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Table 107. Summary of average soil chemical parameters grouped into relative P fixation categories (soils from 23 Colombian sites).

Category	Soil classification	Relative P fixation	% P fixed (10 ppm P added)	pH	Organic matter (%)	Exchangeable Al (meq/100 g)	% Al saturation	Active Al (meq/100 g)	Reactive Al (meq/100 g)
1	Andept	Very high	80%	5.3	20.4	1.3	39.2	12.3	29.8
2	Andept-Oxisol-Ultisol	High	60-80%	5.0	7.8	2.3	40.9	3.8	8.9
3	Oxisol-Inceptisol	Medium	40-60%	4.8	4.2	2.5	56.7	3.1	7.3
4	Mollisol	Low	40%	6.3	4.3	0.2	0.8	0.7	3.4

Category	Free Fe oxide (% Fe_2O_3)	P-Al ppm	% P-Al of total P	P-Fe ppm	% P-Fe of total P	Organic P (ppm)	% organic P of total P	Number of sites
1	2.9	16.2	2.1	6.3	1.1	603.0	72.0	4
2	4.6	4.1	0.8	46.4	6.7	267.1	54.8	6
3	4.7	1.2	0.6	8.7	5.7	126.8	40.2	8
4	2.9	4.5	0.9	6.5	1.4	106.9	21.2	5

LAND RESOURCE EVALUATION OF TROPICAL AMERICA

In order to create a foundation for the effective development and transfer of germplasm based technology, and to facilitate the development and revision of research priorities compatible with geographic realities and economic trends, CIAT, in conjunction with national agencies including the Centro de Pesquisa Agropecuaria dos Cerrados, Empresa Brasileira de Pesquisa Agropecuaria (CPAC-EMBRAPA) in Brazil and the Ministries of Agriculture of other countries, is currently evaluating land resource information in tropical America. The work started in mid-1977 as a specific study of the Oxisol and Ultisol regions to help establish technical priorities for forage improvement. Land information is reduced to a common base in terms of climate, landscape, vegetation, and soils. The study now covers over 850 million ha (Figure 82). The 1977 and 1978 CIAT Annual Reports contain progress reports and some preliminary findings.

With the virtual completion of the study as originally envisaged by mid-1979, its scope was extended to cover regions of interest for CIAT's other commodity programs including cassava, beans, rice and maize (Andean region only), and to provide useful information for crop, forage, and agro-forestry production throughout tropical Latin America in general.

In order to accelerate the analysis of the land resources information, a computerized data storage, retrieval and analytical system, map and data printout facility has been set up. This is readily expandable and permits the analysis of the land resource data in the light of additional information from other sources, particularly economic studies. The information recorded in the data bank has already been made available to agricultural institutions as a series of computer tapes.

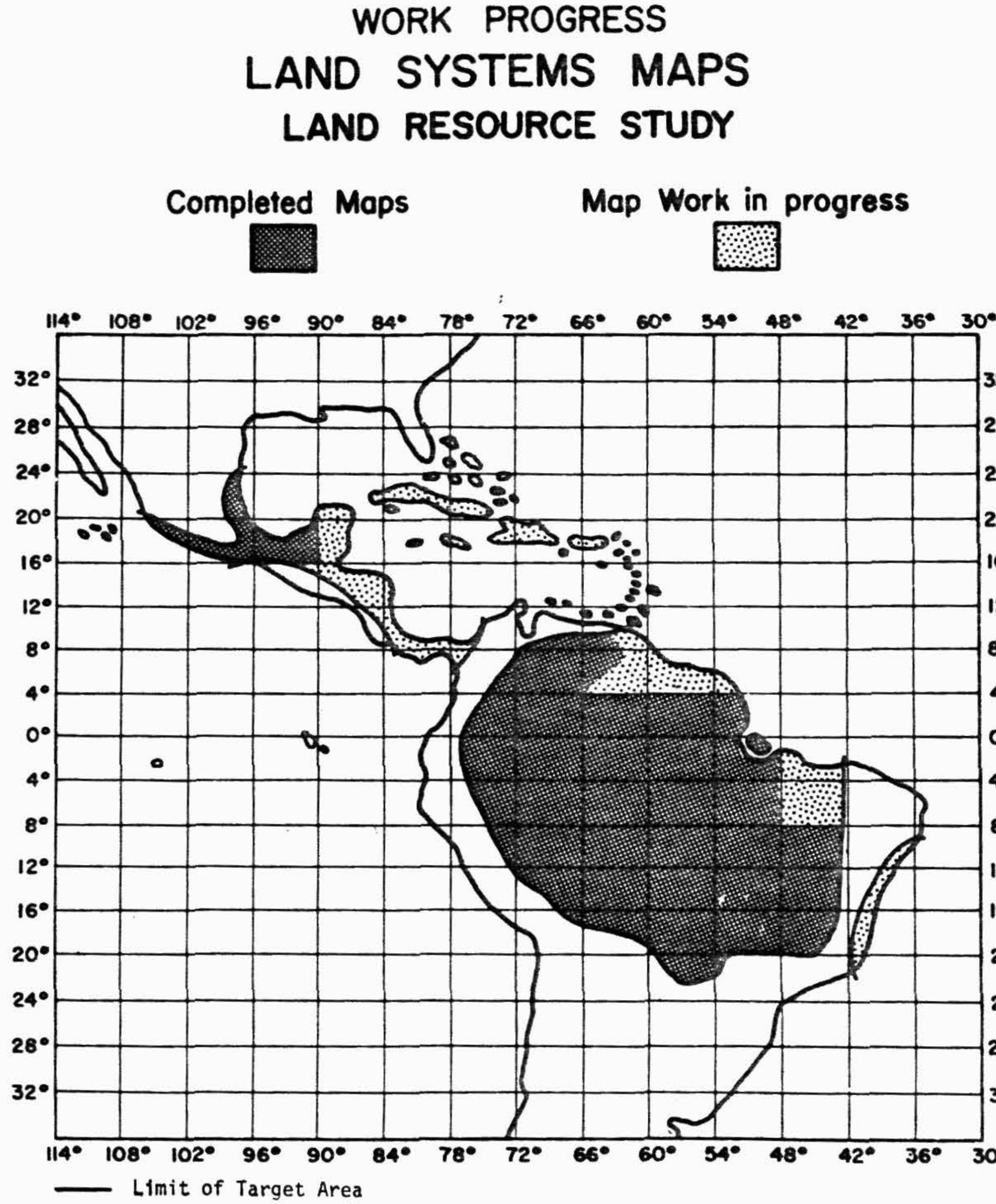

Figure 82. The geographical extent of the study.

Methodology

Land classification

In order to provide a geographical summary of the land resources, it was decided to modify the land systems approach developed by Christian and Stewart in 1953 in their study of the land resources of the Katherine-Darwin region of Northern Australia. For this study, a land system was defined as "an area or group of areas throughout which there is a recurring pattern of climate, landscape and soils". The environmental parameters were arranged in categorical order to form a true land classification:

- Climate
  - Radiant energy received
  - Temperature
  - Potential evapotranspiration
  - Water balance
  - Other climatic factors
- Landscape
  - Land-form
  - Hydrology
  - Vegetation
- Soil
  - Soil physical characteristics
  - Soil chemical characteristics

These were the principal parameters used to delineate a land system. Paradoxically, the delineation of land systems was effectively used not only to describe the land resources of regions where little or no information was available, but also to condense and summarize the great amount of printed information occasionally available for some regions of lesser geographical extent, where detailed studies including soil surveys, climatological studies and in-field experimentation had been recorded. Where information was not available a limited amount of field work was carried out. The land systems maps were made at a scale of 1:1,000,000, and numbered according to the International Chart of the World Index.

Satellite and radar imagery were used to provide an accurate geographical base for the delineation of land systems. Radar imagery was available for the Amazonian region of Brazil. By using satellite and radar imagery, the topographical inaccuracies of many existing maps were avoided.

Climate

Data from 1144 meterological stations throughout Central and South America were initially analyzed for the study, and the analyses for selected representative stations incorporated as an integral part of the land resource data bank. This work is available either as a printout with an explanatory text[1] or as a computer tape.

The methodology used for calculating potential evapotranspiration (ETP) followed that described by Hargreaves. This method was selected because it used available climatic data to give a proven estimate of ETP. It was of fundamental importance that ETP be calculated as realistically as possible to assess the water balance and growing season, and provide a guide as to the total amount of energy available for plant growth. Solar radiation and temperature are the most important factors in determining ETP, the two basic parameters of Hargreaves' equation.

Figure 83 shows a straight printout of the climatic analysis of Luziana, Brazil, used for describing the climate of land system No. 1 of the study.

The precipitation deficit in mm is the difference between the precipitation and the potential evapotranspiration.

Dependable precipitation (PD) is the 75% probability of precipitation occurrence, which can be described as the amount of precipitation that will be equaled or exceeded in three out of four years.

The Moisture Availability Index (MAI) is a moisture adequacy index at the 75% probability level of precipitation occurrence. It is defined as PD divided by the ETP. A MAI value of 1.00 means taht PD equals ETP.

1 Hancock, J.K., Hill, R.W., and Hargreaves, G.H., comp. Potential evapotranspiration and precipitation deficits for tropical America. Cali, Colombia. CIAT. 1979. 398 p.

TARGET AREA SURVEY

POTENTIAL EVAPOTRANSPIRATION AND PRECIPITATION DEFECIT FOR BRAZIL

207C LUZIANIA LAT 16 15 LON 47 56 958. METERS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN TEMP	21.9	22.0	21.7	21.1	19.4	18.3	18.1	20.0	22.1	22.3	21.9	21.6	20.9
REL HUM	72	78	79	61	52	41	38	43	63	75	79	87	64
PCT SUN	59	52	51	69	76	84	87	83	67	55	50	40	64
MEAN RAD.	574	523	481	495	452	440	461	512	526	529	527	475	500
PRECIP.	228	201	229	96	16	7	4	5	27	130	215	317	1475
POT ET	164	135	136	134	120	110	118	139	146	152	145	134	1632
DEF PREC	-65	-66	-93	38	104	103	114	133	119	22	-70	-183	157
DEP PREC	141	123	142	53	0	0	0	0	7	76	132	200	
MAI	0.86	0.91	1.04	0.40	0.00	0.00	0.00	0.00	0.05	0.50	0.91	1.49	

MEAN TEMP ...... **Mean Temperature in Degrees Celcius**
REL HUM ...... **Relative Humidity**
PCT ...... **Percent Possible Sunshine**
MEAN RAD ...... **Mean Solar Radiation in Langleys/Dary**
PRECIP ...... **Mean Precipitation in mm**
POT ET ...... **Potential Evapotranspiration in mm**
DEF PREC ...... **Precipitation Deficit in mm**
DEP PREC ...... **Dependable Precipitation in mm**
MAI ...... **Moisture Availability Index**

Figure 83. A computer printout of the the climatic analysis for Luziania, Brazil.

Apart from the climatic work leading to the estimation of the water balance, separate note was taken of other climatic hazards such as hurricane risks along the Gulf coast of Mexico and Caribbean countries.

A system of direct access information storage and retrieval files is being developed in CIAT to manage the meterological data from this study and from other sources. These files (SAMM DATA) will allow easy programmer access to the data and can be updated to incorporate the best estimates of climatic parameters as they become available. A manual describing the program structure and use will be available in late 1980. The operation of this additional system, and the on-going active accumulation of climatic data, should provide for a more comprehensive analysis of climate in the future.

A defined pattern of climate was used as the first criterion for setting the boundaries of the land systems. The second criterion was landscape.

Landscape

Farming is carried out on units of land. The landscape, especially topographical and hydrological aspects, is often critical in determining the type of farming systems adopted. For this reason, in considering practical agricultural production and evaluating land as a resource for farming, it is necessary to have a clear appraisal of landscape characteristics.

Most of the delineation of land systems was carried out using satellite imagery, using black and white photographic prints of the spectral bands 5 and 7. Band 5 (lower red) gave a useful image of vegetation and topography, and band 7, the near infrared band of the spectrum, gave better haze penetration and land-water discrimination.

Satellite imagery has one major drawback. For the more humid areas of tropical America it is still difficult to obtain cloud-free imagery. The largest area affected by this problem is the Amazon region. Fortunately, side-looking radar imagery has now become available for most of the Brazilian Amazon and this was used as a geographic base for the delineation of land systems throughout that region. Side-looking radar produces an excellent topographical picture of the landscape, but is not so effective as satellite imagery in helping to interpret land resource characteristics such as vegetative cover and hydrological characteristics.

For some other areas, including the wet eastern piedmont of Bolivia, aerial photography was used for interpreting the landscape patterns.

Wherever possible, and especially when little or no information was available in the published literature about land characteristics, field work was carried out to check the photo-interpretation. A small plane (STOL) was used to cover remote areas, and every effort was made within the close time schedule to examine the principal soil sequences that followed the landscape patterns.

With the delineation of land systems, the landscape within individual systems was described in such a way as to enable the computerization of its principal characteristics.

The landscape facets. The subdivision of landscape into facets is used to bridge the gap between land systems and soil units, as facets are often relatively uniform in so far as soil characteristics are concerned. Obviously, in some cases the landscape facets will contain soils with differing properties, but some level of generalization must be accepted in making an inventory of land resources. The objective of the study was not to replace soil survey work *per se;* the smallest map unit is the Land System. However, it is axiomatic that the study should provide an inventory of the land characteristics including soil physical and chemical properties of land facets within the land systems.

Figure 84 illustrates a typical landscape identified as one land system; it is clear that the landscape can be subdivided into facets 1 and 2 to represent the flat plain surface and the minor valley regions. For convenience of computation, land systems were described in terms of a maximum of three land facets.

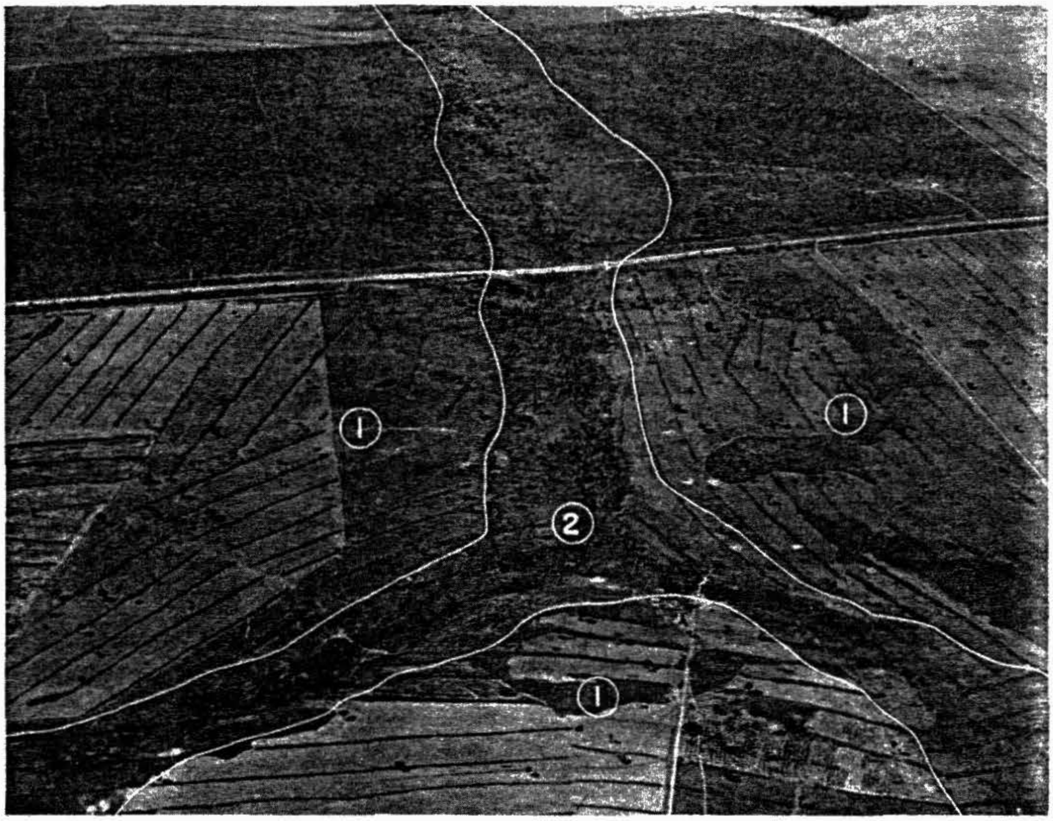

Figure 84. Land system No. 49 subdivided into land facets 1 and 2.

Soil

In order to describe the soils of the land facets, they were classified to the Great Group category of the Soil Taxonomy system used by the USDA, and then categorized in terms of their physical and chemical properties.

In the USDA Soil Taxonomy system, soils are not grouped according to those soils "having similar physical and chemical properties that reflect their response to management and manipulation for use", until the soil Family category is reached. This follows a subdivision of the Great Groups into Sub-groups. However, the separation according to Sub-groups does not add very much to knowledge concerning the characteristics of the soils. Therefore, it was decided to classify soils only as far as the Great Group category, then describe them in terms of their physical and chemical characteristcs in such a way as to facilitate the computer grouping and comparison of properties.

Soil physical properties. Soil physical properties have been classified and coded in terms of slope, texture, presence of coarse material, depth, initial infiltration rate, hydraulic conductivity, drainage, moisture holding capacity, temperature regime, moisture regime, and presence of expanding clays. The categorization is designed to evalute the suitability of soils for crop production from a physical standpoint. It contains the elements necessary to apply the technique developed by Mansfield for assessing land capability for arable crops based on soil physical limitations, and those necessary to use the Soil Fertility Capability Classification, developed by Buol *et al.*

Soil chemical properties. The following are the main soil chemical properties classified and coded for both topsoils (0-20 cm depth) and subsoils (21-50 cm depth): pH, percent Al saturation, exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, K^+ and Na^+, total exchangeable bases, cation exchange capacity, organic matter, P, Mn, S, and trace elements, the presence of free carbonates salinity and cat clays, and elements of importance to animal nutrition.

A classification system was used to describe soil nutritional levels as a first attempt to equate crop needs in the following sense: A = adequate for most crops, B = inadequate for crops requiring high nutrient levels, and C = inadequate for all crops, except those tolerant to very low nutrient levels.

In classifying soil pH, the level less than 5.3 was chosen to identify those soils with the probability of sufficient free Al in the soil solution to indicate the need for liming. For such soils, the formula developed at CIAT[1] for estimating the liming requirement of acid mineral soils for a given crop might profitably be applied.

It should be emphasized that each landscape facet within a land system is described and collated separately. The limit of describing a maximum of three major landscape facets within a land system was set for the convenience of managing the data. This limit can be extended to handle more detailed studies in the future.

With the completion of the collection and collation work the land resource information was recorded in a data bank.

Data management system

The computerized system of data management was created to facilitate and accelerate the diverse analyses contingent to the study. It had to be sufficiently comprehensive to cope with large amounts of data, and flexible enough to permit the analyses of the land resource data with other information from economic and agricultural studies.

The methodology adopted for the system was largely developed by the SAS (Statistical Analysis System, Institute Inc. of North Carolina). The work was carried out using an IBM 370/145 computer with a terminal link-up IBM-3780 at CIAT's administration center, Palmira.

Data input

The input achieved from:

- Land information formats summarizing the landscape, vegetation and soil data in a coded form.

- Map code formats; each 5' x 5' area of the land system maps were coded to permit their reproduction.

- Climatic tapes; the climatic information and analyses of the Hancock, Hill and Hargreaves study was recorded on magnetic tape, which permits direct

1 Cochrane, T.T., J.G. Salinas, and P.A. Sámchez. An equation for liming acid mineral soils to compensate Al tolerance. *In* Tropical Agriculture. Trinidad. Vol. 57, No. 2, April 1980. pp. 133-140.

entry of climatic data to the system. Additional climatic information will eventually be available by input from the SAMM data files.

Data output

It is possible to generate different information according to the varying needs of the users of the land resource evaluation study. Basic information output includes:

- Printouts of the land resources information for individual land systems in terms of the collated climatic, landscape, vegetation, and soil data.

- List of comparative data for selected properties of any predetermined group of land systems or geographical areas.

- Areal totals for any recorded characteristic in terms of the values assigned to those characteristics, either descriptive or numerical, over any predefined geographical area.

- Map printouts of the land systems for any given area.

- Thematic map printouts of any of the parameters evaluated according to their classification, for any geographical area.

Additionally, the system has the capacity to:

- Identify possible correlations between any of the characteristics described.

- Permit the analysis of the land resource data in terms of information obtained from other types of study, particularly economic studies.

The methodology already developed by SAS which integrates the management of data according to their Relational Data Base Concept with procedures for statistical analyses and those that facilitate reporting, was chosen to implement the major part of the storage, analysis and retrieval system. The study has been detailed in a publication available to interested institutions[1].

Application

The value of the study may be illustrated by two examples related to climatic and soil factors, respectively.

An analysis was carried out to check if climatic parameters were related to differences in the natural vegetation throughout Central west Brazil (some 243 million ha). The natural vegetation was compared with a number of variables. Figure 85 shows the result of comparing the vegetation classes with the total wet season potential evapotranspiration (TWPE). TWPE was generated from the climatic data by totalling the ETP figures for those months with a MAI greater than 0.33. As can be seen, the area within the box in Figure 85 indicates that there is a much greater frequency of occurrence of "cerrado" type (savanna) vegetation between the 900 to 1050 mm range of potential ETP.

This observation led to the finding that TWPE is an effective yardstick for classifying lowland tropical climates in tropical America for perennial crop production. It has provided a quantitative basis for the subdivision of the region into climatic sub-regions for CIAT's work in evaluating forage germplasm

The areal totals and distribution of the percent Al saturation in the soils of Central-west Brazil were needed to define preliminary guidelines for establishing criteria for selecting forage germplasm tolerant to soils with varying levels of Al throughout that region. With the appropriate computer program, the areal extent of both the topsoil and subsoil percent Al saturation values were quickly obtained as a printout (Figure 86). The term frequency used on the printout multiplied by 10,000 will give the areas in ha. Thematic maps of the several levels of percent Al saturation coded as part of the soil description of the system were made (Figure 87).

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1 Cochrane, T.T. *et al.* An Explanatory Manual for CIAT's Computerized Land Resource Study of Tropical America. Cali, Colombia. CIAT. 1979. 130 p.

TABLE OF GTWSPE BY COD

TWSPE / COD FREQUENCY PERCENT ROW PCT COL PCT	SEAS.IN. P.	CL+CS	CC	C	CD	TRF	SESF	SDSF	CAAT	OTHER	TOTAL
DE 650 A 699	0	0	0	0	0	0	0	0	2	1	3
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.28	0.84
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.67	33.33	
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.38	4.17	
DE 700 A 749	2	0	0	0	1	0	3	7	3	2	18
	0.56	0.00	0.00	0.00	0.28	0.00	0.84	1.97	0.84	0.56	5.06
	11.11	0.00	0.00	0.00	5.56	0.00	16.67	38.89	16.67	11.11	
	5.41	0.00	0.00	0.00	2.04	0.00	15.00	16.28	23.08	8.33	
DE 800 A 849	1	0	0	0	0	0	0	1	3	0	5
	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.84	0.00	1.40
	20.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	60.00	0.00	
	2.70	0.00	0.00	0.00	0.00	0.00	0.00	2.33	23.08	0.00	
DE 850 A 899	3	2	3	3	4	0	0	4	0	1	20
	0.84	0.56	0.84	0.84	1.12	0.00	0.00	1.12	0.00	0.28	5.62
	15.00	10.00	15.00	15.00	20.00	0.00	0.00	20.00	0.00	5.00	
	8.11	5.00	5.26	4.17	8.16	0.00	0.00	9.30	0.00	4.17	
DE 900 A 949	8	13	17	20	10	1	6	5	0	3	83
	2.25	3.65	4.78	5.62	2.81	0.28	1.69	1.40	0.00	0.84	23.31
	9.64	15.66	20.48	24.10	12.05	1.20	7.23	6.02	0.00	3.61	
	21.62	32.50	29.82	27.78	20.41	100.00	30.00	11.63	0.00	12.50	
DE 950 A 999	5	5	13	21	17	0	4	9	0	1	75
	1.40	1.40	3.65	5.90	4.78	0.00	1.12	2.53	0.00	0.28	21.07
	6.67	6.67	17.33	28.00	22.67	0.00	5.33	12.00	0.00	1.33	
	13.51	12.50	22.81	29.17	34.69	0.00	20.00	20.93	0.00	4.17	
DE 1000 A 1049	6	6	11	14	9	0	3	5	1	1	56
	1.69	1.69	3.09	3.93	2.53	0.00	0.84	1.40	0.28	0.28	15.73
	10.71	10.71	19.64	25.00	16.07	0.00	5.36	8.93	1.79	1.79	
	16.22	15.00	19.30	19.44	18.37	0.00	15.00	11.63	7.69	4.17	
DE 1050 A 1099	2	8	5	3	1	0	3	0	0	2	24
	0.56	2.25	1.40	0.84	0.28	0.00	0.84	0.00	0.00	0.56	6.74
	8.33	33.33	20.83	12.50	4.17	0.00	12.50	0.00	0.00	8.33	
	5.41	20.00	8.77	4.17	2.04	0.00	15.00	0.00	0.00	8.33	
DE 1100 A 1149	9	4	8	10	7	0	1	7	3	9	58
	2.53	1.12	2.25	2.81	1.97	0.00	0.28	1.97	0.84	2.53	16.29
	15.52	6.90	13.79	17.24	12.07	0.00	1.72	12.07	5.17	15.52	
	24.32	10.00	14.04	13.89	14.29	0.00	5.00	16.28	23.08	37.50	
DE 1200 A 1249	0	0	0	1	0	0	0	1	1	1	4
	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.28	0.28	0.28	1.12
	0.00	0.00	0.00	25.00	0.00	0.00	0.00	25.00	25.00	25.00	
	0.00	0.00	0.00	1.39	0.00	0.00	0.00	2.33	7.69	4.17	
MAYOR DE 1250	1	2	0	0	0	0	0	4	0	3	10
	0.28	0.56	0.00	0.00	0.00	0.00	0.00	1.12	0.00	0.84	2.81
	10.00	20.00	0.00	0.00	0.00	0.00	0.00	40.00	0.00	30.00	
	2.70	5.00	0.00	0.00	0.00	0.00	0.00	9.30	0.00	12.50	
TOTAL	37	40	57	72	49	1	20	43	13	24	356
	10.39	11.24	16.01	20.22	13.76	0.28	5.62	12.08	3.65	6.74	100.00

Natural vegetation classes code:

- TWSP .... Total Wet Season Potential Evapotranspiration
- SEAS. IN. P .... Seasonally Inundated Pampas or Savannas
- CL + CS .... Campo Limpo + Campo Sujo (Grasslands)
- CC .... Campo Cerrado (Open Savannas)
- C .... Cerrado (Savanna)
- CD .... Campo Cerrado (Closed Savanna)
- TRF .... Tropical Rainforest
- SESF .... Semi-Evergreen Seasonal Forests
- SDSF .... Semi-Deciduous Seasonal Forests
- CAAT .... Caatinga (Dry Forest)

Figure 85. Comparison of the frequency of occurrence of the native vegetation classes with total wet season potential evapotranspiration levels

LAND RESOURCE STUDY OF TROPICAL AMERICA

PERCENT AL SATURATION

TOPSOIL'S AL SATURATION %

F19	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
1) □ 10%	9506	9506	39.160	39.160
2) 10-40 %	2362	11868	9.730	48.890
3) 40-70 %	4385	16253	18.064	66.954
4) 70%	8022	24275	33.046	100.000

SUBSOIL'S AL SATURATION % MEQ/100 GM

F20	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
1) □ 10%	11780	11780	48.527	48.527
2) 10-40 %	3836	15616	15.802	64.330
3) 40-70 %	2088	17704	8.601	72.931
4) 70%	6571	24275	27.069	100.000

Figure 86. A computer printout of topsoil and subsoil percent Al saturation levels for Central-west Brazil.

A COMPUTER PRINTOUT OF PERCENT AI SATURATION

LEVELS IN TOPSOIL, MAP SC-22 TOCANTINS

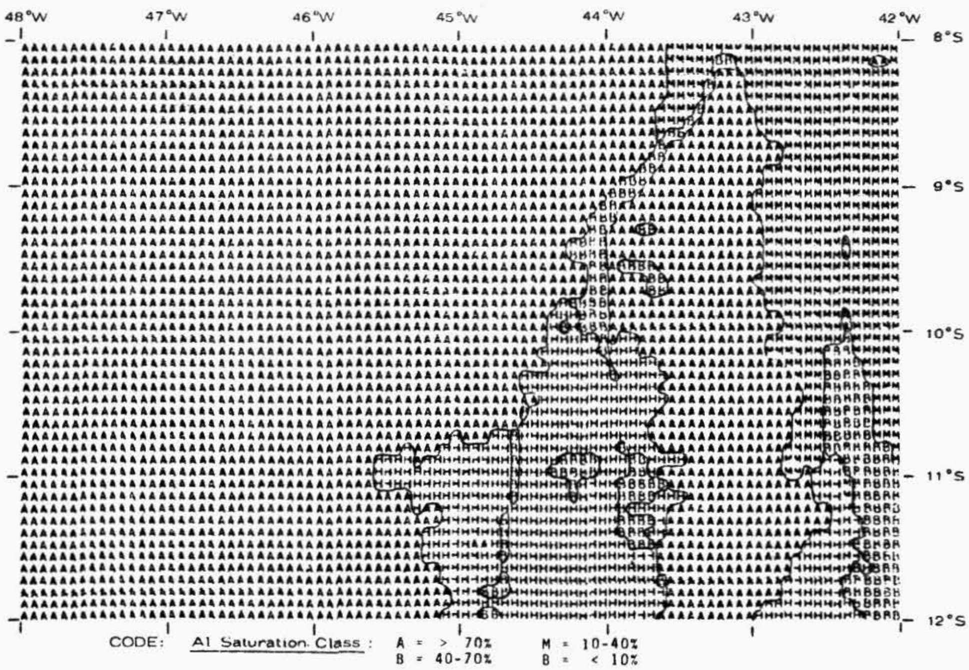

Figure 87. A thematic map printout of percent Al saturation levels. (Map SC-22, Tocantins, Brazil.)