CHAPTER 4 - LULC DYNAMICS: THE COLONIZATION IMPACT

‘A época da rapadura passou. Agora é a do chimarrão.

Mas o chimarrão é amargo, a rapadura é doce.

Só que a rapadura é doce, mas não é mole…’

4.1 - Geotechnologies and LULC dynamics in Amazônia: potentials and pitfalls

The enhanced capabilities in terms of data production and methods of analysis for Earth surface feature information have led to new approaches and to a more integrative vision about LULC change within and across research sites (Burrough and Frank 1995). Using multi-temporal satellite data allows a better understanding about the dynamics of deforestation, land abandonment, pasture conversion, agriculture, and secondary succession within rural landscapes in transformation (Lambin 1997). In Amazônia, the study of LULC change and its human dimensions through the use of geotechnologies may contribute to a more sustainable development of communities under investigation.

Remote sensing and geoprocessing techniques have allowed the integration of spatial data at several scales (Quattrochi and Pelletier 1991, Fotheringham and Rogerson 1995). The generation of global- and local-scale data, the reworking of historical data sets, and some programmatic aspects of land database development have become fundamental themes to the research community (Goodchild et al. 1992, Justice et al. 1995). This has highlighted the mutual benefits of closer links between Geographic Information Systems (GIS) and methods of spatial data analysis. The evolution of these tools has consolidated important elements to solve environmental problems and help decision-making tasks (Coulson et al. 1991). The possibility of testing spatial models through the use of georeferenced databases and algorithms to measure spatial heterogeneity has opened new pathways to research issues such as LULC dynamics in Amazônia.

The increasing interest in ecosystems spatial dynamics have led to the need for new quantitative methods capable of analyzing patterns, determining the importance of spatial processes, and developing models about landscapes (Gardner and Turner 1991, Fortin 1999). Thus, ecological studies have described landscape features in terms of number, diversity, distribution, complexity, and dispersion of their spatial elements (Jurdant et al. 1977, Domon et al. 1989, Robbins and Bell 1994).

Advanced airborne and satellite technologies, image processing and analysis, and extensive capabilities to analyze spatial data through GIS and associated software has catalyzed the development and test of new quantitative methods of spatial assessment (Goodchild et al. 1993, Sample 1994, Burrough and McDonell 1998). The variety of aerial and orbital data in distinct spatial, temporal, and spectral resolutions have required the generation of digital image processing techniques in applications related to the characterization and management of natural resources (Johannsen and Sanders 1982, Szekielda 1988, Richards 1993, Jensen 2000, Lillesand and Kiefer 2000). By the same token, GIS packages have integrated an always increasing and diverse amount of spatial information (Maguire et al. 1991, Dangermond 1992, ESRI 1997, DeMers 2000).

In the Amazon, several applications have been implemented at regional and local scales. The first systematic survey about natural resources for the entire region used side-looking airborne radar (Radambrasil 1972). Experts interpreted an impressive number of images to map geology, geomorphology, soils, vegetation, and other themes. This multitask survey took more than ten years to accomplish the manual compilation of data in several layers for 335 sheets at 1:250,000 scale. Since that initiative, the technological advances mentioned above have taken place, together with the pressing need to understand and monitor recent ecological changes occurring in the region in the wake of development efforts.

Many Amazonian issues have attracted a great deal of attention during the last thirty years. Deforestation is among the most important of them. The Brazilian Amazon has been deforested at an average rate of approximately 0.5% per year (Skole and Tucker 1993, INPE 2000) as a result of several factors, including road building, colonization programs, land speculation, and demographic and geopolitical reasons. Besides being a very large area, the process is complex due to environmental heterogeneity, distinct socioeconomic factors affecting LULC outcomes, and strategic interests at several decision-making levels.

GIS and associated software provide a data structure to efficiently store and manage ecosystems data for large areas; enable aggregation and disaggregation of data between multiple scales; locate study plots and/or environmentally sensitive areas; support spatial statistical analysis of ecological distributions; improve remote sensing information-extraction capabilities; and provide input data and parameters for ecosystem modeling (Haines-Young et al. 1996). Aware of the potential of integration between remote sensing, GIS, and associated software, and based on an international concern about possible broad-scale environmental effects due to the conversion of tropical rain forests, research teams have carried out distinct initiatives. These initiatives include the study of climatic and meteorological mechanisms of interaction between the rain forests and the atmosphere; the rates; extension and possible consequences of deforestation processes; the biogeochemical cycles in the region; the ‘greenhouse effect’ of trace gases; the human dimensions of LULC change; and landscape structure, function, and dynamics (Hall et al. 1996).

Several questions have arisen: When, where, and why is deforestation taking place in Amazônia and what are its consequences? What happens after deforestation? Is the amount of carbon uptake from secondary successional vegetation comparable to the amount of carbon released by deforestation? When and where is deforestation and secondary succession likely to be detected by using remotely sensed digital data? Which sensors and techniques will be necessary to achieve accurate results for these research questions?

The integration of statistical numeric and georeferenced spatial data is an important topic in geographic information science and has been one of the bases of broad-scale research initiatives in the Amazon. Procedures take into account the relationships of predefined regions in space with attributes derived from numeric variables (Bastedo and Theberge 1983, Goodchild and Brusegard 1989, Kareiva 1994). This is not a trivial question when working with the Amazon, mainly due to the diversity of data, inconsistency between different sources, heterogeneity of data collection methods, and differences in presentation of data (scale, legend, material, format, and quality) (Davis et al. 1990, Wickhman and Norton 1994, Burrough and Frank 1995).

Recent development of remote sensors, GIS tools, and associated software (e.g., database management, programming languages, and spatial analysis) has facilitated the achievement of results with significant precision and accuracy, based on objective procedures (Burrough and McDonnel 1998, Lillesand and Kiefer 2000). These techniques have allowed assessment of the spatial organization of Amazonian agroecosystems and natural resources, defining potentials for conservation and development (Coulson et al. 1991).

From this point of view, land zoning is one of the most important recent applications of GIS and associated software, yielding a better management of natural resources in Amazônia. Some states (e.g., Rondônia, Tocantins, and Maranhão) already have an extensive database generated in a GIS and based on 1:250,000 maps. They include several layers of information and synthetic maps defining areas with distinct potentialities for conservation, management, agriculture development, and urbanization (Bognola and Miranda 1999, Miranda 1999, Olmos et al. 1999, Rondônia 2000). All these initiatives used Landsat TM images to produce LULC maps.

Other examples of GIS applications include the spatial analysis done by Alves (1999) and Alves et al. (1999). Making use of maps produced through visual interpretation of Landsat TM images at 1:250,000 scale (INPE 2000), the authors analyzed geographical patterns of deforestation for states, municipalities, and road buffers. Twenty-five percent of the total deforestation was found in less than 4% of the cells and 50% of the total deforestation in less than 10% of the cells. Forty percent of the cells amassed 95% of the deforestation, and 86% of the total deforestation in Amazônia was found within 25 km from areas already deforested in 1978. This is the typical case where geotechnologies were central for the achievement of results at regional scale, showing the concentration of processes of LULC change along roads.

Skole and Tucker (1993), also using Landsat TM images and GIS integration, mapped LULC change for the entire Brazilian Amazon. Deforestation, fragmented forest — defined as areas smaller than 100 km^2 surrounded by deforestation —, and edge effects — within 1 km into forest from adjacent areas of deforestation — were measured for 1978 and 1988. The results showed that deforestation increased from 78,000 km^2 in 1978 to 230,000 km^2 in 1988, while tropical forest habitat, severely affected with respect to biological diversity, increased from 208,000 km^2 to 588,000 km^2. Besides reaffirming the concentration of deforestation processes, the findings supported analyses on the human dimensions of colonization within the region (Skole et al. 1994).

Miranda et al. (1994) used a grid approach to monitor Amazonian fires. They have followed the spatial-temporal magnitude of the phenomenon for almost ten years, counting burning spots indicated by the thermal bands of (National Oceanographic and Aerospace Administration (NOAA) satellites. Although technical problems are always associated with these estimates (Setzer and Pereira 1991, Setzer and Verstraete 1994), the results achieved so far have defined the seasonality, timing, and interannual variations of fires in the region. Recent initiatives are using a multiple sensors for estimating biomass burning at a regional scale (Eva and Lambin 1998).

Another recent application for the entire region is the link of satellite, census, and survey data done by Wood and Skole (1998). The project looks for general trends in deforestation, using regression analysis on socioeconomic variables and GIS database links to census data.

Several other research initiatives using remote sensing and GIS techniques have taken place at distinct sites and more detailed scales in the Amazon. Studies of physical, biological, and social processes have helped understand how human decisions affect local and regional land use (Mausel et al. 1993, Moran et al. 1994, Skole et al. 1994, Brondizio et al. 1996). Nepstad et al. (*Flames* 1999) show the role of logging and fire on the impoverishment of Amazonian forests. A myriad of articles discuss the use of new sensors and techniques to monitor LULC within the region (Adams et al. 1995, Foody et al. 1996, Steininger 1996, Rignot et al. 1997, Saatchi et al. 1997, Yanasse et al. 1997, Lucas et al. 1998).

Following this literature, my research about colonization impacts in Rondônia is a contribution to the use of geotechnologies in spatial-temporal assessments of LULC. Producing multi-temporal information about two distinct settlement designs (i.e., Machadinho and Anari) may improve the capability to include detailed LULC information in regional- and global-scale simulation models through the use of accurate landscape- and property-based data. My goal is to use this research to stimulate a rethinking of settlement designs in the Amazon.

4.2 - Methodological approach

Few political initiatives have had the social, economic and environmental impact of rural colonization projects in the Brazilian Amazon. Despite its importance, examples of planning and monitoring of settlements in the region using geoprocessing techniques to understand the trajectory of those landscapes in transformation are rare. This chapter builds on research carried out at Indiana University, through a framework based on the integration of remote sensing data and anthropological and ecological research in a geographic information system that allows spatial and temporal analyses in several levels and scales. The main goal of this initiative is to understand LULC dynamics in Machadinho and Anari, enriching the debate about planning and monitoring strategies of rural settlements in Amazônia.

In general terms, the methodological approach involved the need to investigate colonization processes within the study area and their environmental implications regarding LULC change. Thus, I intend to explain relationships between LULC dynamics and agroecological processes underlying landscape transformation. Remote sensing, GIS, and spatial analysis played a central role in providing elements for discussion. But how should one distinguish different units of analysis composing a settlement? This hierarchy depends on consideration of the mosaic of patches characterizing the settlement. In Amazonian rural settlements, the biophysical compartments, the socioeconomic context, and the spatial-temporal arrangements of occupation delimit fundamental units of analysis. Within this chapter, findings are presented with emphasis on settlement landscapes, reserves, buffers around roads, and property lots. The analytical strategy, summarized in Figure 47, includes several modules described as follows:

- Questions to be addressed, units of analysis, and level of detail for collection and integration of data;
- Remote Sensing Module: data definition and processing techniques for extraction of information related to LULC in a multi-scalar and multi-temporal basis;
- Statistical Module: numeric analysis of data through descriptive and inferential statistics;

- GIS Module: manipulation of spatial databases generated by the previous modules;
- Analysis and Synthesis Module: integration of spatial and numeric data to answer the research question.

4.2.1 - Multi-temporal analysis: What need have I for this?

It has been shown that deforestation trajectories in Amazonian settlements follow cycles related to stages of establishment, expansion, and consolidation of rural properties. The magnitude of these pulses is a function of lot allocation and condition, time of occupation, structure and composition of the domestic unity, and credit policies (Brondizio et al. in press).

In order to capture the spatial-temporal dynamics regarding LULC changes in Machadinho and Anari, I used satellite images beginning in 1988. This allowed the detection of earlier stages of lot occupation and deforestation, five years after the settlements' implementation. Starting with 1988, a ten-year period was defined to carry out the multi-temporal analysis. The choice of image dates and period of analysis was dependent on several factors. The goal was to depict deforestation processes and conversion to farmland, as well as vegetation regrowth to older stages of secondary succession. For this purpose, images dated 1988, 1994, and 1998 were used. The images were selected after a careful analysis of Landsat TM data availability, cloud cover, and data quality. All images were acquired in June, during the dry season, to allow a better differentiation between forest lands, areas in succession, and farmlands. Collection of training samples during fieldwork was carried out in 1999 and 2000 from June to August, also during the dry season.

4.2.2 - Pre-classification techniques

Several pre-processing techniques were carried out prior to LULC classification. The first step was to correct geometric distortions present in the raw Landsat TM images. Geometric rectification is the process of image adjustment to a pre-established coordinate system (Lillesand and Kiefer 2000). A multi-step procedure was used to maintain consistency during the rectification process. First, the three images were registered together based on control points identifiable in all of them. Then, all bands of all images were combined in a single file and geometrically rectified based on control points taken from topographic sheets at 1:100,000 scale using a UTM projection. The algorithm used for coordinate transformation was *nearest neighbor*, which applies a regression model to determine the coefficient for the transformation equations in x and y. The resampling technique directly assigns the digital number (DN) in the input file that most overlaps the pixel in the output file, maintaining its value (Richards 1993). The RMS (Root Mean Squared) error in all steps was always smaller than a half pixel.

Once geometrically rectified, the images were separated to perform atmospheric correction. When using multi-temporal TM data, atmospheric conditions can vary significantly both spatially and temporally as a result of molecular scattering and absorption. The objective of atmospheric correction was to convert remotely sensed digital numbers (DN) to ground surface reflectance in order to make the data spectrally comparable (Green et al. 2000). There are several methods addressing atmospheric correction issues (Markham and Baker 1986; Chavez 1988, 1996; Vermote et al. 1997). Some of the most accurate methods involve physically based models, which require atmospheric data coincident with remote sensing data acquisition. However, when these data are unavailable, image-based models are recommended. So, the Improved Image-Based Dark Object Subtraction (DOS) model was used (Lu et al. in press). The algorithm takes the atmospheric scattering and absorption into account, correcting the effects caused by path radiance and part of the atmospheric transmittance. The process can be used for atmospheric correction of remotely sensed data, especially for historical image data when atmospheric data are not available. The model is expressed by:

$$R_{\lambda} = p * (L_{\lambda sensor} - L_{\lambda haze})/(TAUv * Esun_{\lambda} * COS(\theta) * TAUz),$$ where:

R_{λ} is the surface reflectance

λ is the wavelength

p is a constant (3.141592)

$L_{\lambda sensor}$ is the apparent at-satellite radiance

$L_{\lambda haze}$ is the path radiance

TAUv is the atmospheric transmittance along the path from the ground surface to the sensor

$Esun_{\lambda}$ is the exo-atmospheric solar irradiance

θ is the sun zenith angle (or 90^{o} – sun elevation angle)

TAUz is the atmospheric transmittance along the path from the sun to the ground surface

After geometric rectification and atmospheric correction, subsets were produced using the settlements' boundaries. Figure 48 summarizes the procedures described so far.

4.2.3 - LULC classification

The transformation of spectral data into information through the extraction of thematic features has been traditionally done through classification techniques. Several textbooks present techniques for *supervised* or *unsupervised* classification, but they do not always indicate the need of emphasizing specific characteristics of each application (Woodcock and Strahler 1987).

The main difference between supervised and unsupervised classification is that the former requires the identity and location of some of the land cover to be known (Mausel et al. 1990), while the latter is based on automatic clustering of pixels with similar spectral characteristics according to statistically determined criteria (Jensen 1996).

The unsupervised classification requires only a minimal amount of initial input from the analyst. However, knowledge about the spectral characteristics of the terrain is necessary to label certain clusters as representing land-cover classes (Landgrebe and Biehl 1995). The supervised classification requires much more input from the analyst, including the collection of training samples, the generation of graphic methods for feature selection, and the selection of appropriate classification algorithms (Lillesand and Kiefer 2000).

Results obtained from the single use of standard classification techniques are not always sufficient, mainly in studies involving complex LULC features (Myers et al. 1989). An alternate approach to increase information content from original and enhanced data is to implement improved classification techniques and methods of analysis. It has been demonstrated that hybrid classification systems are frequently appropriate not only to track past deforestation, but also to see future trends of new agroecological processes (Lucas et al. 1998, McCracken et al. 1999, Brondizio et al. in press).

The method used for LULC classification in Machadinho and Anari was an example of hybrid solutions. The first step was to build a hierarchical classification system based on vegetation structure and physiognomy. The criteria for class definition used a multi-level approach (Anderson et al. 1976) and an official Brazilian classification system for vegetation features (Veloso et al. 1991). Table 12 summarizes LULC classes encountered during fieldwork. For the final classification, the first-level classes were adopted, except for secondary succession, for which two classes were used, as indicated by the results presented in Chapter 3. So, the final classes were: mature forest, advanced secondary succession, initial secondary succession, pasture, agriculture, bareland, infrastructure, and water. In 1988, just one class of regrowth was used. After just five years of settlement implementation, the advanced secondary succession stage would not be present.

The hybrid classification approach consisted of building spectral signature files derived from both unsupervised ISODATA techniques (ERDAS 1998) and supervised classification using training samples collected during fieldwork. All training samples were accurately integrated in the GIS/remote sensing environment through the use of a GPS (Global Positioning System) and associated software. The training sample protocol and fieldwork data collection was already described in Chapter 3. An important part of the process was to carry out interviews with local people to inform the classification of images dated 1988 and 1994.

Separability analysis on the signature files (ERDAS 1998) and analysis of vegetation structure (Brondizio 1996) were used to select the best signatures during the classification process. The spectral curves for all classes in each date show the responses obtained after all techniques used (Figures 49, 50, and 51). Once the best signatures had been selected, a maximum likelihood classification (Jensen 1996) was carried out for each date.

4.2.4 - Post-classification procedures and GIS manipulation

One of the main problems when classifying complex LULC features in the Amazon is related to the spatial configuration of agricultural fields, pasture, and different stages of secondary succession. Both the relatively small size of these patches and the mixed spectral responses of pixels representing their classes are responsible for data misclassifications. Recently, several initiatives have been implemented to overcome these limitations, including the use of data with higher spatial resolution (e.g., IKONOS), non-optical sensors (Rignot et al. 1997, Saatchi et al. 1997), the integration of detailed field data to support the classification process (Mausel et al. 1993, Li et al. 1994, Brondizio et al. 1996, Lucas et al. 1998), the use of spectral mixture analysis (Adams et al. 1995), object-based classifiers (Foody et al. 1996), indices (Steininger 1996), and hybrid techniques. Other problematic land covers to differentiate in the study area are the road network and urban areas. They are often confused with agricultural bare soil because most roads and urban areas are unpaved.

After going through the procedures described in the previous section, some adjustments were necessary to achieve a higher accuracy for the final LULC classifications. First, a 3 x 3 pixels neighborhood filter based on the majority rule was used to remove isolated pixels (ERDAS 1998). The procedure was carried out for all dates using identical rules and produced better cartographic results for the scale of study. To better map roads, urban areas, and rivers, topographic maps and visual interpretation were used to improve the classification in a GIS environment. Field notes and observations about LULC in the study area were always useful to inform decisions about the technical procedures to use.

The results were tested through accuracy assessment. A common method for classification accuracy assessment is the error matrix. The error matrix compares the relationships between ground-truth data (reference data) and classified results category-by-category. From the error matrix, some important measures can be derived, such as overall accuracy, producer's accuracy, and user's accuracy. Many works have provided the meanings and calculation methods for these measures (Congalton 1991, Richards 1993, Janssen and Wel 1994, Campbell 1996, Jensen 1996). Another method to interpret the classification accuracy is to calculate Kappa coefficients (Ma and Redmond 1995, Jensen 1996, Kalkahan et al. 1997). It measures the difference between the agreement between reference data and classification results and the chance of agreement between the reference data and a random classifier. The Kappa coefficient is computed as

$$KAPPA = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(X_{i+} * X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} * X_{+i})},$$

where r is the number of rows in the error matrix, X_{ii} is the number of observations in row i and column i in the error matrix (i.e., the corrected classified number), X_{i+} and X_{+i} are the marginal total in row i and column i respectively, and N is the total number of observations included in the error matrix.

The results for the accuracy assessment of LULC classifications are listed in Table 13. Relatively higher values were found for the 1988 and 1998 classifications. The higher accuracy in 1998 is certainly due to the greater control over field data collected in 1999 and 2000. A considerable number of training samples were selected for this date based on ground truthing. In 1988, the use of just one class of secondary succession was responsible for a better discrimination between classes.

After accuracy assessment, the classifications were integrated in a GIS to allow further manipulations and analyses. Areas were tabulated for each class and date. Transition matrices were performed to answer specific questions on LULC dynamics in Machadinho and Anari. Buffers of 100 m, 200 m, 400 m, and 800 m were created around the road network for manipulations and area calculations within these landscape corridors. Analyses with and without the extractive reserves in Machadinho were performed. Property grids were digitized for both settlements, allowing the extraction of LULC information at the property level. Layouts, tables, and graphics were produced, as presented in the next sections.

4.3 - Land-Use/Land-Cover (LULC) dynamics

4.3.1 - Machadinho and Anari: general spatial trends in LULC

Comparison of LULC classes between the two settlements reveals striking differences in landscape change (Table 14). During the early stage of implementation, both settlements had similar percentages of forest and pasture (about 87% and 6%, respectively). Ten years later, forest cover dropped to 51% in Anari in contrast to 66% in Machadinho. Figure 52 shows the forest cover through time in Machadinho and Anari.

Forest conversion was also different in both areas. In Anari, pastureland increased threefold, while in Machadinho it increased less than twofold (10% of the landscape). While agricultural areas are also larger in Anari (10.3%), Machadinho shows a faster growth of this activity (just 1% in 1988 in comparison to 7% in 1998). According to landowners in both settlements, the condition of agricultural fields is better in Machadinho. This is confirmed by official indices, suggesting a better management of cropland by landowners at this settlement. For example, the productivity of corn in Machadinho is 1,200 kg/ha while in Anari it is just 1,000 kg/ha (IBGE 2000b).

An indication of a slightly higher percentage of abandonment of agricultural fields as well as pasture areas in Anari is indirectly depicted by the total percentage of vegetation regrowth (initial and advanced secondary succession): 16.8% in Anari opposed to 13.5% in Machadinho. If we consider that a remarkable amount of area under vegetation recovery is effectively used for cattle ranching, the trend of Anari for pasture extensification becomes even clearer. Figure 53 shows the dominance of pasture conversion in Anari in contrast to more balanced relationships between LULC categories in Machadinho.

Cartographic outputs and field data reveal LULC spatial patterns within the settlements. In Machadinho, small agricultural fields (mainly coffee plantations) predominate at the central portion of the settlement, on both sides of the Machadinho River. The extractive reserves play an important role in maintaining forest cover (Figure

54). Larger patches of pasture occur mainly within the peri-urban area, in the northern portion of the settlement and along main roads MC-06 (east) and MC-07 (north). Patches of initial secondary succession are often associated with these locations (Figure 55).

In Anari, larger patches of pasture are found in the south and along the main road. Secondary succession is also associated with these areas. The largest patch of pasture at the southeastern border of the settlement indicates land aggregation processes. To the north, along the boundary with Machadinho, small agricultural fields occur, as well as pasturelands in the intersection of the main road and the feeder roads (Figure 54).

4.3.2 - Deforestation, production, and secondary succession: different processes

Different agroecological processes occur in Machadinho and Anari. Deforestation represents the human action to clear the land for production or speculation. Secondary succession is the continuous response of nature through vegetation regrowth whenever humans abandon cleared areas or gaps are formed within forests. The section above showed how LULC changed through time but did not analyze processes of change themselves. This section answers specific questions related to deforestation, production, and succession. What is the pace of deforestation in Machadinho and Anari? Is the deforested land under production or abandonment? How much and when was the deforested land abandoned for succession?

The cartographic result showing land-clearing processes in the study area is illustrated in Figure 56. Areas in southern Anari with no data for 1988 and 1994 represent only 11% of the settlement. It is obvious how the process is associated with the road network, as described further in Section 4.3.4 through buffer analysis. Deforestation before 1988 follows the roads consistently. Colonists in both settlements started to clear their properties as soon as they had access to the land along these paths. The urban area of Machadinho, located in the northeastern limits of the settlement, was also established before 1988. The village of Anari was embedded in a square located between the second and third feeder roads from the north. Deforestation during 1988-1994 and 1994-1998 expanded from the patches cleared before 1988.

Figure 57 illustrates graphically the different paces of deforestation in Machadinho and Anari. Water was not represented (less than 0.5% in both settlements). The period between 1988-1994 showed higher rates of deforestation (13% in Machadinho and 19% in Anari). This is due in part because this period is longer than the period from 1994 to 1998. For the entire period of analysis, Anari's rates of deforestation are always higher than Machadinho's. Moreover, in Machadinho the rates are the same before 1988 and between 1994 and1998 (11%). In Anari, these rates increased from 13% to 16% during the same periods.

The recoding process to answer questions about secondary succession was more complicated. To answer these questions, the original LULC classifications were recoded to four classes: forest, secondary succession (SS1 and SS2), production (pasture, agriculture, and bareland), and others (infrastructure and water). Then, these classes were combined using transition matrices (ERDAS 1998). Secondary succession in Machadinho and Anari follows cycles of clearing and abandonment of production fields. Thus, these two processes (i.e., expansion of production fields and vegetation regrowth) were used as guidelines for the definition of final transition classes (Table 15).

Following deforestation, patches for production since 1988 and 1994 are located closer to roads, in areas cleared for this purpose (Figures 56 and 58). Areas of recent clearing are often located further from roads, as a consequence of the expansion of production activities within the properties. In areas of both settlements, where lots were often not occupied or were abandoned, large areas of recent clearing occur (central-eastern portion of Machadinho and end of eastern feeder roads in Anari). Field observation showed that pasture conversion and land aggregation has occurred in these areas. In Anari, the settlement design facilitates the visual perception of these processes. Other processes occur within areas in succession (i.e., long-fallow cycle, short-fallow cycle, and recent abandonment). They often predominate further from roads, functioning as buffers between areas in production and areas covered by forest (Figure 58).

Figure 59 illustrates the percentage of the settlements covered by each transition class of production or succession. Machadinho has 5% of its area in long-fallow cycles and 3% in short-fallow cycles. In Anari, these succession areas cover 4% of the settlement each. However, recent abandonment is significantly higher in Anari (13%) than in Machadinho (10%), also indicating a better maintenance of production fields in the latter. Percentages of areas in production since 1988, since 1994, and recently cleared are always higher in Anari (7%, 9%, and 9%, respectively) than in Machadinho (4%, 5%, and 6%, respectively).

4.3.3 - Do communal forest reserves make a difference in Machadinho?

The existence of communal forest reserves managed by local rubber tappers in Machadinho is an important factor in producing a distinct outcome in terms of LULC change, as shown above by the difference in forest cover between the two settlements. However, when only private lots are considered, Machadinho's forest cover is similar to Anari's: 83% in 1988, 65% in 1994, and 51% in 1998. These results clearly indicate how the combination of private lots and communal reserves can produce significant effects in the maintenance of forest cover when considering the entire settlement as the unit of analysis.

Machadinho had fifteen State Extractive Reserves decreed in 1995 and one State Forest for Sustainable Management decreed in 1996 (Olmos et al. 1999). However, all of them had already been implemented as reserves during the settlement creation by INCRA in 1983. Figure 6 illustrates their location within the settlement. Five reserves are responsible for 75% of the area decreed as reserves: Aquariquara (25%), Castanheira (15%), Maracatiara (14%), Angelim (13%), and Massaranduba (8%). Figure 60 illustrates graphically the percentage of each forest reserve in relation to the total area of reserves in Machadinho.

The total area of these reserves in Machadinho encompasses 68,477.6 ha, approximately 33% of the entire settlement. Their forest cover in 1998 represented 46.5% of the total forest cover in Machadinho. A population of 401 individuals lives in scattered locations within fourteen reserves (Table 16). Their main activity is rubber extraction, which has maintained forest cover, as indicated by the LULC results. Figures 54, 56, and 58 show that the largest portions of these reserves are still covered by forests.

In Chapter 6, institutional factors are related to the management of forest reserves in Machadinho and their role in interactions among actors within the settlement. The importance of these reserves in maintaining lower levels of landscape fragmentation is also discussed.

4.3.4 - Roads: the path for lot occupation

Access to land is an important variable affecting LULC change in Amazônia. For this reason, distance from roads is often associated with the pace of deforestation and land colonization (Browder and Godfrey 1997, Alves 1999, Alves et al. 1999, Laurance et al. 2001). However, the establishment of road systems in the region is a very complex process, varying regionally and locally. At the regional scale, programs for road building have opened major paths for Amazonian occupation. Towns, rural settlements, and secondary roads have flourished from these roads, making the human footprint visible within the landscape.

The case of Rondônia is singular. As mentioned in Chapter 2, beginning in the early 1970s, the state has been intensively occupied through settlement programs to accommodate migrants from other Brazilian states. The process was accelerated by the building and paving of BR-364, the main road in Rondônia crossing the State from Mato Grosso (southeast) to Acre (northwest). RO-133, the main road crossing Anari from south to north, is a secondary road starting at BR-364, in Jaru. Going further to the north, it reaches the road system of Machadinho (Figures 5 and 6).

This section shows how LULC has changed in distinct and contiguous buffers around roads in Machadinho and Anari. The motivation here is to understand if road system design affected the pattern of LULC change. In this case, the bias caused by reserves increasing the percentage of forest cover within the settlement is attenuated, as the buffers chosen (100 m, 200 m, 400 m, and 800 m) barely reach the reserves' boundaries (Figure 61).[1] So, we can assume that the results are related to LULC change at the property lots.

Figure 62 illustrates trends of deforestation until 1998. The spatial pattern varies depending on which buffers are being analyzed. For the 100-meter buffers, the patterns in Machadinho and Anari are very similar, but deforested areas in 1988 are already larger in the latter. Within the 200-meter buffers, the difference begins to be visible. The percentage of area covered by forests or where recent clearing occurred is lower in Anari, indicating the faster process of lot occupation from roads. Within the 400- and 800-meter buffers, the differences become even clearer. Forest cover within the 800-meter buffers is just 25% in Anari and 44% in Machadinho, showing that deforestation processes extend further from roads in Anari.

When analyzing the numbers for production and succession, one can see similar patterns but different magnitudes in Machadinho and Anari. In general, the results for succession (i.e., SS since 1988, long-fallow cycle, short-fallow cycle, and recent abandonment) are about 2% higher in Anari at all distances. Areas in production since 1988 and 1994 are 5% and 3% larger in Anari in all distances, respectively. The main difference between the settlements occurs in areas of recent clearing. They are practically constant in Machadinho in all buffers but increase from 3% to 10% in Anari as they get further from roads. This also indicates that the process of clearing in Anari is more intense than in Machadinho, even after 15 years of colonization.

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[1] In Machadinho, because of its curvilinear design, areas between the road buffers filled with the color of a buffer class are related to the smallest buffer necessary to fill the polygon.

4.3.5 - Property-based analysis of LULC

The property-based analysis of LULC was possible by overlaying the property grid to the LULC classifications and tabulating areas for each polygon using a GIS. Descriptive statistics and graphic outputs were then produced based on these data. The importance of this procedure relies on the fact that excluding Machadinho's communal forest reserves from the analysis allows a better comparison between the settlements regarding lot occupation and establishment. As mentioned in Chapter 2, Machadinho was implemented in 1982-1984 and Anari in 1980-1982. The two-year separation may produce a subtle difference in the final numbers but do not affect the study of LULC dynamics within the settlements. Moreover, the results show that this difference in time did not blur the picture of property lots within the settlements. Results are presented in hectares (ha) and percentages to facilitate the analysis (Tables 17-22). Boxplots illustrate the distribution of data for LULC classes in all periods (Figures 64-69).

The first important finding to mention is the mean property size of 43.8 ha in Machadinho (Tables 17, 18, and 19) and of 50.0 ha in Anari (Tables 20, 21, and 22). This number per se already provides a sense of property size homogeneity in Anari due to its fishbone design. Rectangular properties of 2,000 by 250 meters make the blueprint of this settlement. In Machadinho, properties vary in size and shape, being 6 ha smaller than in Anari on average, as a consequence of the settlement design being based on topography and the fact that communal forest reserves encompass 33% of the total settlement area (Figure 6).

The percentage and area of forest cover within the properties add new information to the results presented in the sections above. Landowners cleared about the same percentage of their lots in Machadinho (Tables 17, 18, and 19) and in Anari (Tables 20, 21, and 22). However, the area cleared in Anari was larger than in Machadinho. At the former settlement, farmers deforested 1.4 ha/year between 1988 and 1994 and 2.2 ha/year between 1994 and 1998. In Machadinho, they cleared 1.3 ha/year and 1.7 ha/year, respectively (Table 23). In both settlements, deforestation of properties was higher between 1994 and 1998. Standard deviation and variance for forest cover are always higher in Machadinho, indicating a higher heterogeneity in land clearing and different strategies of land use among owners.

Advanced secondary succession had similar patterns in percentage of area in Machadinho and Anari. These areas are relatively small, not exceeding an average of 1 ha per property in 1994 and 2.3 ha per property in 1998 (Tables 17 to 22). Initial secondary succession showed a more dynamic picture. Machadinho has more area and percentage of area per property in SS1 than Anari in all dates. In 1998, this stage of succession covered 15.3% of the properties in Machadinho and 12.5% in Anari (Tables 19 and 22, respectively). Opposite trends occurred with pasture. They started with equal area in 1988 in both settlements (Tables 17 and 20), but in 1994 the higher pasture conversion in Anari is already clear (Tables 18 and 21). In 1998, properties had 8.1 ha (16%) of pasture in Anari (Table 22) and 5.9 ha (13.4%) in Machadinho (Table 19). Figures 65, 66, 68, and 69 illustrate the opposite trends of SS1 and pasture within the settlements.

Agricultural fields had similar land cover in both settlements in 1994 and 1998: about 5.5% of the properties in 1994 (Tables 18 and 21) and about 10% in 1998 (Tables 19 and 22). In 1988, agricultural land was three times larger in Anari (Tables 17 and 20), suggesting that the priority for pasture came with experience and time.

Bareland can be interpreted as a proxy for agriculture and pasture increment. In Machadinho, landowners prepared 1 ha of land in 1988 (Table 17) and 1.3 ha in 1994 and 1998 (Tables 18 and 19, respectively). In Anari, bareland was just 0.4 ha in 1988 against 1.9 ha in 1994 and 1.3 ha in 1998. Although it is risky to draw conclusions solely from these numbers, they indicate a higher homogeneity in farming decision-making in Machadinho through time. Next section discusses the results presented so far trying to relate trajectories of LULC in Machadinho and Anari with the spatial organization within the settlements.

4.4 - The colonization impact in Machadinho and Anari

In the beginning of this chapter, I called attention to the importance of geotechnologies in supporting the study of LULC dynamics in Amazônia. Through a brief literature review, the need of spatial-temporal assessments related to the subject was emphasized and the research was included in this methodological context. After going through the results achieved at distinct units of analysis (i.e., settlement, buffers around roads, reserves, and rural properties), this section discusses the impact of this research for a better understanding about trajectories of LULC in the study area and in Amazonian frontiers of colonization. For this purpose, the section is divided in three main aspects: the methodological and operational issues; the main findings and their meanings; and the trajectories of LULC and trends for the near future.

4.4.1 - Methodological and operational issues

LULC classification in Amazônia is a complex task and its degree of difficulty increases with the number of classes one wants to distinguish. Spectral signatures detected by TM images often include mixed responses for the heterogeneous tropical environment. More than just distinct vegetation types, LULC cover classes represent scenarios within the complex dynamics of vegetation clearing or recovering. In addition, the process occurs at remote and large areas, sometimes of difficult access. Lack of data, such as soil and topographic maps at detailed scale, also complicates the process of classification. In sections 3.5 and 4.1, aspects related to the use of spectral analysis and vegetation structure for understanding LULC dynamics in the Amazon are mentioned. This section discusses some operational and methodological issues faced when tracking the colonization impact in the study area using remote sensing tools.

Some problems are merely operational (e.g., the lack of image data for the southern portion of Anari in 1988 and 1994 or detailed soil maps). Other questions are methodological, such as to use a reasonable classification system to describe the variance of LULC dynamics at the scale and complexity of study. One way to surpass such difficulty is to increase the fieldwork effort by gathering more ground-truth data. In the case of Machadinho and Anari, the total area to be covered (3,383 km^2) was reasonably large to include multiple scenarios within the distinct landscapes and LULC outcomes. During fieldwork, overview flights were carried out in small planes. I also drove through all dirt roads, and walked through properties and forest reserves. The challenge was not just to acquire training data to inform image classifications. It was also to understand the responses of local people to processes of LULC change and landscape transformation.

For this reason, interviews with local people were carried out, helping to achieve a better conceptual approach about local heterogeneity in LULC.

Accuracy assessment of LULC classifications brought attention to some aspects. In areas of steeper topography, mainly along orthogonal roads of Anari crossing ridges and valleys, ground truthing indicated that some agricultural fields and bareland should have been classified as pasture. The confusion between bareland and pasture becomes worse with overgrazing during the dry season, when soil spectral response contributes more significantly to the signature of sparsely covered grassy vegetation. On the other hand, degraded pasture in the process of vegetation recovery often has high densities of *Vismia sp*. and *Orbignya sp*., generating confusion with the spectral response for SS1 or even perennial agriculture. Spectral responses for perennial agriculture can also be confused with SS1, mainly in areas of initial recovery of disturbed gallery vegetation. One way of reducing the risk of misclassification would to group classes such as pasture, agriculture, and bareland as a class named ‘production,’ or collapsing the stages of secondary succession into just one class, which was done for the computation of transition matrices and for the calculation of landscape metrics described in the next chapter. This produces more accurate classifications but at a cost of generalizing LULC classes drastically, not allowing the generation of results such as the ones presented in this chapter.

To overcome possible problems related to the chosen classification system, extensive fieldwork during the dry seasons of 1999 and 2000 and previous studies supported the description of LULC categories and production systems in the area (Miranda and Mattos 1993; Miranda et al. 1997, 1997a). The proximity of Machadinho and Anari also made the study possible by easing the access to most portions of the area under investigation. Also, possible methodological problems related to image classification can be assumed to be similar in both settlements.

4.4.2 - Main findings and their meanings

The results presented in this chapter were produced at distinct units of analysis. This method allowed addressing LULC dynamics in a multi-scale manner, from the landscape (settlement) to the property. The landscape-based analysis provided a general picture about the process in Machadinho and Anari. As expected and assumed at the beginning of this research, both settlements had similar LULC in 1988. This holds for all classes mapped, except for agriculture and bareland. Despite the fact these classes had small land cover at the time, the percentage of agricultural lands in Anari is three times greater than in Machadinho, and the percentage of bareland is twice greater in the former settlement (Table 14). As explained in Chapter 2, Anari settlement was started about two years before Machadinho. These numbers indicate that the process of farm occupation was a little more advanced in Anari in 1988. In 1998, after experiencing many production systems and coping with distinct policies, incentives, and local biophysical heterogeneity, farmers produced a different outcome, with Anari showing a clear trajectory toward higher rates of deforestation and pasture conversion.

As far as intra-settlement spatial patterns are concerned, some findings deserve attention and were corroborated during fieldwork. In Machadinho, larger patches of pasture occur mainly along two roads: MC-7 and MC-6, at the northern and eastern portions of the settlement, respectively. According to local landowners and extensionists, these are zones within the settlements where the less fertile soils occur. Although there are no detailed soil maps available for the area, it makes sense to expect that the rate of abandonment by original landowners and land aggregation for pasture conversion by speculators will be higher in less fertile areas. Within the center of the settlement, properties remain with their original sizes and are mainly cultivated with coffee plantations or mixed production systems including agriculture and pasture.

In Anari, other important patterns were found. Large patches of pasture occur along the main road and at the ends of secondary roads. Here, besides soil fertility, access is also affecting the process of pasture conversion and land aggregation. Along the main road, first colonists and opportunists took over the land with better access and converted it rapidly to pasture to ensure their tenure status. In marginal areas at the border of the settlement, speculators took over abandoned lots, as they did in Machadinho. In these areas, access is poor through dirt roads trafficable only during the dry season, making cattle the only choice of production. Interesting enough, the sector of Anari called 'line of agriculture' by the local population is located at the northern portion of the settlement in mild topography. Besides better access to the urban area and proximity with Machadinho, better soils occur in this area, according to landowners and extensionists.

Section 4.3.2 presented the results for the study of agroecological processes using transition matrices between the multi-temporal classifications. Deforestation processes are clearly associated with roads, urban areas did not grow significantly, production patches follow the deforestation patches, and secondary succession patches often occur further from roads.

The results for production and succession (Figures 58 and 59) do not allow conclusions about intensification or extensification of production systems in Machadinho and Anari. All that can be said is that area in production (pasture and agriculture) is greater in Anari. However, a careful analysis of the results at the settlement- and the property-level indicates a trend. At the settlement level, Table 14 shows that Anari has more pasture in 1998, both in area and percentage. The numbers for agriculture show a different picture. Although the percentage of the settlement covered by this land use is greater in Anari, the rate of agriculture conversion in Machadinho is higher. These opposite trends are clearly shown by the areas of pasture and agriculture per property (Tables 17-22). In Machadinho, the area of agriculture increases from 0.5 ha in 1988 to 4.4 ha per property in 1998, while the area of pasture goes from 2.8 ha to 5.9 ha during the same period. In Anari, the numbers for agriculture are 1.4 ha in 1988 and 5.2 ha in 1998 (higher, but not very different from Machadinho), while pasture area grew rapidly from 2.8 ha to 8.1 ha per property during the same period. This analysis at the property level avoids misinterpretations of results obtained for the entire settlement, as Machadinho has more properties than Anari and properties in Anari are on average larger than in Machadinho.

Still through the transition matrices, it was possible to depict spatial patterns for recent clearings in both settlements. Large areas being cleared are often associated with pasture conversion and are adjacent to other pasture areas. Smaller areas being cleared are located further from roads and are generally associated with the expansion of agricultural fields. Interviews with Anari landowners during fieldwork shed some light on this pattern. According to them, agricultural fields develop better in areas closer to forests because of a cooler microclimate. Moreover, they try to keep these fields at a certain distance from pastures, as the latter are frequently managed through the use of fire. In Machadinho, this pattern is not so clear, as the curvilinear road design does not follow an orthogonal distribution of production fields as in Anari. In addition, this finding is valid only for properties with mixed production systems including agriculture and cattle ranching.

Section 4.3.3 showed the relative importance of communal forest reserves in maintaining a higher percentage of forest cover in Machadinho. The institutional aspects regarding rules in use and interactions among different actors within the settlement are discussed in Chapter 6. The important point here is to reaffirm that the percentage of forest cover in Machadinho in 1998 would be the same as in Anari if the reserves did not exist (i.e., 51%). This brings up an important discussion about the limits of deforestation in Amazônia and in Rondônia, also valid for the results at the property level. Arguments about a reasonable 'Forestry Code' ruling the region are currently in debate. The Brazilian Congress seeks to determine a percentage of deforestation allowed by law. This percentage was of 50%, but recent discussions have vacillated between reducing and increasing this number.

Moreover, land zoning laws often conflict with the 'Forestry Code', making the subject a complicated issue affected by political and economic interests. The contribution of this research to the topic is that multi-temporal analysis using remote sensing has proved to be an effective tool when comparing the trajectories of settlements in Rondônia. In addition, comparative analysis, such as the one carried out during this research, makes it possible to draw a better picture of the heterogeneity of LULC dynamics in the Amazon, particularly in areas of rural settlements with distinct architectural and institutional designs.

Another aspect analyzed in this chapter is the impact of road system design in LULC change patterns. The results show that deforestation extends further from roads in Anari, which is also reaffirmed by higher rates of recent clearing at the 800-meter buffers around roads within this settlement. Deforested areas tend to percolate first in Machadinho because secondary roads are closer to each other than in Anari. The communal reserves play an important role in maintaining large patches of forest encompassed by the road system. However, the discussion about the importance of road system design to the magnitude of deforestation still requires more research. On one hand, questions related to access may affect the process significantly. In general, marginal areas of difficult access at the end of secondary roads tend to be converted to pasture. This happens for two main reasons. First, as mentioned above, speculators take over these abandoned or underused areas and assure tenure by planting grass and introducing cattle. Second, agriculture is often unviable in these areas because secondary roads are too bad for transportation of produced goods. This process is more visible in Anari, where the orthogonal road design and poor maintenance of roads leads to higher rates of pasture conversion. On the other hand, besides infrastructure, incentives toward specific land uses may affect the decision-making process at the property level, generating a spatial pattern at the settlement level. Farmers in Machadinho had several incentive programs for agricultural production, including coffee, cacao, and agroforestry. Despite their questionable success in terms of economic return for the farmers, the LULC outcome was a more heterogeneous mosaic of production systems at variable distances from roads. Institutional aspects related to farmers' decision making and their possible impacts in LULC dynamics and landscape transformation will be discussed in Chapter 6.

The final unit of analysis was at the property level. Results in both percentage of lot and area, and rates of land conversion to different LULC features, provided a better understanding of the colonization process in Machadinho and Anari. Property results showed a higher percentage and area of deforestation per year in Anari after 1988 (Table 23). Higher rate of deforestation in Machadinho's properties before 1988 is probably due to the fact that this settlement was implemented with infrastructure and incentives for production already in place. In Anari, the implementation phase was more chaotic, as discussed further in Chapter 6. Landowners had to cope with difficulties in access to their lots and to incentives. Once they had adapted to these problems, they started clearing the land rapidly (after 1988), at a rate of deforestation higher than Machadinho. A higher pasture conversion rate was also confirmed for Anari. The variance in terms of area tends to increase with time in all classes in both settlements, indicating different farming strategies implemented by landowners.

Perhaps, property-based analyses for transition matrices and the study of a time series with more intervals could provide a better picture of specific trajectories within the lots. The integration of these results with household data for socioeconomic and agroecological variables may also be a valuable approach to take. However, cloud-free images for other dates and household data for Anari were not available. So, the results were based on the multi-temporal data available and the use of geotechnologies to bring light to general LULC dynamics in Machadinho and Anari. Together with the feedback from local people, some trajectories and trends of LULC may be drawn.

4.4.3 - Trajectories of LULC and trends for the near future

The human occupation defined different outcomes in terms of LULC in Machadinho and Anari during the period of study. In 1998, after about 15 years of colonization, properties in both settlements reached an average of approximately 54% of deforestation. The pathways of LULC change underlying the colonization impact is illustrated in Figure 70. Infrastructure and water are not in the graph because they are poorly represented in terms of area in both settlements and their surface did not show significant changes through time (Table 14). However, it is important to mention that the trajectory toward infrastructure and water is diverse. Their patches can be originated from the conversion of any LULC class. Infrastructure includes roads and urban areas. The latter have grown slowly during the period of study through the conversion of forest, SS2, SS1, pasture, agriculture, and bareland. The roads were primarily built during settlement implementation through forest clearing. Newer road building, although rare, may have been converted from any LULC class. The return of infrastructure to other classes is also spatially unimportant but may occur. Water includes rivers and lakes. The former may change their path over time but the effect in terms of area of LULC change is also very small. The lakes, which include water ponds, are generally built for cattle ranching. Their number has increased but their extent is also small.

A more dynamic process occurs between forest, SS2, SS1, pasture, agriculture, and bareland. The trajectories between these classes are associated with cycles of vegetation clearing, degradation, or recovery through the portfolio of strategies among colonists. Forest can be cleared to bareland, converted to pasture or agriculture, and degraded to SS2. Pasture can be cleared or degraded to bareland, converted to agriculture or recovered by SS1. Agriculture can be cleared to bareland, converted to pasture, and recovered after abandonment by SS1. Bareland can be converted to agriculture or pasture, and recovered by SS1. SS1 can be cleared to bareland, converted to pasture or agriculture, or develop to SS2. And SS2 can be cleared to bareland, converted to pasture or agriculture, degrade to SS1, or develop to forest.

A range of factors influences these trajectories and was confirmed during interviews. Local biophysical features can drive LULC changes, mainly because of soil fertility and topography. Distance from roads and urban areas may also affect LULC changes, as mentioned throughout this chapter when explaining higher rates of pasture conversion in Anari. Socioeconomic variables can also impact the outcomes in LULC. Access to credit and incentives, household labor force, previous farming experiences, and available assets are among the most important drivers for land management or abandonment.

Another important consideration to point out is the meaning of each LULC during the time frame being studied. This not only explains specific trajectories toward LULC change, but also defines trends for the near future. In 1988, for instance, agriculture meant annual crops and young perennial plantations (i.e., coffee, rubber, cacao). SS1 was the only class of vegetation recovery at this early stage of colonization, resulting from abandonment of lots or fields. SS2 did not exist because not enough time had passed for vegetation recovery to occur. Forest, pasture, bareland, infrastructure, and water had the same characteristics as in 1994 and 1998. However, in these two latter years, agriculture was mainly represented by older coffee plantations, secondary succession included different stages of recovery, and more dynamic trajectories were taking place as the internal variance in area of each LULC increased within properties (Tables 17-22 and Figures 64-69). Pearson correlation also indicates the relationships between changes in forest cover and selected LULC classes. In Anari, loss of forest cover is strongly associated with the pasture extent. Values of –0.618, -0.700, and –0.626 ($p<0.01$) were found for 1988, 1994, and 1998, respectively. Correlations for SS1, agriculture, and bareland are also higher in Anari, where the deforested area for production at farm lots is greater than in Machadinho (Table 24).

Despite major LULC trajectories presented in this chapter, some other trends deserve attention, particularly in agricultural production. In general, trends are represented by experiences with different crops. These crops have attractive economic returns, but also some uncertainty related to market demands. Black pepper is one example. Many farmers have tried to produce it, but they claim it is a difficult and expensive crop to implement. Guaraná (*Paulinnia cupana*) is relatively difficult to cultivate with high productivity. Palm heart production and *mamona* seeds for oil production are not reliable crops because market demand and access are questionable for farmers in Machadinho and Anari. Tree plantations for lumber depend on a very long cycle. On the other hand, cacao and rubber tree producers are not happy with the results.

For these reasons, coffee is still the most common option when farmers choose a type of agriculture. Productivity and quality of coffee plantations are often low, but they provide extra income for landowners, who came mostly from southern and southeastern Brazil, and are used to coffee production systems. Last but not least, trends of LULC change for the near future may also be affected by rural and urban development. Rural power lines, mechanization, irrigation, better rural extension practices, and the use of better crop varieties are already being discussed and implemented.

All LULC processes described in this chapter affect landscape transformation in Machadinho and Anari. But the analysis of LULC change by itself does not allow a comprehensive approach about the effect of these processes in the spatial pattern of landscapes, classes, and patches within the settlements. Chapter 5 addresses this matter.