OPTICAL AND DIGITAL INTERPRETATION OF "SPOT" IMAGERY FOR LAND RESOURCES PLANNING AND MANAGEMENT IN NORTHEASTERN BRAZIL.

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ABSTRACT

Northeastern Brazil is an area of low rainfall and high temperatures coupled with topographic, soil and land problems which make it difficult for agricultural and economic development. To solve these problems requires a sophisticated and effective land use plan utilizing current knowledge and up-to-date technology.

The present investigation, using multispectral SPOT imagery, was conducted over an area of approximately 3,000 km^2 in northeastern Brazil (parts of the states of Paraiba and Rio Grande do Norte). Optical and digital analyses, supplemented with selected ground truth data gathered by field survey of the site in March to April 1988, were conducted to derive information about surface water, erosion and drainage patterns; land use and land cover classes; major soils; and land capability classes. Optical interpretations were made for the entire scene at a scale of 1:110,000 while digital interpretations were made only of the Santa Luzia municipality and adjoining areas using 1,000 by 1,000 pixels. Through optical interpretation, all the large and small lakes and reservoirs were located on the map and the following drainage patterns identified: dendritic, parallel, sub-parallel and braided. The land use and land cover classification resulted in seven general categories at Level I, 14 somewhat detailed categories at Level II, and 27 very detailed ones at Level III. Major soils were identified at the level of sub-order and sub-group. A total of 18 soil mapping units and seven land capability classes were identified. For digital interpretations, the SPOT data were processed with ERDAS (Earth Resources Data Analysis System) software operating on a PC's Limited 30386-based supermicrocomputer. The system consists of hardware and software for the subsetting and reformatting, radiometric and geometric correction, classification and display of digital images. Based on field observations, 41 training areas were selected, using the interactive capabilities of the ERDAS system, for the land cover classes of interest which resulted in classification of five general categories at Level I, 12 categories at Level II and 24 at Level III. Land capability and soil sub-order maps were produced by a recoding of the original 41 classes of land use and land cover shown on the digital maps. Six distinct capability classes and 11 soil sub-order classes were identified and mapped at the same scale. Field observations conducted on site confirmed the relationships between the optical and digital interpretations.

INTRODUCTION

Land resource planning and management for northeastern Brazil requires current and accurate information about the type, amount, availability and condition of the renewable natural resources. Earth observation satellite systems such as the American Landsat Thematic Mapper and French SPOT (System Probatoire d'Observation de la Terre) employ the necessary technological advances and marketing strategies to provide data on a continuing basis for renewable natural resource surveys. The first French environmental satellite, SPOT-1, launched in February 1986, transmits three bands of multispectral data of high quality and high resolution (20 meters).

The present study was carried out on terrain which ranges from mountainous to alluvial and low lands and includes natural and artificial reservoirs and lakes in the semi-arid regions of the states of Paraiba and Rio Grande do Norte, Brazil. Elevations of the study areas range from 270 to 900 m above sea level. The area lies between 36°39'W to 37°08'W longitude and 6°47'S to 7°21'S latitude. It includes the municipalities of Santa Luzia, Sao Jose do Sabugi, Equadore, Junco do Serido, Quixaba, Assuncao, Salgadinho, Taperoa, Sao Mamede, Passagem, and Cacimba de Areia (Figure 1).

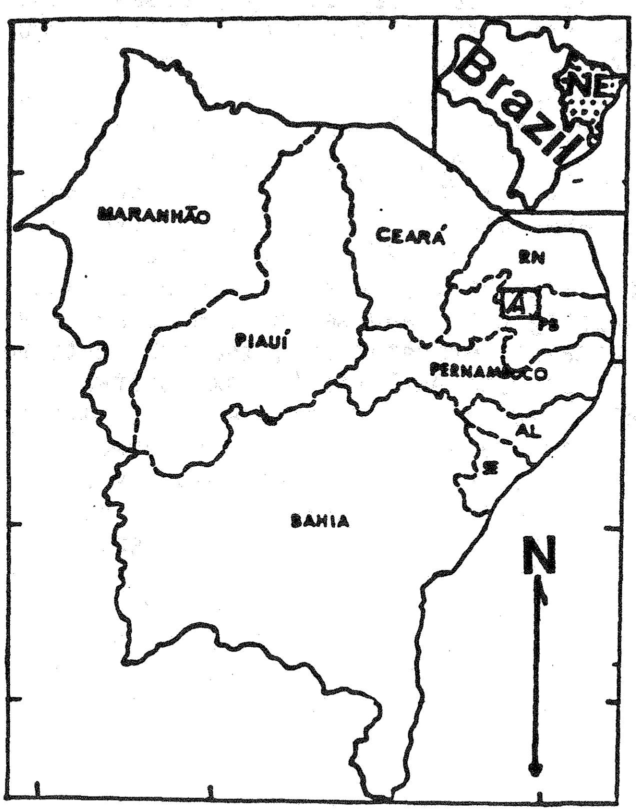


Figure 1. Study Site (A) in northeastern Brazil, partly in Paraiba and Rio Grande do Norte. The location of the north-eastern area is shown on the inset map of Brazil.

Using data and imagery from SPOT, optical and digital interpretations were carried out for Santa Luzia and environs to discriminate and map the following:

a) Surface water, erosion and drainage patterns.
b) Land use and land cover.
c) Major soils.
d) Land capability classes.

GENERAL PHYSIOGRAPHY OF THE STUDY AREA

Geologically, the area is covered by the following major formations: Halocene (alluvium, sands, etc.); Precambrian(B) (mica schist, phyllite, muscovite, biotite schists, etc.); Precambrian(CD) (gneisses, migmatites with mica schists and granites) and Plutonics (mainly granites). Physiographically, the study area falls into three categories: (1) Serido - slightly undulating and hilly to mountainous with depressions. Soils are moderately fertile with rocks and stones and with coarse to medium textures, but sometimes fine texture soils also are present. Major soils of the area are: Non-Calcic Brown, Red-yellow Podzolic, Halomorphic Alluvial and Hilly and Rocky; (2) Borborema Central-strongly undulating to mountainous areas with deep valleys with some depressions. Soils are moderately to poorly fertile. Major soils found in this region are: Latosols, Red-yellow Podzolic, Alluvial, Lithosols, etc.; (3) Hinterland of the Piranhas (Sertao do Piranhas) - level to undulating lands with scattered hills and rock ridges. Soils are slightly to moderately fertile with severe problems of salinity/alkalinity in patches. The soils are coarse to medium textured and major types are Red-yellow Podzolic, Non-Calcic Brown, Alluvial, Halomorphic and Hilly and Rocky. Hydrologically, the area is drained by a network of the Sabugi and Farinha Rivers which form lakes at Lagoa do Meio, Barra and Acude Publico de Santa Luzia. Limited parts of the area are irrigated with reservoir waters, but most crop production is dependent on natural rainfall.

The area falls into two bioclimatic types of Gaussen (1967). The first area is classed as tropical with high drought (4aTH) possibility where the dry period ranges from 7 to 8 months and the xerothermic index is between 150 and 200. It occurs mainly in the zone of Hinterland and in the northwestern part of the study area. The second area is classed as tropical or sub-desertic (equatorial hot) (2b) where the dry period ranges from 9 to 11 months and the xerothermic index varies between 200 and 300. It occurs particularly in the Hinterland and in nearly all of the Borborema Central. Vegetationally, the area is characterized by xerophytic plants because of its semi-arid to arid climate. The principal types of natural vegetation (forests) occurring in the area, using the Brazilian classification, are: Caatinga hipoxerofila, Caatinga hiperxerofila, Caducifolia forest, and Sub-caducifolia forest.

METHODOLOGY

Data from the French environmental satellite, SPOT, were used to detect and delineate surface water, erosion patterns and drainage patterns of major rivers and their tributaries; land use and cover; and major soil types for selected semi-arid areas of the States of Praiba and Rio Grande do Norte, Brazil. A dual approach using optical and digital interpretations was developed using both false color imagery and data in digital format. The two procedures are complementary - optical interpretation provides the detail required for boundary definitions and information extraction from imagery, whereas digital interpretation provides a mechanism for the automated processing, analyzing and retrieving of large quantities of information. On-site studies to verify optical and digital interpretations were carried out in March and April 1988.

OPTICAL INTERPRETATION

Optical interpretations were carried out for the entire study area using a multi-spectral false color composite of SPOT imagery Bands 1,2 and 3 at a scale of 1:110,000. An enlarged paper print of this composite was placed on a light table and boundaries of areas homogeneous in color and/or pattern were drawn in by hand. The mapping units thus recorded were identified by: (1) comparison with published technical reports and maps, (2) comparison with a generalized interpretation key (Teotia, 1981); and (3) verification with ground truth data collected on site in March and April 1988. These visual interpretations resulted in the preparation of four maps: 1). surface water, erosion and drainage patterns; 2). land use and land cover classifications according to Anderson et al. (1976); 3). major soil associations following the USDA Soil Taxonomy (1975) and SUDENE (1972); and 4). the Land Capability Classification of the USDA (1966), and of SUPLAN (1978) and Alves (1986). The Anderson et al. (1976) classification system was modified to suit the climate and physiography of the study area. The classification system prepared for the State of Connecticut (USA) by DEP-NRC/USGS-NMD (Avery and Berlin, 1985) was used in part for detailed classifications (Level III). The research on land use/cover for planning in Paraiba by Teotia and Ulbricht (1985) also was of value. To facilitate interpretations of the SPOT image, the results of studies by Colomb, Kennard and Civco (1985) and by Civco and Kennard (1983) were utilized.

RESULTS AND DISCUSSION

The optical interpretations resulted in the preparation of four maps: surface water, erosion and drainage pattern; land use and land cover; soil; and land capability. These maps, originally prepared at a scale of 1:110,000, were reduced to a scale of 1:1,000,000. Through optical interpretation, all the large and small lakes and reservoirs were located on the map and the following drainage patterns recognized: dendritic, parallel, sub-parallel and braided (Figure 2).
The land use and land cover classification resulted in seven general categories at Level I, 14 somewhat detailed categories at Level II, and 27 very detailed ones at Level III. Elements of the land use and land cover classifications at Level I, II, and III are given in Table 1 (See also Figure 3).

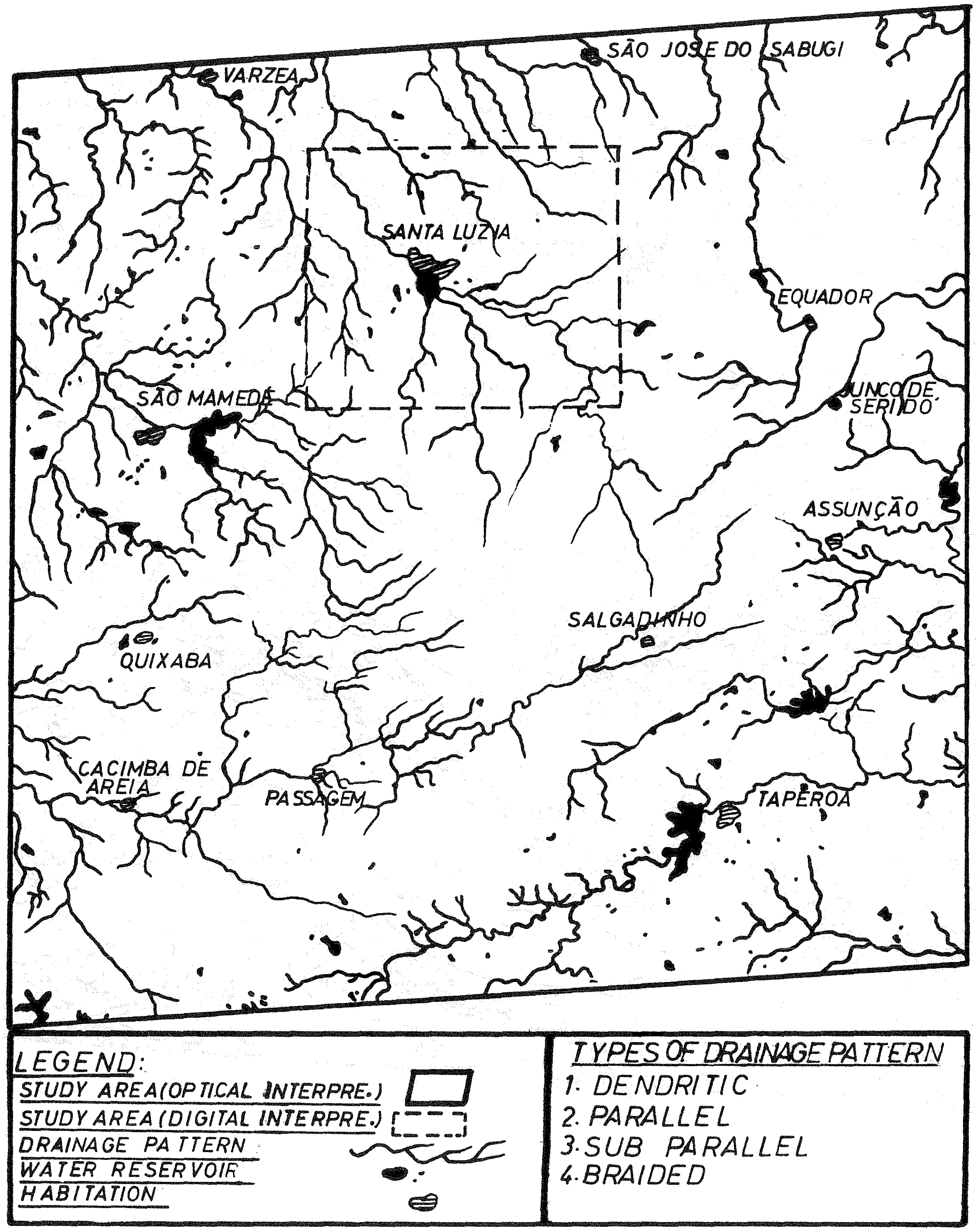


Figure 2. Surface water, erosion and drainage patterns of the study area.

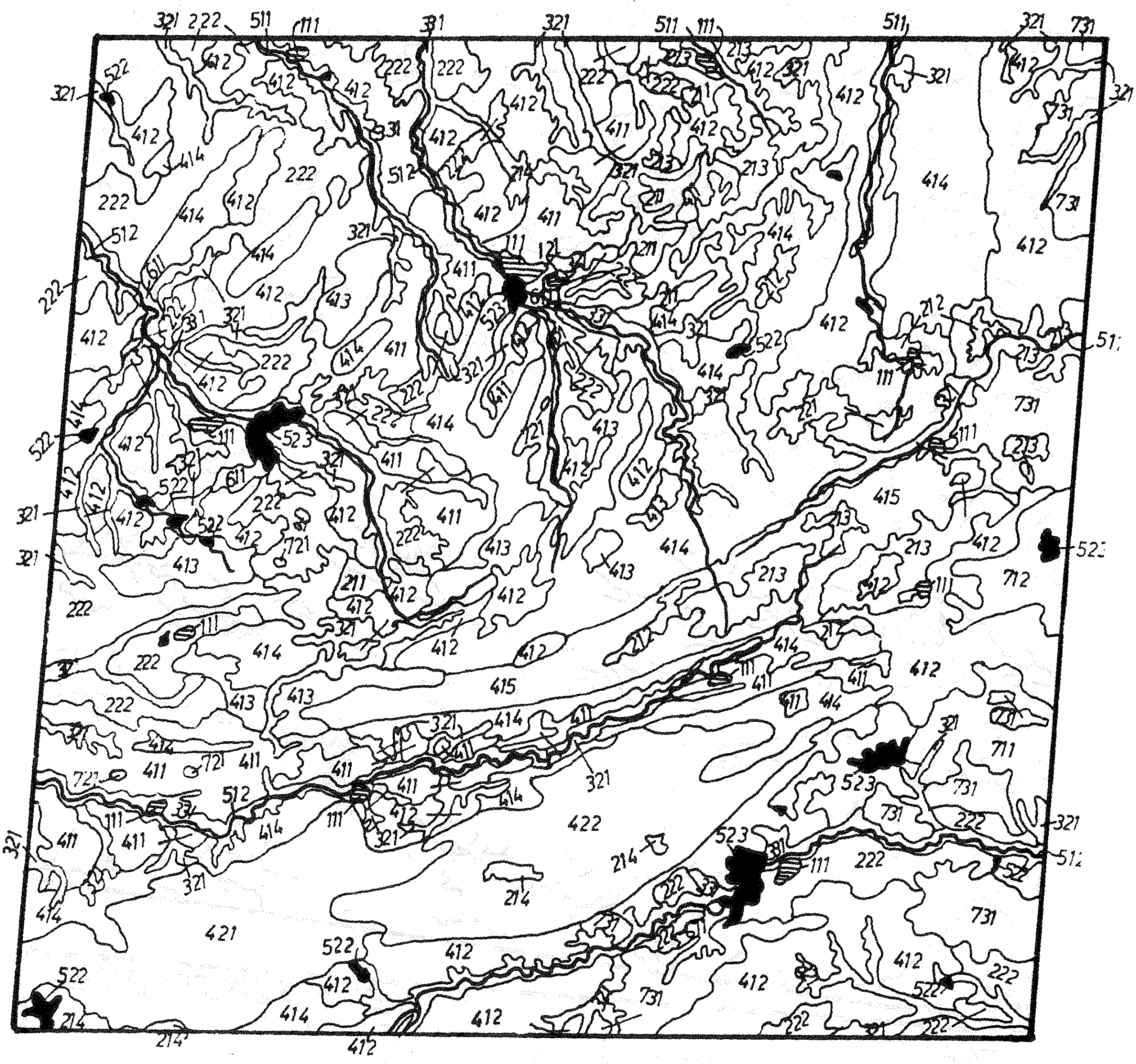


Figure 3. Land and land use classes of the study area (for key to codes see Table 1).

Table 1. Land use and land cover classification of the study area

Level I	Level II	Level III
1 Urban or built-up land (Red)	11 Residential	111 Compact urban cities
	12 Other urban and built-up	121 Scattered urban and barren land
2 Agricultural land (Light brown)	21 Cropland and pasture	211 Cultivated on nearly level and coarse-textured soil
		212 Pasture on nearly level to nearly sloping and coarse-textured soil with few rocks
		213 Cultivated and fallow on slightly undulating to nearly level and dominantly coarse-textured soil.
		214 Beans, maize and cotton cultivated on slightly undulating and coarse to medium textured soil
	22 Other agricultural land	221 Mixed crop, cultivated land on slightly undulating and coarse to medium-textured soil
		222 Mixed crops, cultivated land on slightly undulating and medium to fine-textured soil
3 Range land (Light orange)	32 Shrubs and brush land	321 Sparse shrubs, trees and cultivated crops and eroded land
	33 Mixed rangeland	331 Dense shrubs, trees, cultivated crops and eroded land
4 Forest land (Green)	41 Caatinga forest	411 Sparse Caatinga hiperxerofila on slightly undulating and medium textured soil
		412 Sparse to moderately dense Caatinga hiperxerofila on undulating to strongly undulating and coarse to medium-textured soil
		413 Sparse to moderately dense Caatinga hiperxerofila on rocky, stony and coarse to medium-textured, hilly land
		414 Moderately dense to dense Caatinga hiperxerofila on strongly undulating and hilly and coarse to medium-textured soil
		415 Dense Caatinga hiperxerofila on hilly to to mountainous, coarse-textured and stony land

Table 1. (continued)

Level I	Level II	Level III
	42 Mixed Caatinga forest	421 Mixed Caatinga forest of hiperxerofila and hipoxerofila and Caducifolia forest on rocky, stony and coarse to medium-textured, strongly undulating to hilly soil
		422 Mixed Caatinga forest of hiperxerofila and hipoxerofila and Caducifolia forest with cultivated patches and pasture land on strongly undulating, stony, coarse to medium-textured soil
5 Water (Dark blue)	51 Streams/rivers	511 Dry streams or tributaries
		512 Perennial streams
	52 Lakes	521 Many very small lakes (non-mapped)
		522 Many medium size lakes (few mapped)
		523 Few large lakes
6 Wet land (Light blue)	61 Non-forest wetland	611 Non-forest wet alluvial land with some cultivation and shrubs and barren land
7 Barren land (Gray)	71 Dry salt flats	711 Dry saline and waste land on slightly undulating and medium to fine-textured soil
		712 Dry saline soils mixed with non-calcic brown and lithic soils of coarse to medium texture and natural pastures and sparse Caatinga forest on slightly undulating land
	72 Bare, exposed rocks	721 Bare rock outcrops
	73 Mixed bare land	731 Hilly and rocky land with shallow soil of coarse to medium texture and sparse vegetation and little cultivation.

The major soils which were detected on the SPOT imagery by optical interpretation are Alfisols (Non-Calcic Brown Soils, Red-yellow Podzolic, Ultisols (Latossols), Entisols and Inceptisols (Alluvial Plain Soils), Entisols (Regosols), Inceptisols (Cambisols) and Lithic Sub-groups of various orders (Lithosols) and Rock-Outcrops. The major divisions of the classification at the sub-order and sub-group levels are given in Table 2 (See also Figure 4).

Capability classification is one of several interpretive groups designed primarily for agricultural purposes. It provides three categories of soil groups: 1). capability class, 2). sub-class and 3). capability unit (Figure 5). The capability category is divided into eight classes. The probability of soil damage or limitation in use becomes progressively greater from class I to VIII. The sub-class is a grouping of capability units having similar limitations, identified by adding a lower case letter (e,w,s,c) to the class number where: e = erosion, w = excess water, s = root zone limitations and c = climatic limitations. Soils were classified only at the sub-class level as shown in the following listing:

Table 2. Soil classifications of the study area at the sub-order and sub-group levels.

MAPPING UNITS	SUB-ORDERS	MAJOR SOIL ASSOCIATIONS AT SUB-GROUP LEVEL+
U_1	USTULTS-USTALFS-OCHREPTS	T.RHODUSTULTS-T.HAPLUSTALFS-T.USTOCHREPTS
Al_1	USTALFS-USTERTS-USTALFS	V.HAPLUSTALFS-L.HAPLUSTALFS-T.CHROMUSTERTS-T.NATRUSTALFS
Al_2	USTALFS-OCHREPTS	V.HAPLUSTALFS-L.HAPLUSTALFS-T.NATRUSTALFS-T.USTOCHREPTS
Al_3	USTALFS-ORTHENTS	T.NATRUSTALFS-T.HAPLUSTALFS-T.USTORTHENTS-L.USTORTHENTS
In_1	OCHREPTS-USTULTS-ORTHENTS	O.USTOCHREPTS-T.RHODUSTULTS-T.USTORTHENTS
In_2	OCHREPTS-USTULTS-ORTHENTS	O.USTOCHREPTS-L.USTOCHREPTS-T.RHODUSTULTS-T.USTORTHENTS**
In_3	OCHREPTS-ORTHENTS	O.USTOCHREPTS-T.USTOCHREPTS-T.EUTROCHREPTS-T.USTORTHENTS-L.USTORTHENTS**
L_1	ORTHENTS-USTALFS	L.USTHORTHENTS-T.HAPLUSTALFS-L.HAPLUSTALFS
L_2	ORTHENTS-USTALFS	L.USTORTHENTS-L.HAPLUSTALFS-T.HAPLUSTALFS-T.NATRUSTALFS
L_3	ORTHENTS-USTALFS	L.USTORTHENTS-L.HAPLUSTALFS-V.HAPLUSTALFS-T.NATRUSTALFS
L_4	ORTHENTS-USTALFS	L.USTORTHENTS-L.HAPLUSTALFS-V.HAPLUSTALFS**
L_5	ORTHENTS-USTALFS	L.USTORTHENTS-T.HAPLUSTALFS-L.HAPLUSTALFS**
L_6	ORTHENTS-USTALFS-OCHREPTS	L.USTORTHENTS-L.HAPLUSTALFS-T.USTOCHREPTS-L.USTOCHREPTS**
L_7	ORTHENTS-PSAMMENTS-USTALFS	L.USTORTHENTS-L.USTIPSAMMENTS-L.HAPLUSTALFS**
A_1	FLUVENTS-PSAMMENTS-OCHREPTS-ORTHENTS-USTALFS	T.USTIFLUVENTS-T.USTIPSAMMENTS-T.USTOCHREPTS-T.EUTROCHREPTS-T.USTORTHENTS-T.NATRUSTALFS
E_1	PSAMMENTS-ORTHENTS-OCHREPTS	T.USTIPSAMMENTS-T.USTORTHENTS-T.USTOCHREPTS
E_2	PSAMMENTS-OCHREPTS-ORTHENTS	T.USTIPSAMMENTS-T.USTOCHREPTS-T.USTORTHENTS-L.USTORTHENTS**
R_1	ROCK-OUTCROPS-ORTHENTS	ROCK-OUTCROPS-L.USTORTHENTS

+ Explanation of letter designations: L=Lithic, O=Oxic, T=Typic and V=Vertic.

** Rock-Outcrops present

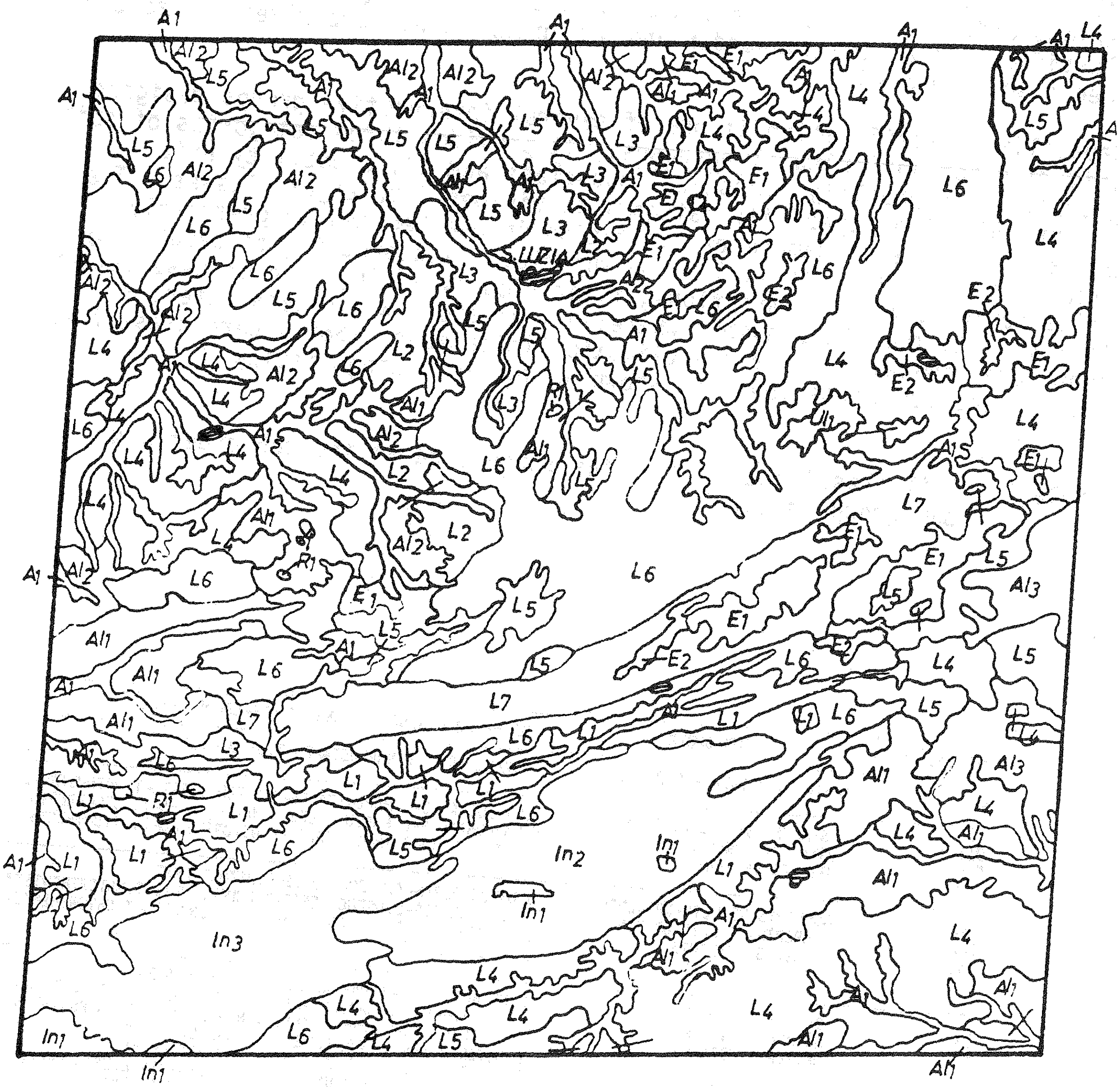


Figure 4. Soil mapping units of the study area (See Table 2 for key to soil classes).

Capability Units	Characteristics
	LAND SUITED FOR CULTIVATION AND OTHER PURPOSES
	Moderately Good Land for Cultivation
IIIs	Land has limitations of low fertility & slight slope
IIIsw	Land has limitations of low fertility & occa.inundation
IIIes	Land has limitations of erosion,slope and soil
	Relatively Good Land for Cultivation
IVes	Land has limitations of erosion,slope and soil
	LAND NOT SUITED FOR CULTIVATION
VIes	Land suited for pasture or range land and has limitations of erosion, slope, and soil(depth and rockiness/stoniness)
VIIes	Land suited for pasture and forest and has limitations of erosion, slope and soil
VIIIes	Land not suited for cultivation,pasture and forest and has limitations of erosion and soil(Rock-Outcrops)

Figure 5. Land capability units of the study area.

Land Suited For Cultivation And Other Purposes

Class III. Soils have severe limitations that reduce the choice of plants or require special conservation practices.

IIIs Soils are moderately deep to deep and are found on nearly level to slightly undulating topography. The major limitations of these lands are low fertility and slight slope. Mapping Unit - Ul_1

IIIsw Soils are deep to very deep and are found on nearly level to slightly undulating topography. The major limitations of this unit are low fertility and occasional inundation in rainy season. Mapping unit A_1

IIIes Soils are moderately deep to deep and are found on slightly undulating to undulating topography. The major limitations of this unit are erosion, slope and soil. Mapping units Al_1, Al_2, In_1, E_1

Class IV Soils have very severe limitations that restrict the choice of plants or require careful management.

IVes Soils are shallow to moderately deep and are found on slightly undulating to undulating topography. The unit has major problems of erosion, slope and soil. Mapping units Al_3, In_2, L_2, L_3, E_2

Land Not Suited For Cultivation

Class VI Soils have severe limitations that make them generally unsuited for cultivation, and limit their use largely to pasture or rangeland, woodland or wildlife food and cover.

VIes Soils are dominantly shallow and are found on strongly undulating topography. The unit has major problems of erosion, slope, soil depth, rockiness and stoniness. These can be used for forestation. Intensive management is required. Mapping units In_3, L_4, L_5

VII Soils have very severe limitations that make them unsuitable for cultivation, and restrict their use largely to grazing, woodland and wildlife.

VIIes Soils are shallow on hills and mountainous topography. Major problems of this unit are soil depth, slope, and erosion. Mapping Units L_6, L_7

VIII Soils and landforms have limitations that preclude their use for commercial crop production and restrict their use to recreation, wildlife or water supply or to esthetic purposes.

VIIIes Lands generally are barren rock outcrops. They have problems of erosion and soil depth which is very thin. Mapping unit R_1

DIGITAL INTERPRETATION

The purpose of the digital interpretation phase of this project was to apply image processing and pattern recognition techniques to SPOT multispectral image data to derive three types of earth resources information:

1. Land use and land cover to three levels of classification detail (after Anderson et al., 1976)
2. Land capability classes (after USDA, 1966)
3. Soil suborder classes (after USDA, 1975)

Table 3 lists the three levels of the classification hierarchy for which land use and land cover were determined.

Level 1B multispectral data from the SPOT-1 HRV scene dated 10 May 1987 (728,364) were processed with ERDAS (Earth Resources Data Analysis System) software operating on a PC's Limited 30386-based supermicrocomputer. This system consists of hardware and software for the subsetting and reformatting, radiometric and geometric correction, classification, and display of digital images. The system is capable of displaying 512 by 512 pixel images in as many as 16 million colors. The hardcopy color display can reproduce scaled images and maps in as many as 4098 colors and patterns. The ERDAS configuration consists also of a 9-track tape drive and high-volume disk storage devices.

A 1,000 by 1,000 pixel subscene centered around Santa Luzia in the State of Paraiba, Brazil, was subset from 9-track magnetic tape for subsequent analysis. Figure 6 is an illustration of SPOT HRV Band 3 for a 25 km^2 portion of the study area. Field studies conducted in Paraiba during the months of March and April 1988 provided the ground truth reference data necessary for land use and land cover classification from the SPOT multispectral data. More than 30 unique sites were visited, all contained within the study area, and observations for land cover, land forms, and soils were made. These observations were used to conduct a supervised classification of the SPOT image.

Based on the field observations, 41 training areas were selected, using the interactive capabilities of the ERDAS system, for the land cover classes of interest. The relevant statistics (i.e., means and variance/covariance matrices) were generated for these training areas and a maximum likelihood classification was applied to the entire 1,000 by 1,000 pixel image. After inspection of the initial classification, certain categories were aggregated and others deleted to reduce potential misclassification while still retaining maximum information. This resulted in the classification of five general categories at Level 1, 12 somewhat detailed categories at Level II, and 24 very detailed ones at Level III.

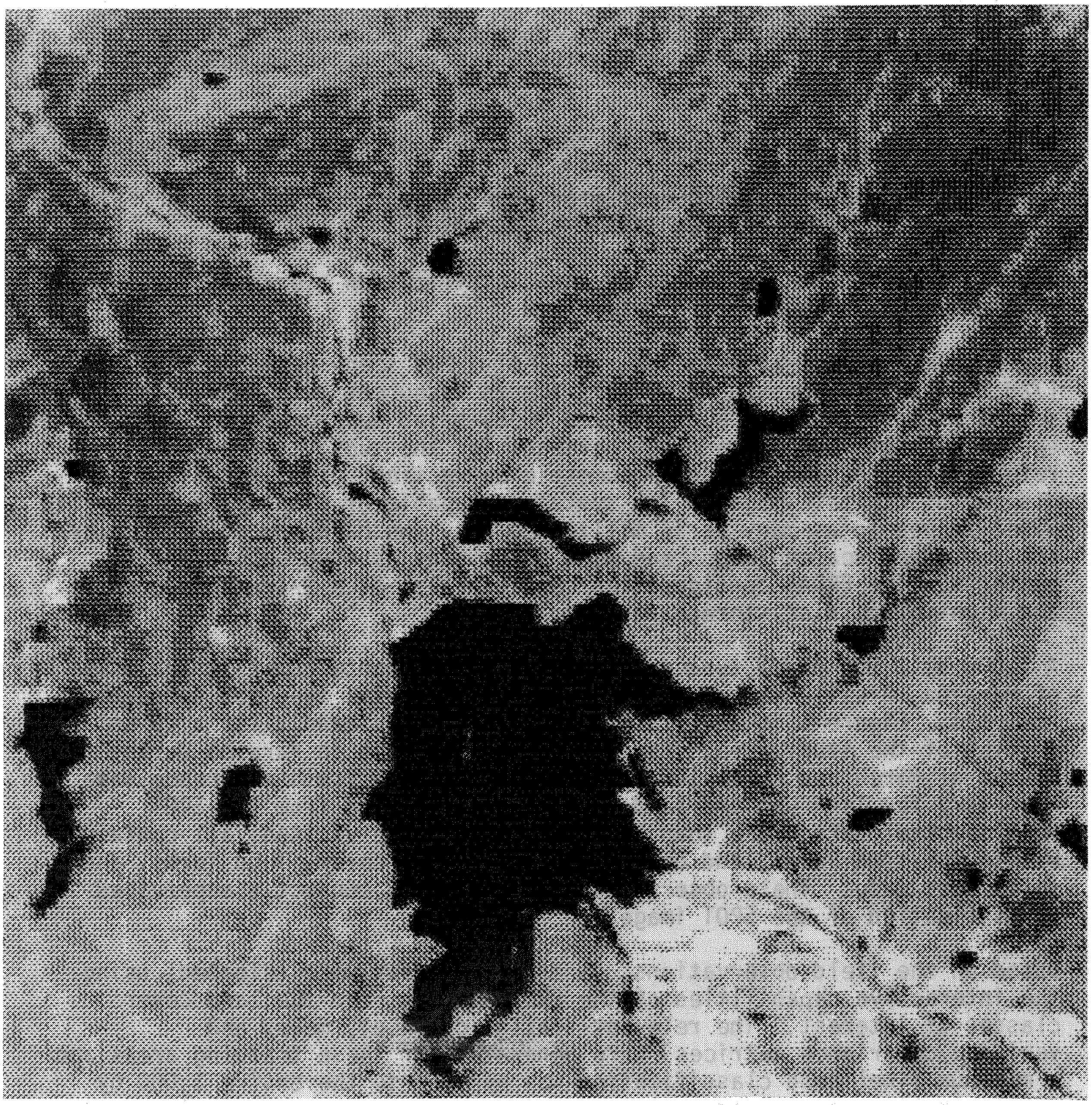


Figure 6. Gray scale rendition of SPOT Band 3 image data for a 25 km^2 portion of the study area (Scale = 1:30,000)

Table 3. Land use and land cover categories for Santa Luzia Municipality and its adjoining areas - number of pixels for each category given in first parentheses and classification accuracy percentage in the second parentheses.

1 Urban/Barren	(20,004)	(86.5)	11 Urban/Barren	(20,004)	(85.4)	111 Urban/Barren	(20,004)	(81.2)
2 Agriculture	(480,563)	(65.2)	21 Cultivated	(120,556)	(72.0)	211 Beans and Cotton	(13,437)	(22.9)
						212 Cotton & Cult.	(66,010)	(57.3)
						213 Fallow	(41.109)	(56.7)
			22 Pasture	(170,886)	(40.8)	221 Pasture W/R.	(49.067)	(39.0)
						222 Pasture W/O R.	(80,495)	(39.0)
						223 Pasture (stony/ fallow)	(50,324)	(25.6)
			23 Cultivated Pasture	(180,121)	(64.4)	231 Maize and Past	(11,222)	(52.4)
						232 Mixed Cul.&Past.	(91,085)	(66.1)
						233 Cotton and Past.	(77,814)	(35.0)
3 Rangeland	(24,313)	(74.8)	31 Shrubs/Cult.	(10,457)	(47.5)	311 Mod. Dense, Cult.	(10,457)	(42.9)
						312 Mod. Dense, S/Cul	(4,262)	(65.6)
						313 Dense & Some Cult	(9,594)	(70.0)
			32 Shrubs & Trees	(13,856)	(73.0)	321 Shrubs & Trees	(22,484)	(36.2)
4 Forest	(486,662)	(96.9)	41 Caatinga & Cult	(22,484)	(38.6)	411 Sparse Caatinga & Cult	(86,937)	(71.9)
			42 Sparse Caatinga	(91,094)	(53.0)	421 Steeply Undulat	(102,223)	(84.6)
						422 Slightly Undulat	(42,496)	(12.1)
			43 Mod. Dense Caatinga	(288,260)	(78.9)	431 Steeply Undulat	(87,408)	(41.5)
						432 Mountainous	(10,050)	(56.1)
						433 High Hills	(50,240)	(35.4)
			44 Dense Caatinga	(66,824)	(79.7)	441 High Hills	(60,969)	(53.6)
						442 Mountainous	(5,855)	(10.7)
5 Water	(6,458)	(99.8)	51 Mod. Deep Water	(2,279)	(96.3)	551 Mod. Deep Water	(2,279)	(96.3)
			52 Deep Water	(4,179)	(100.0)	521 Deep Water	(4,179)	(100.0)
Total Pixels	1,000,000			1,000,000			1,000,000	

Simultaneous with the selection of training areas for the supervised classification, test area pixels were chosen for each of the categories at each of the three levels of detail. These test areas were used to quantify mapping accuracy. The accuracy of each level of mapping was assessed by intersecting the maximum likelihood classification results with their respective ground truth digital maps. This intersecting of maps revealed the per-category amount of agreement and disagreement.
The land capability and soil suborder maps were produced by a recoding of the original 41 class land use and land cover digital maps. Six distinct capability classes and 11 soil suborder classes were identified and mapped. This recoding was possible because of the high degree of correlation of land use and land cover with these two other features. Field investigations conducted at the sites confirmed this relationship.

All digital analyses were performed using the Level 1B SPOT data. Geometric corrections were applied only after the operations were performed. Ground control points were selected from a 1:100,000 scale map of the area. The image positions of these coordinates were interactively identified and an affine transformation matrix was calculated (RMSE < 1 pixel). This matrix was used to register the digital data to a Universal Transverse Mercator (UTM) projection. The image data were resampled to 20 meters using a cubic convolution algorithm, whereas the land use, land capability, and soils digital maps were resampled using a nearest neighbor algorithm.

RESULTS AND DISCUSSION

Figure 7 is a Level I land use and land cover map, derived from computer processing of the SPOT digital data, centered around Santa Luzia, of the five general categories, and Table 3 is an enumeration of the classifications at all three levels for the entire study area. Visual inspection of on-screen displays of all three levels of land cover classification detail, and comparison with reference information, revealed them to resemble closely field observations. A more rigorous, quantitative measure of accuracy performed using the test areas, however, indicated that some categories were classified and mapped more reliably than others. Table 4 shows the degree and distribution of misclassification at Level I of the hierarchy. It is evident that there is quite a bit of confusion among certain categories, particularly between agriculture and forest. An examination of the Level II classification matrix (Table 5) elucidates, to some extent, these errors of omission and commission by indicating the source of confusion at the subcategory level. Many pixels omitted from what should have been classified as pasture or cultivated pasture were committed into the sparse or moderately dense Caatinga forest categories. Likewise, many of the pixels omitted from what should have been classified as Caatinga forest and cultivated lands or sparse to moderately dense Caatinga forest were committed into the pasture or cultivated pasture categories. This confusion is due to the spectral similarity between these categories and is often a problem with pattern recognition (i.e., classification) methods dealing with per-pixel spectral data alone. Other spatially-oriented data are required to augment and enhance the classification process (Civco, 1987). Also, the limited spectral range of the SPOT HRV sensor (green, red, near infrared) may

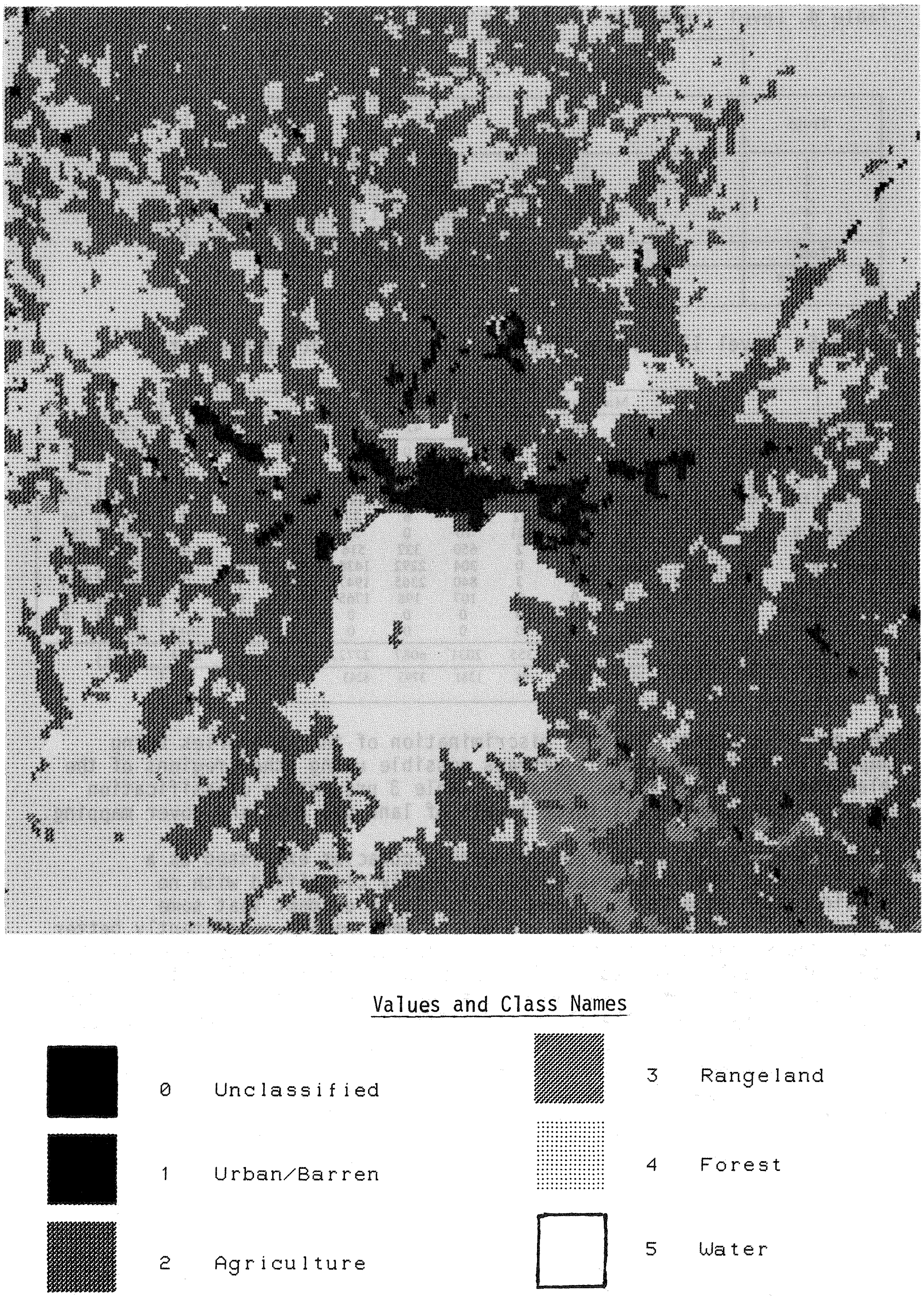


Figure 7. Level I land use and land cover map derived from maximum likelihood classification of SPOT HRV multispectral data (Scale = 1:30,000)

Table 4. Level I maximum likelihood classification error matrix

Truth	Maximum Likelihood Classification 1	2	3	4	5	Total	Omit
1	437	6	0	62	0	505	68
2	314	9905	5	4952	18	15194	5289
3	0	44	455	109	0	608	153
4	0	1266	9	40339	1	41615	1276
5	0	5	0	0	2775	2780	5
Total	751	11226	459	45462	2804	60702	
Commit	314	1321	14	5123	19		

Table 5. Level II maximum likelihood classification error matrix

Truth	Maximum Likelihood Classification 11	21	22	23	31	32	41	42	43	44	51	52	Total	Omit
11	481	7	2	3	0	0	0	0	69	1	0	0	563	82
21	30	1096	72	70	0	0	0	149	66	20	1	18	1522	426
22	1	213	3175	237	0	0	9	285	3814	56	0	0	7790	4615
23	239	616	370	4167	1	5	98	460	499	11	0	0	6466	2299
31	0	0	1	35	96	22	13	6	22	7	0	0	202	106
32	0	0	1	7	17	321	10	0	54	30	0	0	440	119
41	0	0	3	162	0	2	650	332	516	20	0	0	1685	1035
42	0	8	18	169	0	0	304	2292	1438	90	0	0	4319	2027
43	0	3	704	77	0	3	840	2365	19479	1224	1	2	24698	5219
44	0	0	0	5	0	2	107	198	1765	8163	0	0	10240	2077
51	0	5	0	0	0	0	0	0	0	0	158	1	164	6
52	0	0	0	0	0	0	0	0	0	0	0	2613	2613	0
Total	751	1948	4346	4932	114	355	2031	6087	27722	9622	160	2634	60702	
Commit	270	852	1171	765	18	34	1381	3795	8243	1459	2	21		

not permit adequate spectral discrimination of the categories being mapped -- discrimination is perhaps possible using other regions of the electromagnetic spectrum. Finally, Table 3 presents a classification accuracy overview at all three levels of land use and land cover mapping.

Shown here are the simple per-category accuracies expressed as a percentage of the test area pixels correctly classified with no consideration of errors of commission. It is evident that some categories, especially forest and water, were mapped consistently better than others, and that classification accuracy typically worsened as the level of detail increased. This phenomenon is typical of a hierarchical classification in which the more detailed classes within a parent category are often very spectrally alike and difficult to discriminate. In fact, the only Level III categories which were classified with an acceptable level of accuracy (> 85 percent) were urban/barren lands and the two subclasses of water. The relatively low accuracies at Level III, and also at Level II, can be attributed to cross-confusion among related categories. This is particularly evident among the agricultural subcategories and among the forest subcategories.

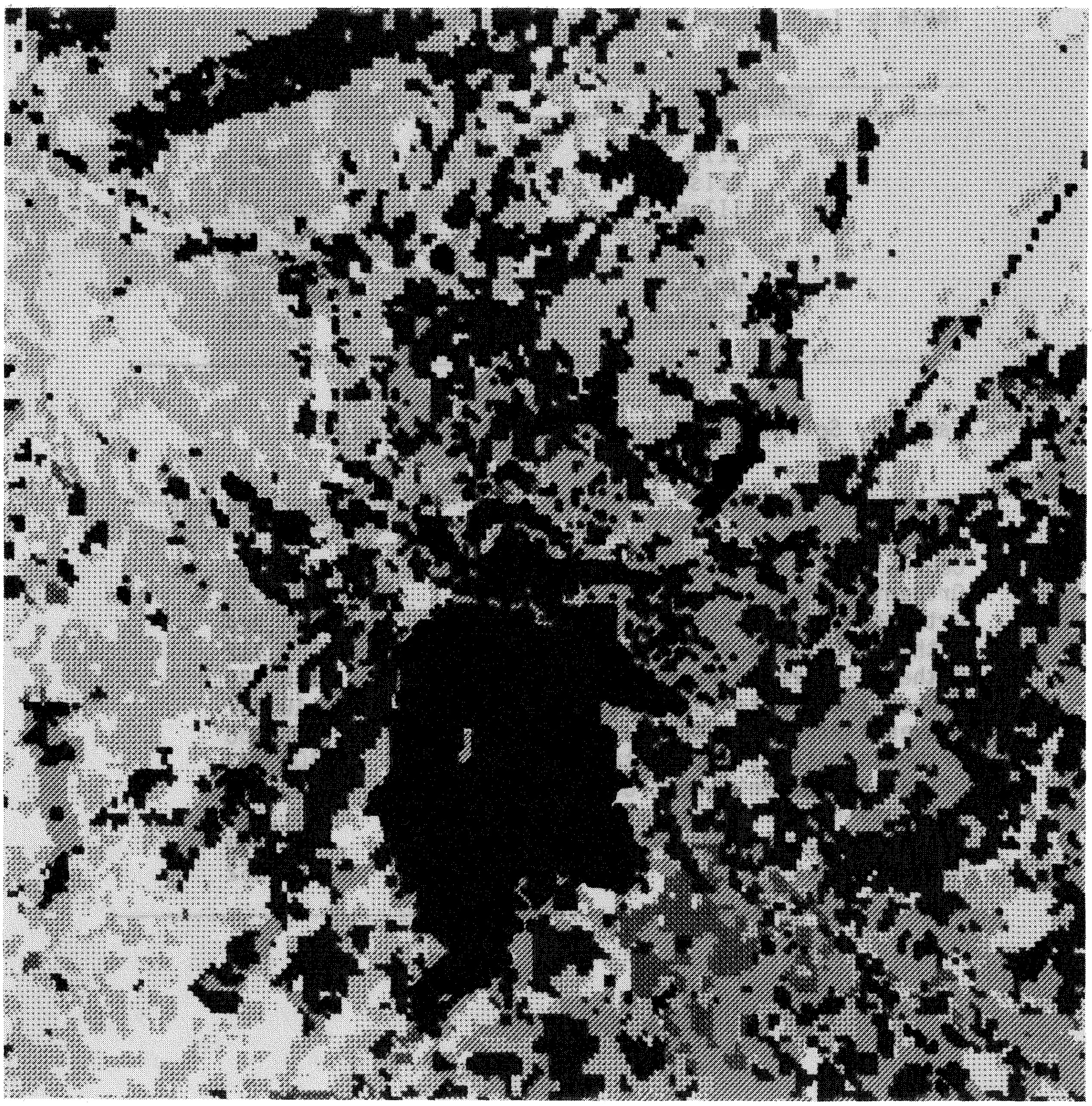
Figures 8 and 9 are examples of the land capability and soil suborder maps, respectively, derived from the original 41 category digital land cover maps. Tables 6 and 7 show the summary data for these two features for the entire study area. Although quantitative accuracy assessments were not performed on these maps, the familiarity of the principal author with the study area indicates them to be sufficiently reliable to be used in a natural resources management context, such as a digital geographic information system (GIS), for planning and decision-making purposes.

Table 6. Land capability classification summary

Capability class	Number of Pixels
IIIs	159,813
IIIsw	14,719
IIes	135,777
IVes	244,016
VIes	255,850
VIIes	193,363
not rated	26,462

Table 7. Soil sub-order classification summary

Soil Sub-order	Number of Pixels
Ochrepts-Ustalfs-Orthents	65,192
Orthents-Psamments	75,479
Orthents-Ustalfs-Ochrepts	63,944
Orthents-Ustalfs-Psamments	9,112
Orthents-Ochrepts-Psamments	145,129
Fluvents-Ochrepts-Psamments	10,457
Fluvents-Psamments-Ochrepts	13,856
Orthents-Ustalfs-Rock Outcrops	408,373
Orthents-Psamments-Rock Outcrops	20,373
Orthents-Ustalfs-Psamments-Rock Outcrops	101,335
Orthents-Psamments-Ustalfs-Rock Outcrops	60,290
Non-soil Areas	26,462



Values and Class Names

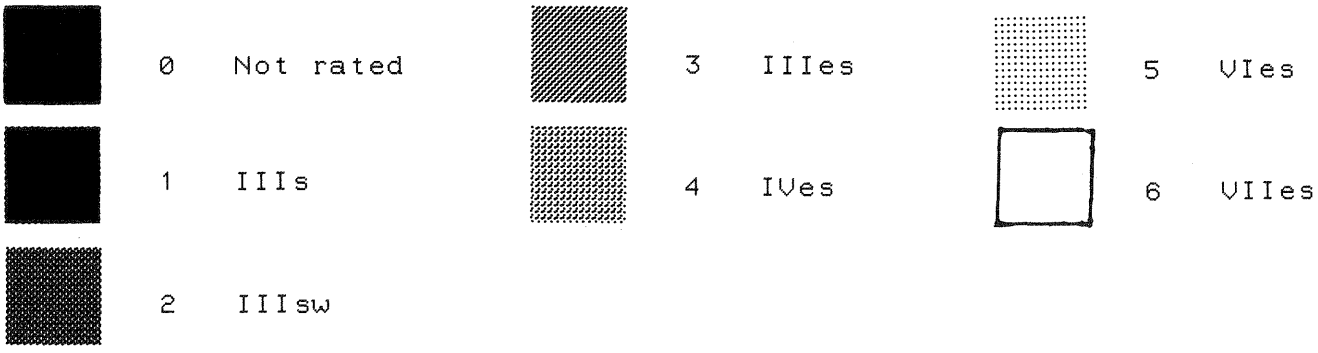
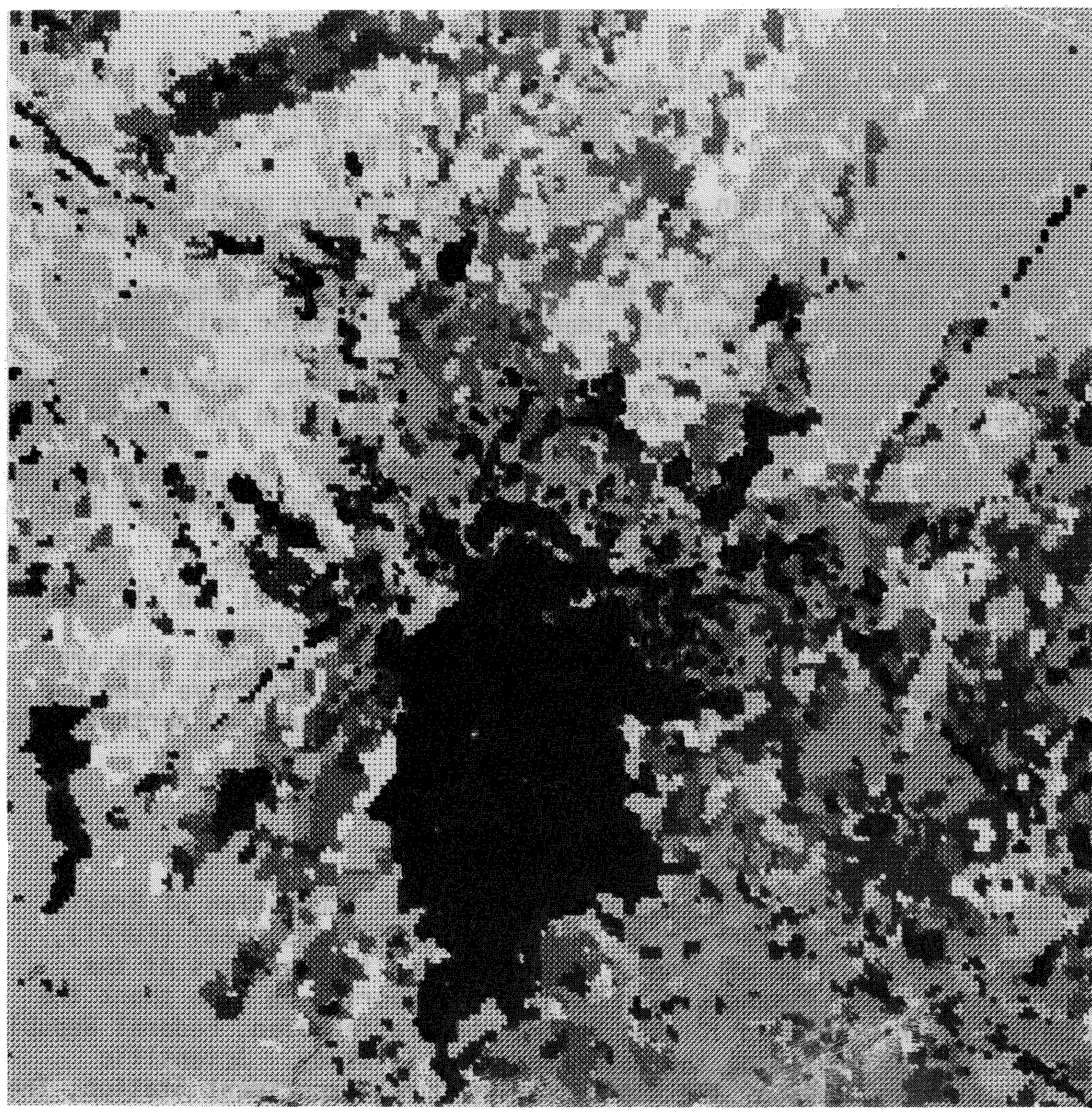
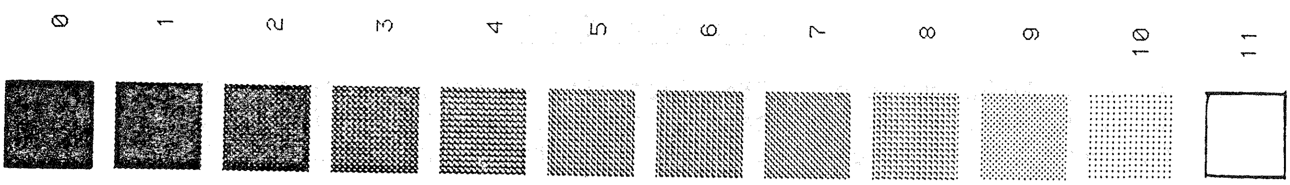


Figure 8. Land capability classes derived from land use and land cover data (Scale = 1:30,000)



<u>Values and Class Names</u>



0 Non-soil
1 Ochrepts-Ustalfs-Orthents
2 Orthents-Psamments
3 Orthents-Ustalfs-Ochrepts
4 Orthents-Ustalfs-Psamments (RO
5 Orthents-Ochrepts-Psamments
6 Fluvents-Ochrepts-Psamments
7 Fluvents-Psamments-Ochrepts
8 Orthents-Ustalfs (RO)
9 Orthents-Psamments (RO)
10 Orthents-Ustalfs-Psamments (RO)
11 Orthents-Psamments-Ustalfs (RO)

Figure 9. Soil suborder classes derived from land use and land cover data (Scale = 1:30,000)

CONCLUSIONS

1. Optical and digital interpretations of SPOT 20-m resolution imagery proved to be effective in determining soils, surface hydrology and land use/cover for a selected area in the semi-arid region of northeastern Brazil.
2. Optical interpretation of small-scale SPOT imagery permitted general synoptic mapping, whereas digital processing of SPOT multi-spectral data permitted more detailed assessment.
3. Optical interpretations of the 1:110,000 scale SPOT false-color composite permitted accurate identification of major soil groups, especially when supplemented with field observations.
4. Accuracy assessments of the digital classifications showed that some categories such as forests and water were identified and mapped more accurately than other categories.
5. The limited spectral range of the SPOT HRV sensor (green, red and near infrared) did not appear to permit adequate discrimination of land use and land cover categories, especially at Level III.
6. Classification became less accurate as the level of detail increased--the relatively low accuracies at Levels II and III were attributed to cross-confusion among related categories.
7. Optical and digital interpretations of natural resources data are complementary and, together, provide a base for effective land use planning and management in a drought-prone area such as northeastern Brazil.

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