SPOT SURVEY OF AGRICULTURAL LAND USES IN THE BRAZILIAN AMAZON

James B. Campbell, Professor
Department of Geography
Virginia Polytechnic Institute and State University

and

John O. Browder, Associate Professor
Department of Urban Affairs and Planning
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061 USA

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PURPOSE:

Recent colonization of Brazilian Amazonia has provoked concern over losses of large areas of primary forest and the difficult prospect of establishment of sustainable agricultural systems in this region. This study examines land use patterns within a recently colonized region of Rondonia, southeastern Brazil. On-site data were gathered by individual site surveys and interviews with individual colonists. Multispectral SPOT scenes (June, 1986; July, 1991) of area were examined to identify each site, and the pattern of crops and land use within each site. The distinction between forested and non-forested regions is clear. Areas cleared for pasture, and the initial stages of succession to secondary forest are likely to be distinguished with some reliability. However, reliable identification of areas planted to coffee, and especially to crops such as rice, maize, and beans is problematical, largely because of variability within fields and the similar spectral responses, at least during the season we examined. Comparison of SPOT multispectral scenes 1986-1991 reveals that, within this interval, vegetative succession in abandoned pasture acquires a spectral response very similar to that of primary forest. Thus, after an interval estimated to be perhaps eight years or so, identification of regrown areas using this method likely to be very difficult at best.

KEY WORDS: Agricultural Land Use, Remote Sensing, Deforestation, Brazil, Amazonia, SPOT Multispectral Data, Colonization.

1. PURPOSE AND SCOPE

1.1 Purpose

The purpose of this study is to inventory the pattern of agricultural land uses within a colonized region of the Brazilian Amazon, using field data and SPOT multispectral data. This paper reports the results of our initial efforts with emphasis upon some of the difficulties presented by this research task. These results form the basis for a continuing effort based on further analyses of these data, and of additional data to be collected.

2. REGIONAL SETTING

2.1 Location and Extent

This study describes a region in Rondonia, southeastern Brazil, positioned at approximately 11° South latitude, 62° West longitude. Our study area is positioned near the city of Rolim de Moura, a regional agricultural settlement founded in 1977. This date marks the beginning of the region's short but rapid developmental history. The city's population, only 200 in 1978, grew to 5,000 by 1980, and in 1990 was estimated to be 28,000. Most of the colonists in this region have been peasant families displaced from other regions of Brazil (Browder, 1988).

Our study area is positioned just to the west of the city, in a region of about 3,600 sq km (1390 sq mi) opened for colonization as a formal governmental program in 1977. This region once supported a continuous cover of primary tropical transitional forest, much of which has since been cut and burned by individual colonists to form clearings for small-scale agricultural development. Climate here is characterized by annual rainfall of 1800 to 2000 mm, with a dry season during the interval April to May. Annual average temperature is about 28°C (82°F). We do not have topographic data for this region, but relief is relatively low, and the terrain is gently rolling, with low hills forming gentle divides between broad valleys. The drainage pattern, visible in broad detail both on the imagery and on cadastral maps, has a dendritic form, with the appearance of rather high density, perhaps because of the high rainfall characteristic of this region.

Much of the cleared land is now in pasture of varying quality. Smaller plots are planted to coffee, maize, beans, rice, and other crops. After several years of cultivation, many of the naturally available nutrients are depleted, much of the cleared land degrades, and colonists clear additional land or seek resettlement in undeveloped territory. Unproductive fields often are left unused to support growth of a secondary forest.

2.2 Context for This Study

This study is an investigation of the feasibility of using SPOT multispectral data as a means for inventory of agricultural land uses in this region. To what extent can these data record changes in the extent of primary forest? Can these data separate between primary forest and the secondary regrowth that occurs as unproductive land is abandoned? Can SPOT data distinguish the varied agricultural land uses that occupy cleared land? This paper reports our efforts to lay the groundwork to answer these questions.

Studies such as those of Nelson and Holben, (1986), Goodwell et al (1987), Woodwell et al (1987), Carneiro et al, (1982), Matricardi (1989), and Stone et al (1991) examined gross rates and patterns of deforestation using AVHRR and TM data. Others, such as Stone et al (1989) and Roy et al (1991), and Sader et al (1989, 1990) have examined variations within tropical forests, often using aircraft multispectral data or other detailed data.

Our study differs from these first in that it examines the possibility of monitoring land cover patterns within cleared areas (without of course ignoring changes in extent of forest), and secondly that it uses finer detail than previous satellite-based studies. Most, if not all, previous studies have relied upon AVHRR and TM data, of relatively coarse spatial resolution. Although studies focussed on tropical forestry have used detailed field data, the studies examining the rate and pattern of deforestation were conducted largely without the use of on-site observations, and have not examined the land cover within the deforested regions. Thus our work is one of the first to evaluate usefulness of the relatively fine detail of SPOT multispectral data in this environment.

2.3 Land Use Patterns

Colonized land in this region has been surveyed to form a regular system of uniform lots, shown on the cadastral surveys at 1:100,000 available for this study. A main road extends directly east-west through Rolim de Moura; from this road, secondary north-south feeder roads are spaced at intervals of 4 km (Figure 1). Each highway is lined with lots 0.5 km in width, and 2 km in depth, creating holdings of 100 ha each. Except for the first 2 km of each secondary road, the narrow side of each lot faces the road. Usually colonists have cleared this narrow side, facing the road, first, so pasture, crops, coffee, dwellings, and farm structures are usually positioned near the road (Figure 2).

In contrast, interiors of lots typically are occupied by primary or secondary forest. Although some lots have been almost completely cleared, typically (in 1991) a third to a half of most lots is still in primary forest. Often smaller clearings for pasture or crops are found in the interior, completely or partially surrounded by forest. By July of 1991, very few lots remained without any cleared land. It is this process that creates the characteristic herring bone pattern seen in the aerial views of this region often illustrating colonization of Brazil's rainforest. Remnants of primary forest, in the interiors of the lots, form corridors that alternate with contrasting strips of cleared areas bordering the highways.

Our area has been at least partially occupied by agricultural colonists since 1977. Most of this area therefore forms, by local standards, a rather established landscape.

2.4 Image Data

Our study area was imaged by SPOT HRV XS images on 22 June 1986, and again on 20 July 1991 (Figure 3). Both images give clear views of our region, free of clouds, haze, or smoke. The region of overlap gives dual coverage of the northern half of the study area, and a portion of the southern region. The western half of the 1986 image shows a systematic shift in brightness not corrected by system processing. Although this effect is visually noticeable, our examination of the digital values reveals only the subtlest differences from one side to the other, within forested regions. We have not yet assessed effects within non-forested areas.

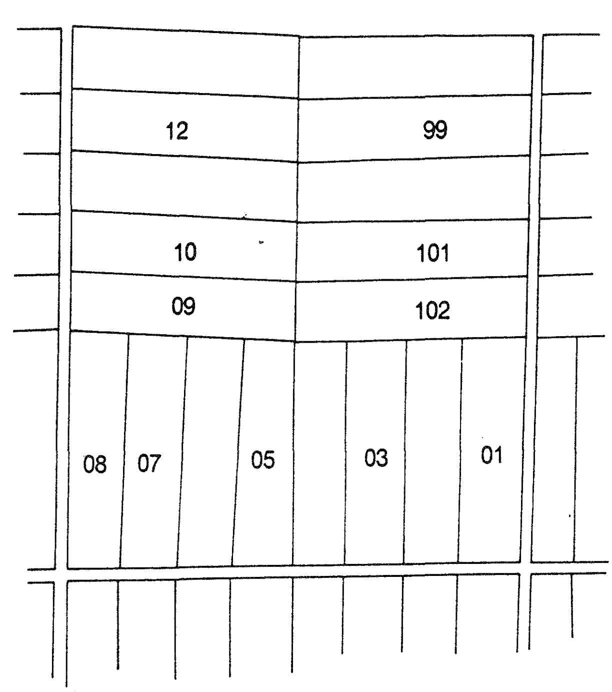

Figure 1. Pattern of Land Division Within The Study Area. Single lines represent lot boundaries; double lines represent roads. Numbers, taken from the cadastral map of the region, show legal designations of selected lots.

TABLE 1. Field Data Summary, 1991.

Site	Forest	Pasture	Brush	Orchard	Coffee	Corn	Beans	Rice
1.	28	12		2				
2.	31	7		2				
3.	30	8	1	x	x		x	
4.	28		8		x			
5.	24	13			x	x	x	
6.	x	x	x		x			x
7.	x	x	x		x	x	x	x
8.	x	x	x		x	x	x	x
9.	x	x			x	x	x	x
10.	x	x	x		x		x	x
11.	x	x	x					
12.	x	x						
13.	24	18						
14/15.	x	x	x	x	x	x	x	
16.	22	20						
17.	34	5	1		x	x		
18.	37	1	1		x	x		
19.	35	2		x				
20.	x	x		x	x	x		
21.	x	x			x			x
22.	x	x			x	x	x	x
23.	x	x		x	x			
24.								
25.	x	x			x	x	x	
26.	x	x			x			x
27.	x	x	x		x			x
28/29.	x	x	x	x	x	x	x	
31.	x	3			4	1		
32.	31	8		x	x		x	
33.	x	14			x		x	x
34.	x	x			x		x	
35.	x	x		x				
36.	x	x	x		x			x
37.	x	x			x	x	x	x
38.	x	x	x		x		x	
39.	x		x		x			
40.	x	x			x	x		x
41.	27	8			x	x		x
42.	33	8		x				
43.	x	x	x		x	x	x	x
44.	x		x		x			
45.	x	x			x	x	x	x
46.	x	x			x	x		x
47.	x	x		x	x			
48.	x	x	2		x			
49.	x	x			x	x		x
50.	34	x			x			
51.	x	x			x			
52.	34	6						
53.	x	x			x	x	x	x
54.	x	x			x			
55.	x	x	x	x	x	x	x	x
56.	x	7		x		x	x	x
57.	x	x			x			
58.	25	6		x	8			x
59.	19	8			2		x	x
63.	22	19		x				
64.	x	x				x	x	x
66.	26	12	2		x		x	x
67.	21	12			x	x		x

x = this category present at this site
12 = number indicates that field notes give areal estimate, in alqueres. 1 alquere = 2.46 ha.

Because of the systematic network of roads aligned with the geographic graticule, it was possible to identify a network of ground control points (GCPs) with accuracy and confidence. Rectification was conducted using bilinear interpolation with 12 GCPs, producing a RMS of less than 1 pixel, retaining the 20 m detail of the SPOT HRV data. Our evaluation of the rectified images revealed that the process produced minimal alteration of the brightness values, and produced an image with a geometry very close to that of the base map recording the lots within the colonization project.

2.5 Field Data

Field observations used for this study were collected as part of a broader project to examine migration and colonization in Amazonia. Land use data, household surveys, and interviews were collected in July of 1985 for 70 farms in the Rolim de Moura sector of Rondonia. In July of 1990, 40 of these farmers were re-interviewed, and detailed land use surveys were prepared for each lot. Table 1 summarizes the occurrence of land cover classes encountered during this field season. Each interviewer prepared a field sketch for each lot, showing extent of primary forest, secondary forest, pasture, and the crops cultivated in the cleared land. These maps were prepared on-site, during interviews with the farmers, who assisted in their preparation. Typically the portion of the lot nearest the road was cleared of forest, so the cropped areas were subject to direct observation. In contrast, forested portions of the lot are usually positioned further from the road, and could not be directly observed by the interviewer. Therefore, maps of these sections could show only that detail reported by the farmer. In some instances, the interviewer recorded areas within each land cover class.

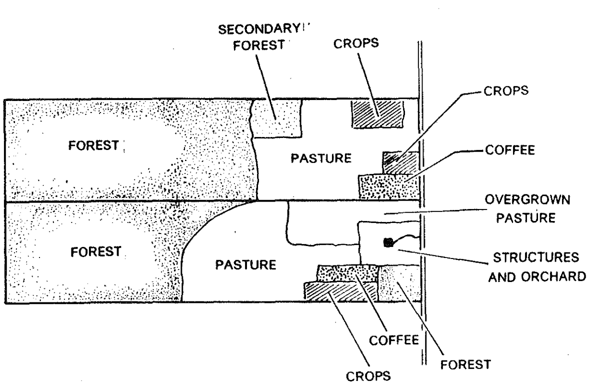

Figure 2. Sketch Illustrating Typical Patterns of Land Use Within Lots. "Crops" designates annual crops, such as beans, rice, or maize. In the lower lot, the representation of the grouped dwelling, farm structures, road, and nearby orchards is not depicted at scale, but only to suggest a typical configuration and position within the lot.

This procedure provided a convenient method for presenting an initial interpretation, examining its merits, revising it as necessary, and finally, recording it in a way that could be easily referenced later. Each site was examined individually, to compare the field record with the image with respect to location, land cover pattern, and consistency with the patterns of neighboring lots. In addition to features mentioned thus far, the drainage pattern, visible on the image, and also recorded on the survey map and the field notes, provided an important locational aid. Field sites that could not be confirmed by this process were discarded for use in this study.

Our analysis has proceeded along two interdependent tracks. First is the visual interpretation of the image to identify each site recorded in the field data. This processes depends in part on knowledge of the multispectral qualities of each land cover class, and its manifestation on the image. Second is the effort to apply this information to a quantitative analysis of the digital data to extend information from the field data to the broader region in the vicinity of Rolim de Moura.

3. MANUAL INTERPRETATION

3.1 Interpretation Procedure

Our image has good visual qualities-- the image is clear, there is good spatial detail, and adequate spectral and radiometric information for visual differentiation of land cover parcels. The systematic survey system provides an accurate and clearly visible reference system for matching field notes to the image.

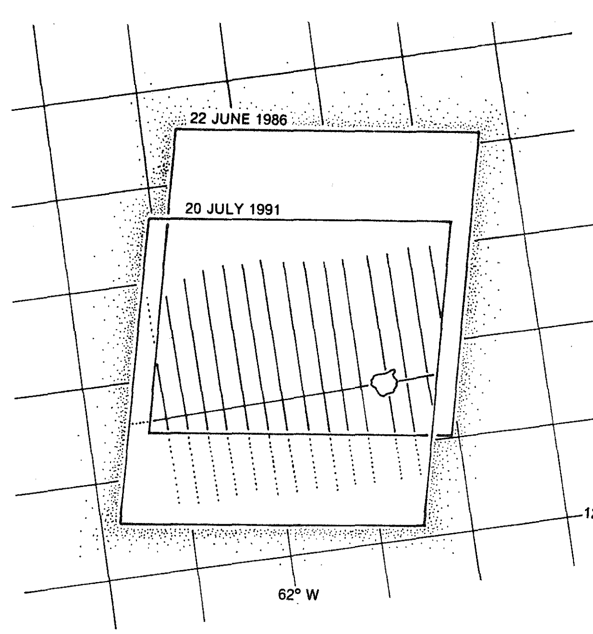

Figure 3. Coverages of Two SPOT Scenes Used for This Study.

Nonetheless, it was necessary to devote considerable attention to accurately match field notes to the correct image area. The field data used for our 1991 image were collected one year prior to acquisition of the image, so it was always necessary to consider the possibility of land cover change during the interval between collection of the field data and the image data. We do not believe these changes to be substantial, but in unclear cases, the possibility created an additional element of uncertainty. Most field notes formed schematic, rather than literal, renditions of the land cover pattern. Interviewers were not able to see into the interiors of the lots, so patterns beyond the first forest border were not subject to direct observation by the interviewer. The land use pattern as it appears on the image has an abundance of linear features that often offered, on initial inspection, the opportunity to misidentify, or mislocate, lots.

To address these kinds of problems, the field sketches were redrawn to a consistent scale, with areas of parcels accurately represented, when such areas were given. Each lot was found within the image, displayed, and enlarged on a computer display, then photographed in color. Prints of these photographs formed the vehicle for our detailed interpretation. Lot boundaries, and land cover parcels within each lot, were marked on translucent overlays registered to each photograph. Figure 2 illustrates the nature of these overlays.

4. MULTISPECTRAL ANALYSIS

4.1 Overview of Sample Data

To lay the foundations for multispectral analysis of our data, we selected a sample of those sites believed to provide the most reliable record of the sizes and configurations of the land cover parcels depicted in the field notes. Figure 4 illustrates the range of sizes and shapes of parcels recorded in the 1991 field data. These diagrams have been drawn to scale, as permitted by notes and sketches prepared from on-site observations and interviews with colonists. This selection in no way forms a rigorous sample, but it does illustrate the range of sizes and shapes of parcels associated with specific cover types.

From these sketches, we prepared estimates of the numbers of 20 m pixels that would be associated with each field, assuming that the identities and outlines could be reliably determined on the image. From the total area of each field as reported in the field notes, we then subtracted the area occupied by border pixels (i.e., those likely to form mixed pixels, atypical of land cover class in question). The resulting figures (Table 2) provide rough estimates of the numbers of multi spectral samples that could be derived from each field.

Note that those classes associated with small field sizes or elongated shapes are characterized by relatively high proportions of border pixels, and therefore require larger areas to meet a given standard for providing a minimum of pixels.

From the figures we can conclude that these data are likely to satisfy, in formal sense, the guidelines proposed by Joyce et al (1976) for multispectral classification of multispectral data. That is, the field data are likely to provide the number of multispectral samples recommended by their guidelines. However, additional considerations are significant in this instance.

First, we have encountered difficulty in making reliable identifications and delineations of specific fields, even when we have made confirmed identifications of the specific lot in question. This difficulty arises because boundaries are not always distinct, and because fields are not always internally uniform.

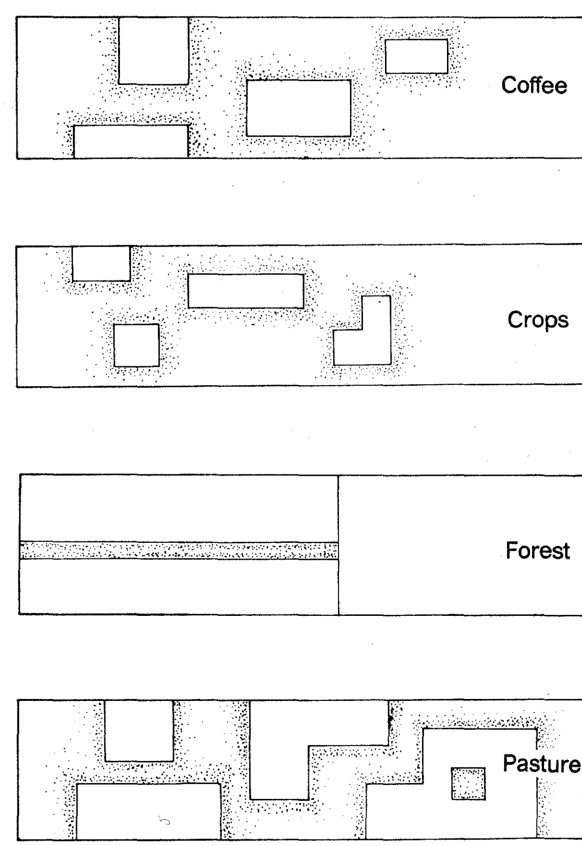

Figure 4. Diagram Illustrating Varied Sizes and Shapes of Land Cover Parcels. These have been selected from field sketches that have given areal estimates of parcel size. Parcels have been drawn to scale based upon sketches made in the field. Parcels have been placed within areas representing the size and shape of a standard lot. Areas, shapes, and orientations of parcels are intended to approximate those of actual parcels, but placement within lots is arbitrary. Here "crops" designates annual crops such as maize, rice, and beans.

Secondly, some of the labels are very broad and imprecise. This difficulty exists because the data were originally collected for socioeconomic surveys of colonists, rather than as field data for remote sensing. Work now underway will use a different protocol specifically designed to collect data to support remote sensing analysis.

4.2 Spectral Separability

To determine effects of these issues, especially internal variability of spectral properties, we conducted a preliminary assessment of the separability of the classes proposed for the study.

Using data identified through the procedure outlined above, we prepared samples of spectral responses for each of the land cover classes represented in the field data. These data represent preliminary efforts because of the difficulty in determining the exact outlines of fields within each lot. From these samples we then estimated means and standard deviations of spectral values within each class.

Then it was possible to calculate the normalized differences between means for pairs of classes (Swain and Davis, 1978), as shown in Table 3.

5. TEMPORAL ANALYSIS 1986-1991

The two images used for this study provide a good record of the changes in principal land cover classes that have occurred over this five year interval. At the time of preparation of this text, our inventory of changes was not yet complete. However, preliminary results based on visual interpretation of a few selected sites may suggest the nature of changes during this interval:

1. Portions of our area seem to have experienced only modest losses in primary forest during the past five years. These losses appear to have occurred mainly at edges between forested and cleared land, although there are examples of new clearings in the interiors of lots. These interior clearings do not seem to be numerous, nor to be large in area, individually or in the aggregate, but are distinctive. Therefore, their distinctiveness can create an inflated impression of their significance.

2. The principal land use changes in the areas we have examined thus far seem to be in those areas that were in pasture, or possibly other open land, in 1986, and now have been abandoned. Many areas that appeared to be in use in 1986 now show signs of abandonment or degradation to a land cover of overgrown pasture. Some areas that appeared to be overgrown pasture in 1986 now seem to support a complete canopy of secondary growth. Spectrally, these areas appear to be similar to primary forest, although visually the smother texture of these regions contrasts with the rough, pebbly, texture of primary forest. The spectral similarity may indicate that the usual classifiers may have difficulty in distinguishing between mature regrowth and unaltered primary forest.

Our spectral separability analysis (Table 3) suggests that primary forest can be distinguished from what we called "recent regrowth," that is, overgrown pasture that supports a growth of woody plants. (We should emphasize that this label has been derived from examination of the image, not from the field data.) The temporal comparison indicates that the spectral separability of these two classes declines rapidly, so that with five years (the interval between our two scenes) there are only rather subtle differences between primary forest and the overgrown pasture.

It appears that manual interpretation can make these distinctions, at least in some instances. Secondary growth, after an interval of perhaps five to eight years, appears slightly brighter in the infrared and has a smoother texture than does primary forest. These differences are probably too subtle to be identified by the usual digital classifiers, and may escape

TABLE 2. SUMMARY OF PIXELS REQUIRED TO REPRESENT PARCELS DEPICTED IN FIGURE 4.

Category	total	edge	interior	%edge
Coffee:	144	46	98	32%
	180	54	126	30%
	66	32	34	48%
	120	50	70	42%
Crops:	56	28	28	50%
	90	40	50	44%
	120	50	70	42%
	60	30	30	50%
Pasture:	464	120	344	26%
	292	80	212	27%
	132	44	88	33%
	250	68	182	27%
Forest:	660	132	528	20%
	550	128	422	23%
	1125	138	987	12%

TABLE 3. NORMALIZED DISTANCE BETWEEN MEANS, 17 JULY 1991 SPOT DATA

	Cleared Forest	Recent Regrowth	Primary Forest	Coffee	Beans	Crops	Road
Cleared Forest	----						
Recent Regrowth	29.4						
Primary Forest	20.5	2.6					
Coffee	14.7	3.4	3.3				
Beans	51.2	1.0	3.3	3.2			
Crops	12.0	2.2	2.6	0.8	2.6		
Pasture	16.7	3.2	3.5	2.6	4.1	0.5	
Road	29.5	3.2	6.7	5.4	5.0	3.4	3.3

identification by manual interpretation as well. Based on present evidence, it seems doubtful that either approach can provide reliable distinction, once the succession exceeds the five-year interval examined in this study.

Sader et al (1989) found that multispectral aircraft data could not separate successional classes older than 15 to 20 years. Our results suggest that the interval may well be shorter in our area, but their study used data of finer resolution that may permit distinctions not feasible in our study.

These are offered as tentative results, to be tested in the light of our continuing study. We believe they are likely to be correct for the areas examined thus far, but these areas may not necessarily be typical of the broader areas we wish to examine.

Efforts are now underway to conduct a more systematic inventory of land cover classes, the changes 1986-1991, and to verify our interpretation using new data from the 1992 field season in Rondonia.

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