THE USE OF GIS TO ASSESS THE AGRICULTURAL SUSTAINABILITY IN TROPICAL RAIN FORESTS

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ABSTRACT:

Machadinho d'Oeste County (State of Rondônia) has been the target of a long-term study of the agricultural colonization in the Amazonian Rain Forest. Since its implementation in 1982, the characteristics and environmental impacts of the human occupation in this region have been monitored by EMBRAPA-NMA and ECOFORCE using remote sensing and geographic information systems techniques. Created as a settlement project for small farmers (INCRA and World Bank's POLONOROESTE Program), this area has been through alternated periods of prosperity and difficulties. In 1988 it became a county, growing from the initial area of 2,090 sq.km and population of 3,000 families to 11,800 sq.km and over 44,000 inhabitants. Since 1986, around 450 properties have been monitored by satellite images and by geocodified field surveys through 200 agronomical, socioeconomical and environmental variables. Maps of Machadinho d'Oeste were digitized using a Brazilian GIS ("Sistema de Informações Geográficas" - SGI, INPE). This cartographic database was then reclassified according to the relational databases. Virtually 200 maps were generated for each study period. These diachronic data were the basis for the search and identification of sustainability indicators for the farming systems in the agricultural settlement. Thanks to the use of GIS techniques it was possible to define some indicators, to select the best farms in the studied sample according to their performances, and to map all variables, classes of efficiency and indicators.

1. INTRODUCTION

Sustainability has been one of the most discussed and controversial aspects of agricultural policies and development plans. Many things have been said about preservation of productive resources, how to avoid their exhaustion or extinction, how to assess agricultural sustainability, and which criteria and indicators of sustainability to consider in the case of agricultural projects.

In the Amazon Region, the difficulties for implementation and sustainable maintenance of agroecosystems, in areas of tropical rain forest, are generalized.

Thousands of small farmers have moved to public and private settlement projects in that region, particularly in the states of Rondônia and Mato Grosso, during the past 20 years. The environmental impacts caused by their activities have been extensively disclosed, specially deforestation and agricultural burnings (Baena *et al.*, 1985; Teixeira, 1989; Homma, 1993; Engle, 1994).

Due to the dynamics of the Amazonian ecological and socioeconomical systems, the search of sustainable systems for the agricultural colonization projects in the region and their assessment require time and perseverance.

For that reason, concerned with middle and long-term environmental monitoring, a team of researchers from the Environmental Monitoring Center (NMA) of the Brazilian Agency for Agricultural Research (EMBRAPA) and from the non-governmental organization

ECOFORCE - Research & Development has, for the past 10 years, studied the region of Machadinho d'Oeste, in northeastern Rondônia, in order to understand the agricultural transformation of the Amazon and its consequences. Almost 450 small farms have been followed thanks to various institutional arrangements and cooperations, particularly the financing from the International Development Research Centre (IDRC, Canada) and the support from the Red International de Metodología de Investigación de Sistemas de Producción (RIMISP)

These farmers, counting only on luck and on their former experiences, have developed in that region, a big multilocal and multifactor agricultural experiment. The study of their properties allowed the identification of cases of success among them, which could be generalized and serve as examples for social and environmental progress.

Prior publications have thoroughly described, every three years, the agronomical, socioeconomical and ecological characteristics of the agriculture practiced in Machadinho d'Oeste (Miranda, 1987; Miranda *et al.*, 1989; Mattos *et al.*, 1990a, 1990b; De Miranda & Mattos, 1992; Miranda & Mattos, 1992, 1993)

As a result of this 10-year monitoring project, this paper presents the first identification and definition of the systems of production and the agriculturists of Machadinho d'Oeste with the best agronomical, socioeconomical and environmental performances. The use of geographical information systems techniques (GIS) was one of the main tools for this research.

2. OBJECTIVES

The main objectives of this research project were to identify the most sustainable systems of production practiced by the small farmers in Machadinho d'Oeste, Rondônia, from the agronomical, socioeconomical and environmental points of view, and to disseminate the results to other areas in the Amazon.

These main objectives were translated into the following specific objectives for this first phase of the research:

- To characterize the existing systems of production and indicators of their perfomance, based on the data obtained in previous fiel surveys (1986 and 1989);
- To identify the most efficient farms for each type of existing systems of production;

Several methodological developments were necessary to assure that each one of these specific objectives were accomplished, specially the ones related to the mapping of numerical data.

This paper shows the use of GIS as a tool to identify the most sustainable systems of production.

3. MATERIAL

3.1 Machadinho d'Oeste

The Machadinho d'Oeste County had its origin in the former Machadinho Colonization Project. This was implemented by the National Institute for Colonization and Agrarian Reform (INCRA) in 1982, as part of the POLONOROESTE Program and with the World Bank's financial support, in the northeastern part of Rondônia State. It lied between the counties of Ariquemes and Jaru, limited by the geographical coordinates 61°47'-63°00' Longitude West and 9°19'-10°00' Latitude South (Figure 1)

Most of the 2,090 km^2 of the Project's area were dedicated to subsistence agriculture and to small scale animal husbandry: 2,934 50-hectar parcels distributed in 4 big sections. There were also 17 forest reserves (680 km^2), one airport one main urban center and 10 secondary urban centers.

In 1988, when the former Colonization Project was turned into the County of Machadinho d'Oeste, new areas were incorporated (4 other colonization projects and 8 urban centers), growing from the initial 2,090 km^2 to 11,800 km^2. The initial population of 3,000 families also grew to over 44,000 inhabitants in 1991, from which 25% were living in urban areas and 75% in rural areas.

3.2 Equipments, hardware and softwares

It was used for this work the version 2.4 of the "Sistema Geográfico de Informações (SGI-340)", a Brazilian GIS developed by the National Institute of Space Research (INPE).

The basic digital system included:

- PC (central processor 80486 - 16 bits, floating point coprocessor 80487), 180 Mbytes Hard Disk, 5.1/5" and 3.5" Floppy Disk Drivers, 8Mbytes RAM, super VGA color monitor;
- UVI-340 graphic board;
- 1024x768 image visualization unit, 256 levels and 8 bits/pixel;
- A0 digitizing tablet;
- A4 scanner;
- color electrostatic plotter;
- laser printer.

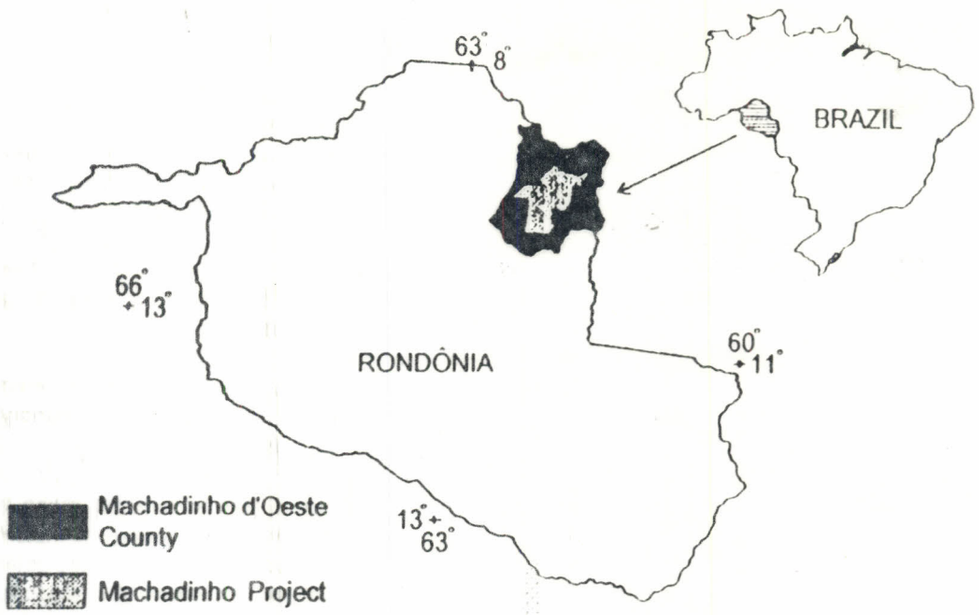

Figure 1. Location of Machadinho Colonization Project and Machadinho d'Oeste County

The following softwares were also used for word processing, desktop publishing, charts and graphics construction: Microsoft Word 5.5, Quattro Pro 1.01, Xerox Ventura Publisher, Windows 3.0, DOS 5.0. The databases were made with DBase III Plus and the statistical treatments with SAS and SOC ("Software Científico" - EMBRAPA/NTIA).

3.3 Cartographic material and satellite imagery

The basis for all maps generated through GIS was the INCRA map for the Machadinho Project, at the scale of 1:100,000 (INCRA, 1985).

Landsat images of different dates and scales were also used.

Landsat MSS paper images:

Orbit/Point	Date	Bands	Scale
248/67	Jun 18, 80	4	1:250,000
248/67	Jun 18, 80	5	1:250,000
248/67	Jun 18, 80	7	1:250,000

Landsat TM5 paper images:

Orbit/Point	Date	Bands	Scale
231/67	Aug 7, 85	2	1:250,000
231/67	Aug 7, 85	3	1:250,000
231/67	Aug 7, 85	4	1:250,000
231/67	Jul 30, 88	3	1:250,000
231/67	Jul 30, 88	4	1:250,000
231/67	Jul 30, 88	5	1:250,000
231/67	Jul 30, 88	3/4/5	1:250,000
231/67	Aug 5, 90	3/4/5	1:250,000
231/67(QA)	Jul 30, 88	3/4/5	1:100,000
231/67(QB)	Jul 30, 88	3/4/5	1:100,000
231/67(QN)	Aug 5, 90	3/4/5	1:100,000

4. METHODS

4.1 Characterization of the existing farming systems

In December 1986 and September 1989, field surveys were conducted on a random sample of 45% of Machadinho d'Oeste's effectively occupied properties. The farmers were interviewed and the structures and systems of production were analised: 438 farms in 1986

and 489 in 1989. The same questionnaires were used in both years to collect the data, consisting of almost 200 variables:

- location variables (12),
- socioeconomical variables (83),
- agronomical variables (30 for each one of the crops and 14 for animal husbandry).

Two big numerical databases were generated with DBase, one for 1986 and another for 1989. They were used as starting points for this work.

The numerical data were digitized and statistically treated, generating detailed agronomical and socioeconomical profiles of the agriculturists and their systems of production (Miranda, 1987 and Miranda & Mattos, 1993).

4.2 Definition of some indicators of performance or efficiency of the systems of production

After characterizing the main existing systems of production, an assessment of their performances and sustainability was conducted.

The methodology for definition of the indicators of performance and sustainability consisted of the following steps:

A - Discussion and definition of the aspects that should be sustainable;
B - Identification of the potential indicators of sustainability for these phenomena, based on the available data;
C - Selection and evaluation of the indicators to be quantified, based on the existing data;
D - Preliminary exploration of the potential uses of the indicators for different types of dischronic and synchronic analysis.

In order to initially classify the systems of production practiced in Machadinho, 10 indicators of agronomical, socioeconomical and environmental performances were selected or constructed based on the 200 variables stored in the numerical databases:

1. level and stability of maize productivity (kg/ha),
2. level and stability of rice productivity (kg/ha),
3. level and stability of beans productivity (kg/ha),
4. value and stability of cultivated area per active person in the family (ha),
5. value and stability of cultivated area per person in the family (ha),
6. value and stability of pasture area per active person in the family (ha),
7. value and stability of pasture area per person in the family (ha),
8. deforested area per active person in the family (ha),
9. deforested area per person in the family (ha),
10. percentage of the property deforested.

It was considered as active person in the family those from 5 to 60 years old, who were economically productive in the farm. The deforested areas comprised cultivated areas, pasture and second growth vegetation areas.

4.3 Arrangement of the properties based on the efficiency of their systems of production, according to the pre-selected and quantified indicators

For each one of the indicators, 355 farms were ordered according to their agricultural, labor, animal husbandry and environmental performances.

Contingency tables were generated in order to make a first selection of the farms that presented simultaneously good agronomical, socioeconomical and environmental performances. With this exclusively numerical procedure, about 10% of the properties were selected as having good performances.

These 36 farms were then revisited in 1993 to confirm their efficiency and to validate the selected indicators.

4.4 Spatialization of the limits and classes of the systems of production's efficiency, through GIS

Simultaneously and complementarly to the numerical analysis and classification of the systems of production, GIS techniques were used to map the studied variables, indicators, and generated results.

Thematic maps of Machadinho (soils, vegetation, infrastructure, hidrography...) were digitized at the scale of 1:100,000 using the Brazilian GIS "SGI", developed by National Institute of Space Research (INPE).

Using as reference the INCRA map for the parcels' limits (INCRA, 1985), a digital cartographic database was generated at the scale of 1:100,000 (Figure 2). The data input was carried out with a keyboard and a digitizing tablet with 0.1 mm accuracy.

This geocodified database was reclassified according to the numerical data from 1986 and 1989. Effectively, 118 maps of the main numerical indicators were thus generated for each study period. But virtually, a greater number of maps are available through GIS.

Each one of these maps was then analysed as for the results obtained in the previous phase of the work. The objective was to identify any spatial pattern that could influence the distribution of the sample, such as areas

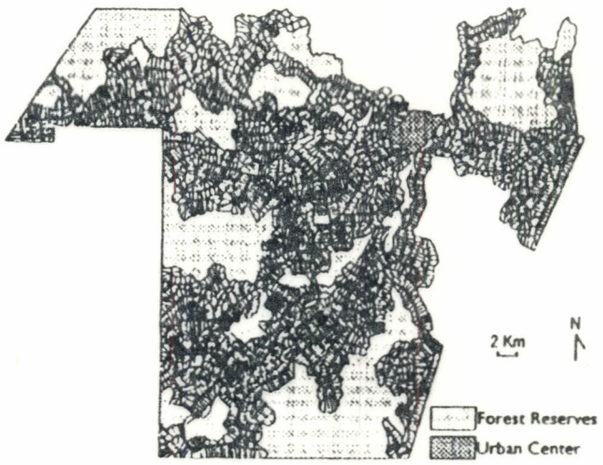

Figure 2: Farms' limits in Machadinho d'Oeste.

with extremely fertile or unsuitable soil types, drainage patters, distance to urban centers, etc.

Remote sensing techniques were also used for a precise evaluation of the region's evolution. Landsat/TM5 and MSS images were analogically interpreted in order to characterize the land uses and their recent spatial progression.

5. RESULTS

Almost 200 maps such as figure 3 were generated by GIS for each study period (1986 and 1989).

Thanks to the use of GIS it was possible to constitute preliminary groups of farms with good performances, based on the indicators used. Contingency tables were made to cross different types of performance, groups of properties, structures and periods of production (crossings were made both in one and two of the study years). During this analytical process of synthesis, several essays were made, both numerical and cartographical, using GIS.

A final analysis of the various arrangements of the farms, GIS maps, contingency tables and classes of agronomical, socioeconomical and environmental performances allowed the identification of 5 groups of good-performance farms:

Group 1: Properties with good agronomical performance only;

Group 2: Properties with good agronomical and labor performances, simultaneously;
(groups 1 and 2 consist of properties with not very diversified systems of production and that do not explore their natural resources excessively)

Group 3: Properties with good agronomical, labor, environmental and animal husbandry performances (usually this group includes properties with more diversified systems of production, that cause more serious environmental impacts than those of groups 1 and 2);

Group 4: Properties with good animal husbandry performance, usually their main activity;

Group 5: Properties with good performance of only one isolated cultivation system but not of all the production systems.

6. CONCLUSION

The agriculture practiced in the tropical rain forest is extremely diverse and complex. To assess its sustainability it is necessary to work with a large number of agricultors, for a long period of time, and to use many variables.

The construction of a digital cartographic database for a sample of 450 farmers in Machadinho d'Oeste helped to assess the agricultural sustainability of their systems of production between 1989 and 1993:

- it allowed to generate almost 200 maps for each study period;
- it guaranteed the study of the spatial distribution patterns of the performance indicators;
- it helped to integrate the agronomical, socioeconomical and environmental variables in geocodified databases, besides numerical ones

This work, that already covers the periods of 1986, 1989 and 1993, will be prolonged for more 10 years.

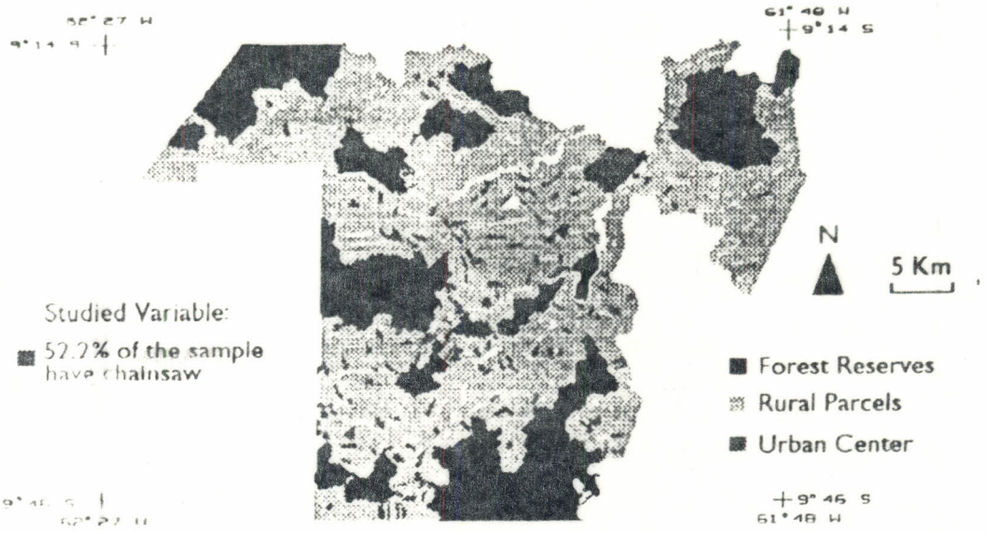

Figure 3 Example of the mapping of studied variables and indicators using GIS.

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