Nitosols and Cambisols. The coffee farming systems are similar to those in Machado, employing medium to high level technology, and can also produce quality coffee.

The study area of Patrocínio was outlined by geographic coordinates 46°51'34" to 47°06'14" of longitude West and 18°36'04" to 18°47'03" of latitude South, encompassing portions of the topographic maps of the Army Ministry, sheets Patos de Minas and Monte Carmelo, scale 1:100,000. The environment is characterized by large flat areas, with altitudes ranging from 820 to 1100 m, mild climate, average total annual

rainfall of 1500 mm, but with a marked dry winter season, moderate water deficiency, flat to gently sloping landscapes, with the predominance of Latosols. This is a region of large entrepreneurial farms, with large scale technological production systems which usually depend on mechanically powered implements for cropping, including the harvest and preparation of the coffee beans. All these factors give this region the potential for producing fine beverages.

2 METHODOLOGY

The coffee lands and the environments in which they are inserted were characterized and surveyed. Using remote sensing and digital image processing, a geographic database was generated for each study area using Landsat 7 ETM+ images and the geographic information system SPRING, a Brazilian software developed by the National Space Research Institute – INPE (CÂMARA et al., 1996). From this database, thematic land use maps for the years 2000 and 2003 were generated. The Spatial Language for Algebra Processing (LEGAL), available in SPRING, was used to evaluate the changes, in space and time, of each region's coffee lands.

The following TM Landsat 7 images, bands 3B, 4R, 5G and band 8 (panchromatic) were used: Machado - 219/75, images from 17th June/ 2000 and 23rd April/ 2003; Patrocínio - 220/73, images from 21st April/ 2000 and 30th April/ 2003; São Sebastião do Paraíso - 220/74, images from 27th June/ 2000 and 30th April/ 2003; and Três Pontas - 219/75, images from 17th June/ 2000 and 23 April/ 2003. These dates were chosen because at this time of the year coffee plants are more vigorous and their canopies reflected better in band 4, facilitating the identification of coffee fields.

The steps followed in the work were:

1. Field survey to define ground truth patterns of coffee environments and georeference sample areas;
2. Implementation of a geodatabase with information of the coffee lands surveyed;
3. Digital image processing (segmentation and interpretation of Landsat images) to map the distribution of coffee areas;
4. Field survey to check the preliminary land use maps produced;
5. Reinterpretation and correction of data to obtain the final maps of coffee occupation;
6. Overlaying of the maps obtained for the two periods analyzed;
7. Generation of output thematic maps and quantitative information;
8. Evaluation of the changes in coffee distribution in the study areas.

After the first field survey to choose the study regions, a second, more detailed one, was carried out in each study area selected. During these field works, systematic surveying and georeferencing of coffee lands were carried out to obtain field references and patterns for the classification of the Landsat images and mapping of coffee plantations.

The satellite images were segmented and visually interpreted in the composition 3B-4R-5G. The land use classes mapped are defined bellow:

Production coffee: corresponds to the coffee fields where the plant canopies covered more than 50% of the soil. Usually coffee fields 3 or more years old with plants over 1.5 m high;

Coffee in formation/renovation: corresponds to recently planted coffee fields, under 3 years old, with partial exposition of the soil and fields that have been pruned for renovation and also have exposed soil between crop lines;

Forest: corresponds to the areas occupied by natural vegetation;

Urban area: corresponds to urban occupation;

Water bodies: corresponds to rivers, natural and artificial lakes;

Reforestation: areas planted with eucalyptus or pines;

Other uses: areas of natural and/or cultivated pastures and annual crops.

To identify the coffee land use classes in the images, expertise from other previous works was used (ALVES et al., 2000; ALVES et al., 2003; ALVES et al., 2006; RESENDE et al., 2000; VIEIRA et al., 2000; VIEIRA et al, 2006). After the preliminary visual interpretation, the points of doubt were checked in the field. Although accuracy was not statistically measured, during the field surveys all points of doubt were checked and more than a hundred random points in each study area were collected with a GPS and checked. With the information obtained, the maps were corrected and the final land use maps were produced.

To evaluate the changes of the coffee lands in the study areas, the land use maps of the years 2000 and 2003 were overlayed using SPRING and LEGAL.

The resulting land use maps were reclassified in the classes presented below, which were obtained using the rules presented in Table 1:

- **New Coffee Areas:** shows the areas that were not cultivated with coffee in 2000 but appeared planted with the crop in 2003;
- **Areas of Intersection:** shows areas classified as coffee in the images of both years analysed;
- **Extinct Coffee Areas:** shows areas classified as coffee in 2000 but not in 2003.

The maps were generated in the SPRING SCARTA module and exported to the GIF format in the SPRING IPLOT module. The quantitative data of each thematic map generated was obtained and exported to Microsoft Excel@ software, where the graphs and charts were done.

3 RESULTS AND DISCUSSION

The results are shown in Tables 2 and 3 and in Figure 2. Table 2 shows the total area occupied by the coffee crop in the study areas of Machado, São Sebastião do Paraíso, Três Pontas and Patrocínio. Figure 2 presents the maps resulting from the overlay process and Table 3 shows the quantitative results related to these maps.

As shown in Table 2, a decrease in areas occupied by coffee was observed in São Sebastião do Paraíso and Machado. In Patrocínio, although the area planted with the crop remained unaltered, there was an increase of the areas of productive coffee, demonstrating the constant evolution of the crop and an increase in the area's productivity. In Três Pontas, coffee areas increased and presented the greatest renovation due to the substitution of old fields for newer coffee trees.

It is observed in Table 2 that, in 2003, 22.30% of the total area of Machado was occupied by coffee. It is also observed that, from 2000 to 2003, there was an increase of 5.37% in the areas of coffee in production and a reduction of 7.46% of the areas of coffee in formation/renovation. This shows that the total coffee lands decreased 2.04%. However, the region's production may have increased due to the increase of the areas with productive coffee. Table 3 shows a reduction of the coffee lands of Machado, since the total area of fields with new coffee trees is smaller. The renovation of the coffee lands is presented in Figure 2.

In Patrocínio the coffee lands are also constantly changing. Table 2 shows that the total area cultivated with coffee remained practically the same. Nevertheless, the area's production increased as the fields planted in 2000 started producing. The 2.97% increase of the area of coffee in formation is due to the areas planted after the year 2000 or those in process of renovation (with some type of pruning). The data in Table 3 confirm that there was no significant growth of the coffee lands, although they are clearly changing (Figure 2).

In São Sebastião do Paraíso the coffee lands decreased 2.88%, as presented in Table 2 and confirmed in Table 3, which also shows that the extinct

Table 1 – Model used to overlay land use maps of the years 2003 and 2000 and evaluate the changes in the areas occupied by coffee.

Overlay Classes	Land Use/2000	Land Use/2003
Areas of intersection	Production Coffee + Coffee Formation and Renovation.	Production Coffee + Coffee Formation and Renovation
New Coffee Areas	Forest + Urban Area + Water Bodies + Reforestation+ Other Uses	Production Coffee + Coffee Formation and Renovation
Extinct Coffee Areas	Production Coffee + Coffee Formation and Renovation	Forest + Urban Area + Water Bodies + Reforestation+ Other Uses

Table 2 – Areas occupied by coffee, in km², and percentage of the total study area, for the years 2000 and 2003.

Area occupied by coffee - Years 2000 e 2003								
Study regions	2000				2003			
	Coffee in Production		Coffee in Formation		Coffee in Production		Coffee in Formation	
	km²	%	km²	%	km²	%	km²	%
Machado	71,91	13,49	58,12	10,90	100,50	18,86	18,34	3,44
São Sebastião do Paraíso	64,34	12,37	12,19	2,34	55,45	10,66	6,08	1,17
Três Pontas	51,52	10,09	49,91	9,77	56,50	11,06	63,35	12,40
Patrocínio	49,82	9,58	43,42	8,35	78,29	15,06	15,46	2,97

Table 3 – Quantitative results of the overlaying of the coffee land maps (2003 and 2000) for the four regions studied, according to the classes defined in Table 1.

Results of coffee land maps overlaying – 2003/2000								
	Machado		Patrocínio		São Sebastião do Paraíso		Três Pontas	
Classes	km2	%	km2	%	km2	%	km²	%
Areas of Intersection	80,17	15,04	73,38	13,77	44,92	8,64	91,65	17,94
New Coffee Areas	38,54	7,23	20,38	3,82	16,09	3,09	28,20	5,52
Extinct Coffee Areas	50,40	9,46	19,88	3,73	29,84	5,74	9,78	1,91

coffee areas were larger than the new ones. The reduction of the region's coffee lands is presented in Figure 2.

The coffee lands of Três Pontas today are characterized by old farms that are being renovated, as shown in Tables 2 and 3. Considering the study region's total area, an increase of 3.6% of the coffee areas was observed. Taking into account only the coffee lands, the increase was 15.37%. Figure 2 presents this dynamic.

4 CONCLUSIONS

Although the application of remote sensing for coffee mapping in regional scales still has many theoretical and practical challenges to overcome in order to become more operational, it is recognized that satellite imagery offers the most promising and feasible way for mapping and monitoring coffee lands over large geographical areas, providing the necessary repeatable procedure for analysing the dynamics of this crop's evolution.

The work that has been carried out for the coffee lands of Minas Gerais showed that digital image processing procedures and the GIS SPRING are efficient tools in the evaluation, in space and time, of the dynamics of the coffee areas of the state.

These geotechnologies provided a greater comprehension of the coffee environments of Minas Gerais and helped to create a georeferenced database that, in turn, facilitates agricultural planning.

The evaluation of the crop's evolution indicates different behaviours in each of the coffee production regions analyzed. In São Sebastião do Paraíso and Machado the areas occupied by coffee decreased, in Patrocínio the area planted with the crop remained unaltered and, in Três Pontas, coffee areas increased. These different behaviours, even for the short period studied, illustrate the dynamics of the main coffee production regions of the state of Minas Gerais, emphasizing the need for improved mapping methods. Geotechnologies can be very useful in this process.

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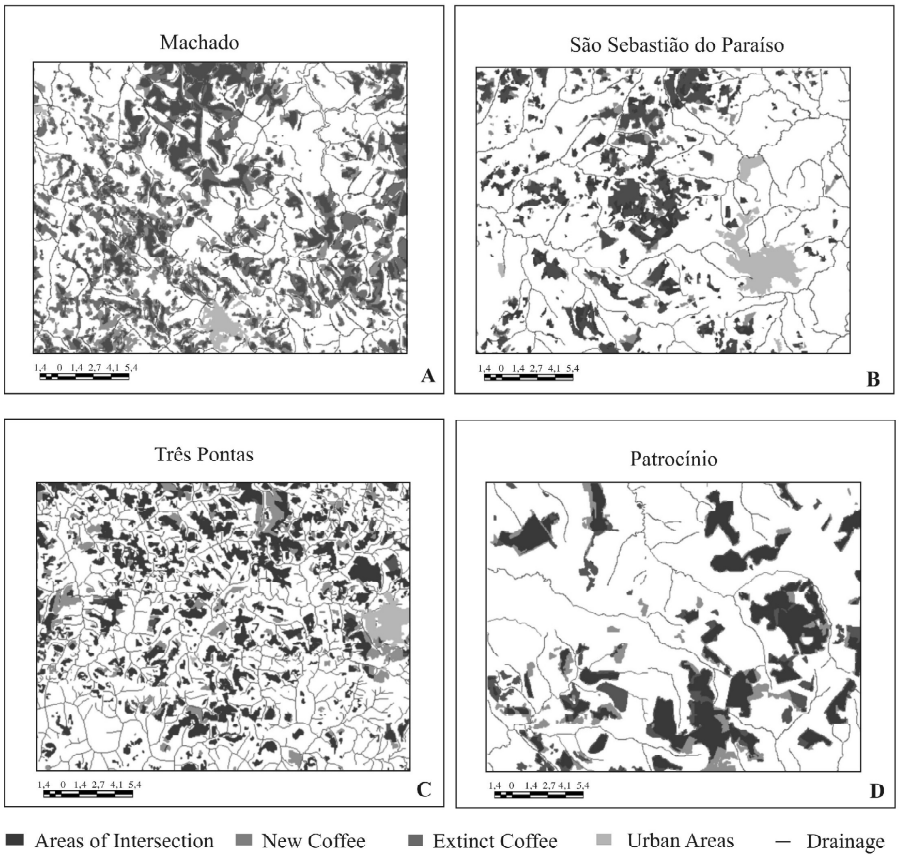

Figure 2 – Changes in the coffee lands of Machado (A), São Sebastião do Paraíso (B), Três Pontas (C) and Patrocínio (D), from the years 2000 to 2003.

GeoSolos, of the Agricultural Research Institute of Minas Gerais - EPAMIG/CTSM.

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