ASSESSING AND MAPPING CHANGES, IN SPACE AND TIME, OF COFFEE LANDS OF THE STATE OF MINAS GERAIS IN BRAZIL

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Technical Commission II

KEY WORDS: Remote Sensing, GIS, Crop Mapping, Land Use, Agriculture Monitoring

ABSTRACT:

Coffee is one of Brazil's most important cash crops due to the incomes generated by exportation. The state of Minas Gerais' production, which represents approximately half of the total national product, is concentrated mainly in its southern and western regions. Although the south remains the main production region, the greatest expansion of the crop has been observed in the west. Due to the changes observed and, as a requirement for future planning, it is important to establish efficient methodologies to map and monitor these fields, with the possibility of an easier periodical updating of the information. The objective of this work was to evaluate the changes, in space and time, of the areas occupied by coffee plantations of Minas Gerais using geotechnologies. Land Use Maps of representative study areas were generated for the years 2000 and 2003 using the software SPRING and Landsat images. The results of the quantitative comparison of these maps indicated different behaviours for the regions. In São Sebastião do Paraíso and Machado, both in the south, a decrease of the areas occupied by coffee was observed, whereas in Patrocínio, western part of the state, the area occupied by the crop remained unaltered. In Três Pontas, one of the most important production areas of the southern region of Minas Gerais, the area with coffee fields increased. Remote sensing and geographic information systems were efficient in the evaluation of the spatial-temporal dynamics of coffee areas of Minas Gerais, providing information that can subsidize regional land use planning.

1. INTRODUCTION

The survey of land use and land cover is fundamental in proposing solutions to the problems of unregulated development and environmental degradation. The analysis and mapping of lands and their uses are based on studies of the physical environment and its evolution dynamics. These studies should be important in the development planning of a determined region to reduce socio-economic losses and to make this a sustainable process in time.

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 to their application. In Brazil, land use data is limited to small areas surveyed for specific purposes. Remote Sensing and Geographic Information System are technologies that can be used to map and characterize coffee areas, providing valuable information for the elaboration of agricultural zoning and planning and for the establishment of evaluation models of land use and occupation (Novo, 1992). Together, they facilitate the study of these dynamics (Vieira et al., 2003).

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, ranging from subsistence farming to small and medium sized farms, with scales of technology ranging from intermediate to high input systems, and to the big agro-industrial enterprises, 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.

The objective of this work was to evaluate, in space and time, the coffee areas of the main producing regions of Minas Gerais using Remote Sensing and Geographic Information System (SPRING). 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 databases that convey valuable information to producers and decision makers.

2. CHARACTERIZATION OF THE 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 regions of Minas Gerais, were chosen. The areas were selected first on the basis of secondary information regarding the importance of the 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. The location

of the four study areas selected for the work are presented in Figure 1.

Machado is one of the main coffee production regions of the State. A representative 520 km^2 area was selected for this study, limited by UTM coordinates 392 000 and 418 000 m E and 7620 000 and 7600 000 m N, zone 23, according to the topographic maps of the Brazilian Institute of Geography and Statistics (IBGE), scale 1:50,000, sheets Machado and Campestre. Its environment is characterized by altitudes ranging from 780 to 1260 meters, mild climate subject to frost, moderate water deficiency, gently to steep slope landscapes, with the predominance of Latosols and soils with argillic horizons. Coffee farmers are predominantly small holders, but with intermediate to high level of technology applied production systems, *i.e.,* farmers use updated technologies that have been recently developed by research in order to produce quality coffees.

Figure 1. Map with the location of the four study regions selected in the state of Minas Gerais

The study area of Patrocínio is outlined by UTM coordinates 278 000 and 304 000 m E and 7942 000 and 7922 000 m N, zone 23, 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 mechanical powered implements to perform all the cropping practices, including the harvest and preparation of the coffee beans.

In São Sebastião do Paraíso, the selected study area is outlined by UTM coordinates 274 000 and 300 000 m E, and 7680 000 and 7700 000 m N, zone 23, 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 by a predominance of undulated to gently undulated landscape and of Red Latosols and Nitosols with high content levels of iron.

In Três Pontas the area chosen for this study is outlined by UTM coordinates 422 000 and 448 000 m E, and 7626 000 and 7646 000 m N, zone 23, encompassing portions of the IBGE topographic maps, scale 1:50,000, sheet Três Pontas. 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, Cambisols. The coffee farming systems are very similar to Machado.

3. METHODOLOGY

The coffee lands and the environments in which they are inserted were characterized and surveyed. Using geoprocessing and remote sensing, a digital 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). From this database, thematic land use maps for the years 2000 and 2003 were generated. The Spatial Language for Algebra Processing (LEGAL) was used to evaluate the changes, in space and time, of each region's coffee plantations.

The following 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 23rd 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.

After the first field survey to select the study regions, a second, more detailed field survey was carried out in each study area. During these field works, systematic surveying and georeferencing of coffee lands were carried out in order 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 classes defined for the mapping were:

- **Production coffee:** corresponds to the coffee fields where the plant canopies covered more than 50% of the soil. Usually coffee fields with 3 or more years of age and plants over 1.5 m height.
- **Coffee in formation/renovation**: corresponds to recently planted coffee fields, under 3 years of age, with partial exposition of the soils and fields that have been pruned for renovation and have also 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.

For the identification of the coffee land use classes in the images, expertise gained from other work carried out before was used (Alves et al., 2000a; Alves et al., 2000b; Resende et al., 2000; Vieira et al., 2000; Vieira et al., 2003). After the preliminary photo interpretation, the points of doubt were

checked in the field. Although accuracy has not been statistically measured yet, 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 in the printed preliminary land use maps. 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 the SPRING GIS. The computer programming language LEGAL was used because, in this way, the overlaying processing is quicker, more precise and can be generated in just one operation.

The land use maps resulting from this process were reclassified in the classes presented bellow, 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.

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

The overlaying maps were generated in the SPRING SCARTA module, exported to the GIF format in the SPRING IPLOT module and are presented in Figures 2, 3, 4 and 5. The quantitative data of each thematic map generated was obtained and exported to Microsoft Excel© software, where the graphs and charts were done. The last step in the methodology was to evaluate the information. This evaluation will be described in the following item.

4. RESULTS AND DISCUSSION

The results are shown in Tables 2 and 3 and in Figures 2, 3, 4 and 5. Table 2 shows the evolution of the coffee crop in the 520 square kilometres study areas of Machado, Patrocínio, São Sebastião do Paraíso and Três Pontas. Figures 2, 3, 4 and 5 present the resultant maps from the overlaying of years 2000 and 2003 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 production 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 plantations.

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. 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 new fields, which substituted the older ones, is smaller. The renovation of the coffee lands is presented in Figure 2.

Area occupied by coffee				
Study Regions	**Coffee in Production**		**Coffee in Formation**	
	km²	**%**	**km²**	**%**
	2000			
Machado	71.91	13.49	58.12	10.90
Patrocínio	49.82	9.58	43.42	8.35
S. S. do Paraíso	64.34	12.37	12.19	2.34
Três Pontas	51.52	10.09	49.91	9.77
	2003			
Machado	100.50	18.86	18.34	3.44
Patrocínio	78.29	15.06	15.46	2.97
S. S. do Paraíso	55.45	10.66	6.08	1.17
Três Pontas	56.50	11.06	63.35	12.40

Table 2. Areas occupied by coffee, in square kilometres and percentage of the total area of each study region in the years 2000 and 2003

Results of coffee land maps overlaying				
	Machado		**Patrocínio**	
Classes	**km²**	**%**	**km²**	**%**
Areas of Intersection	80.17	15.04	73.38	13.77
New Coffee Areas	38.54	7.23	20.38	3.82
Extinct Coffee Areas	50.40	9.46	19.88	3.73
Classes	**S.S. do Paraíso**		**Três Pontas**	
Areas of Intersection	44.92	8.64	91.65	17.94
New Coffee Areas	16.09	3.09	28.20	5.52
Extinct Coffee Areas	29.84	5.74	9.78	1.91

Table 3. Results of the coffee land maps from year 2000 and 2003 overlaying, for the four regions studied, according to the classes defined in Table 1

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 3).

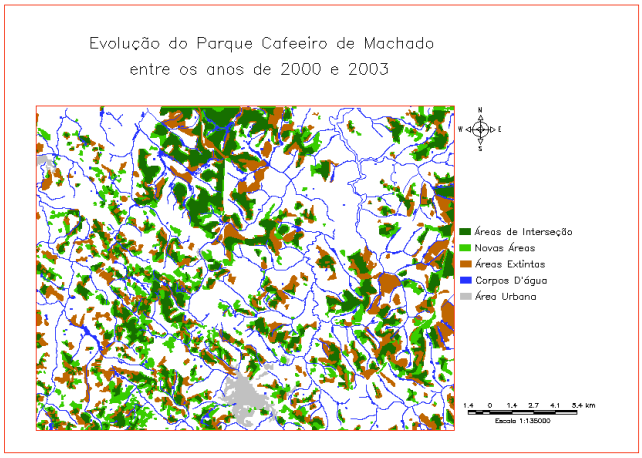

Figure 2. Changes in the coffee lands of Machado from the year 2000 to 2003

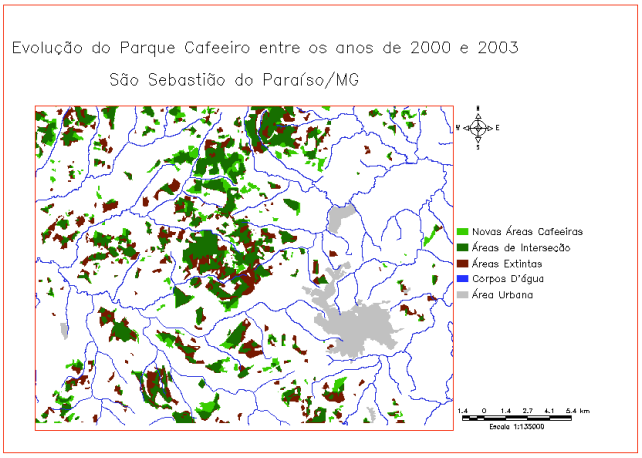

Figure 4. Changes in the coffee lands of São Sebastião do Paraíso from the year 2000 to 2003

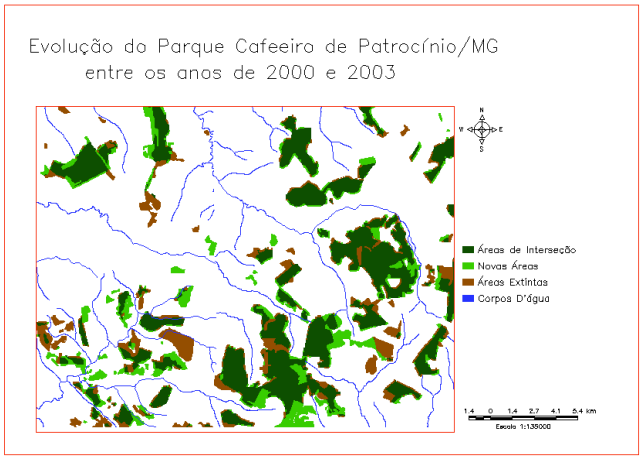

Figure 3. Changes in the coffee lands of Patrocínio from the year 2000 to 2003

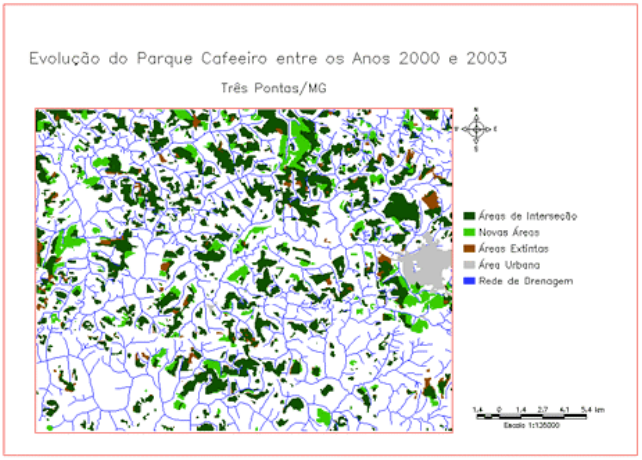

Figure 5. Changes in the coffee lands of Três Pontas from the year 2000 to 2003

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 coffee areas were larger than the new ones. The reduction of the region's coffee lands is presented in Figure 4.

The coffee lands of Três Pontas were, for many years, the largest and most productive in Brazil. Today, they are characterized by old farms that are being renovated, as shown in Tables 2 and 3. In relation to the study region's total area, an increase of 3.6% of the coffee areas was observed. Taking into account only the areas planted with coffee, the increase was 15.37%. Figure 5 presents this dynamic.

5. CONCLUSIONS

Although applications of remote sensing for coffee mapping at regional scales still have many theoretical and practical challenges to overcome in order to become more easily operational, it is accepted 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 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 to be used in the evaluation, in space and time, of the dynamics of the coffee areas of the state, providing valuable information for the analysis of tendencies and future scenarios.

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 and management.

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 illustrate the dynamics of the main coffee production regions of the state Minas Gerais, emphasizing the need for improved mapping methods and knowledge on coffee extent and distribution.

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ACKNOWLEDGMENTS

This work was financed by CBP&C/Café and carried out by the Geoprocessing Laboratory – GeoSolos, of the Agricultural Research Institute of Minas Gerais – EPAMIG/CTSM.