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THE METHODOLOGY OF CIAT'S LAND RESOURCE STUDY OF TROPICAL AMERICA

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ABSTRACT

CIAT is carrying out an agricultural land resource evaluation of Tropical America to create a base for the effective development and transfer of germplasm oriented technology. The study started in mid-1977 and now covers 850 million ha. It reduces land information to a common base in terms of land systems defined as repetitive patterns of climate, landscape and soils. These are delineated directly onto satellite and side-looking radar imagery. Within land systems, soils are separately described in terms of the major landscape topographical facets.

Once the land resource information is summarized, it is recorded as a computerized data storage, retrieval and analytical, map and data printout system, to speed-up analysis. The system facilitates the analysis of the land resource data with other information including economic parameters. The collated information is already available as a series of computer tapes. Examples of the application of the study are given.

The work is already helping CIAT focus endeavor in developing and transferring promising pasture grass and legume accessions, in accordance with the realities of Tropical America's ecosystems. It is also playing an increasingly important role as a dynamic land resource data bank of the region for crop, pasture and agro-forestry production generally.

I. INTRODUCTION

CIAT's special interest area is Tropical America. In order to create a foundation for the effective development and transfer of germplasm based technology compatible with geographic realities and economic trends, CIAT in conjunction with national agencies, is currently evaluating land resource information. The work started in mid-1977 as a specific study of the Oxisol and Ultisol soil regions to help establish technical priorities for pasture improvement[1,2,3], and reduces land information to a common base in terms of climate, landscape, vegetation and soils. It now covers over 850 million hectares, Fig.1. The study was extended in 1979 to cover regions of interest for all CIAT's commodity programs including cassava, beans, rice and maize, and to provide useful information for crop, forage and agro-forestry production throughout Tropical America generally.

LAND SYSTEMS MAPS

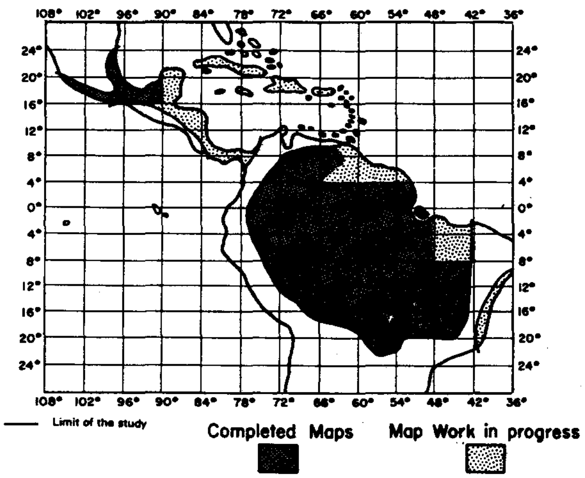

Figure 1. The geographical extent of the study.

To speed-up the analysis of the land resource information, a computerized data storage, retrieval and analytical, map and data printout system has been created. This system is readily expandable, and permits the analysis of the land resource data in the light of additional information from other sources, particularly economic studies.

II. METHODOLOGY

To provide a geographical summary of the land resources, it was decided to modify the land sys-

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tems approach developed by Christian and Stewart in 1953[4] in their study of land resources in Northern Australia. A land system was re-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:

1. Climate
   a) Radiant energy received
   b) Temperature
   c) Potential evapotranspiration
   d) Water balance
   e) Other climatic factors
2. Landscape
   f) Land-form
   g) Hydrology
   h) Vegetation
3. Soil
   i) Soil physical characteristics
   j) Soil chemical characteristics

These were the principle 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 copious amounts of printed information occasionally available for some regions of lesser geographical extent. When information was not available, a limited amount of field work was carried out. The land systems maps were originally made on the millionth scale as transparent overlays to the International Chart of the World Index.

A. CLIMATE

Data from 1,144 meteorological stations throughout Central and South America were initially analysed for the study. This work is available either as a printout with explanatory text[6], or as a computer tape.

Potential evapotranspiration ETP, was calculated to assess the amount of energy available for plant growth and to determine the water balance and growing seasons. Solar radiation and temperature are the most important factors in determining ETP. To provide a common yardstick for estimating ETP throughout the region, it was decided to use Hargreaves method[7]; this gives consistently good estimates of ETP, as illustrated by Hargreaves[8].

Table 1 records the data of the computer printout of the climatic analysis of Luziania. The data recorded and calculated are:

MEAN TEMP	Mean Temperature in degrees Celcius.
REL HUM	Mean Relative Humidity
PCT SUN	Percent possible Sunshine
MEAN RAD	Mean solar radiation in Langleys per day
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

Table 1.

POTENTIAL EVAPOTRANSPIRATION AND PRECIPITATION DEFICIT FOR BRAZIL

2070 LUZIANIA LAT 16°15"S LON 47°56"W 958. METERS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MEAN TEM	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	76	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	

The precipitation deficit is the difference between the precipitation and the potential evapotranspiration, whereas the dependable precipitation PD, is the 75% probability of precipitation occurrence.

The moisture availability index MAI, is a moisture adequacy index at the 75 percent probability level of precipitation occurrence. The equation is:

$$MAI = PD/ETP$$

A MAI value of 1.00 means that dependable precipitation equals potential evapotranspiration. In order to develop a classification for measuring soil moisture adequacies from climatic data, Hargreaves[9] proposed that MAI be adopted as a standard index, using the following classification:

MAI = 0.00 to 0.33 very deficient
MAI = 0.34 to 0.67 moderately deficient
MAI = 0.68 to 1.00 somewhat deficient
MAI = 1.01 to 1.33 adequate
MAI = 1.34 and above excessive.

This classification seems applicable to the more favourable soil conditions; Hargreaves notes "when the soil moisture storage capacity is adequate for less than a week, the correlation between MAI and crop production will be lowered." Nevertheless, the MAI is a convenient way of defining moisture stress, and provides a ready made yardstick for defining a dry month, one with a MAI less than 0.34, remembering always that this level may be too high for soils with very low moisture holding capacities. The index is a first attempt to equate the climatic potential to extract soil moisture at a given location at a given time, with the ability of the soil to store and supply water.

It is noted that a system of direct access information storage and retrieval files has recently been developed in CIAT to manage the meteorological data from this study and from other sources, the South America monthly meteorological data SAMM DATA, files. Further, separate note was taken of other climatic hazards such as frosts and high winds.

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

B. LANDSCAPE

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

Satellite and side-looking radar imagery, and in some cases normal aerial photography, were used to help define land system boundaries. Fig.2 illustrates land system mapping on a satellite image[10]. Techniques for interpreting satellite imagery and remote sensing techniques generally are well documented[11,12], and advances in this field of endeavor are continually being[13,14] made. With the exception of Amazonia, most of the delineation of land systems was made directly onto 1 to 1,000,000 satellite imagery using black and white photographic prints of the spectral bands 5 and 7.

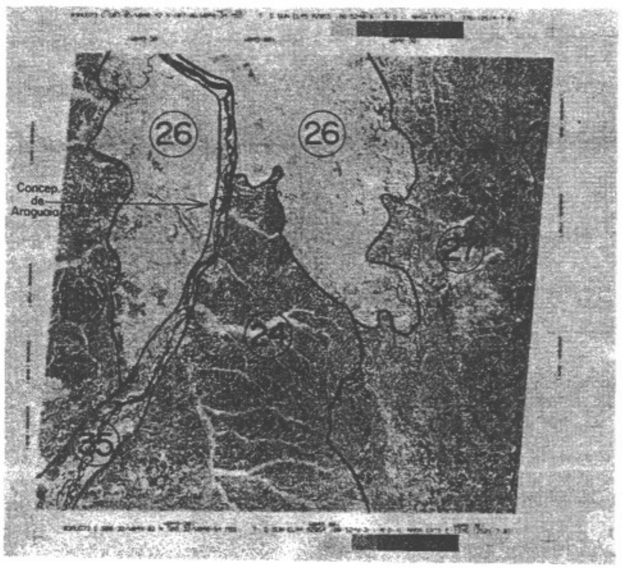

Figure 2. Land system delineation on satellite imagery.

Satellite imagery has one major drawback. For the wetter areas of Tropical America it is still difficult to get cloud-free imagery. Fortunately, side-looking radar imagery has now become available for most of Amazonia[15] and this was used as a geographical base for the delineation of land systems throughout that region, Fig.3. Side-looking radar imagery produces an excellent topographical picture of the landscape, but it is not near-

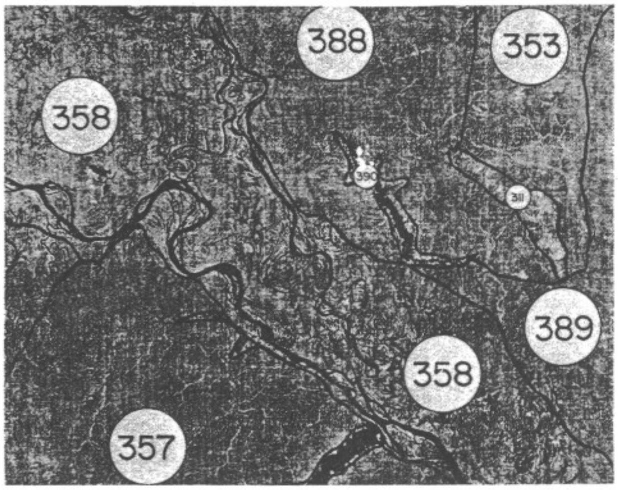

Figure 3. Land system delineation on radar imagery about 300 km west of Manaus.

ly so useful as satellite imagery in helping to interprete land resource characteristics such as vegetative cover and soil moisture features. For some other areas such as the wet eastern piedmont of Bolivia, aerial photography was used for interpreting the landscape picture.

Wherever possible, field work was carried out to check the photo-interpretation. A small aeroplane with short airstrip landing and take-off capacity, was used to cover remote areas, and every effort 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 the individual land systems was described and coded on a series of formats to enable the computerization of its principal characteristics. Land systems were subdivided into land facets for the detailed description of topography, vegetation and soils.

The subdivision of landscape into facets is crucial to the study. Fig.4 illustrates a landscape identified as one land system; it is clear that it can be subdivided into two major facets to represent the flat plain surface and the minor vale region respectively.

The identification of land facets within land systems is used to bridge the gap between land systems and soil units; facets are often relatively uniform in so far as soil characteristics are concerned. Obviously, in some cases the 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 sê; the smallest map unit is the land system. However, it is axiomatic that the study

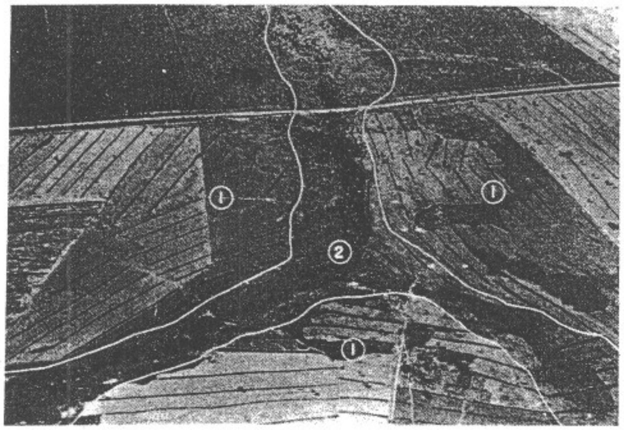

Figure 4. Land system No.49, showing a clear subdivision into two land facets.

should provide an inventory of the land characteristics including the vegetation and soil physical and chemical properties of the land facets within the land systems. Each land facet within a land system is described and collated separately. For convenience of computerization, land systems were described in terms of a maximum of three land facets.

C. SOILS

The soils of the individual land facets were coded separately. They were first classified as far as the Great Group category of the U.S. Department of Agriculture's Soil Taxonomy System[16], then categorized in terms of their physical and chemical properties.

In the U.S. Soil Taxonomy, 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 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 our knowledge concerning the characteristics of the soils per sê. 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 characteristics to facilitate the computer grouping and comparison of properties.

Soil Physical Properties.

The soil physical properties were 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 evaluate the suitability of soils for crop production from a physical standpoint. It contains the elements necessary to apply the technique developed by Mansfield[17] for assessing land capability for arable crops based on soil physical limitations, and those necessary to use the Soil Fertility Capability Classification method developed by Buol et al[18].

Soil Chemical Properties.

Soil chemical properties for both topsoils 0-20 cm, and subsoils 21-50 cm, were coded onto formats, including pH, percent Al saturation, exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}, TEB, CEC, O.M., P, Mn, S, trace elements, the presence of free carbonates, salinity, cat clays, and elements of importance to animal nutrition.

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, Fig.5.

			T	S
pH		28	H (F17)	H (F18)
> 7.3	A			
5.3-7.3	M			
< 5.3	H FCC M.			
Al SATURATION		30	A (F19)	H (F20)
40-70 %	H			
10-40 %	M			
< 10 %	B			
> 70 %	A FCC M.			
Unknown	U			
EXCHANGEABLE Al meq/100 gm soil		32	A (F21)	M (F22)
> 1.5	A			
0.5-1.5	M			
< 0.5	B			
Unknown	U			
EXCHANGEABLE Ca meq/100 gm soil		34	B (F23)	B (F24)
> 4.0	A			
0.4-4.0	M			
< 0.4	B			
Unknown	U			

Figure 5. A part of format S_1 used to code the soil chemical properties of the land facets of land system No.1. (T= Topsoil and S= Subsoil).

For these soils, the formula developed by Cochrane et al[19] for estimating the minimal liming requirement of acid mineral soils for a given crop might profitability be applied.

Further details relevant to the classification of soils and their physical and chemical properties may be found in the Explanatory Manual[5]. With the completion of the collection and collation work, the land resource information was recorded in the data bank.

D. THE DATA MANAGEMENT SYSTEM

Because of the quantity and complexity of data from the study, and in view of the likely interaction within this data and with other agronomic and economic data, it was decided to create a computerized system of data management or "data bank", that would facilitate diverse analyses and decision making.

The methodology developed by SAS, Statistical Analysis System Institute Inc.[20], 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 work was carried out using an IBM 370/145 computer.

The Data Input.

The input of the climatic, landscape and soil data is achieved in the following way.

a) Climate: Directly via the magnetic tape records of the summarized climatic information.

b) Landscape map units: Via map code formats summarizing each 4' x 5' area of the land systems maps.

c) Landscape and soil information: Via the land information formats and the soil information formats summarizing the landscape and soil data respectively.

The Data Output.

It is possible to generate different information according to the varying needs of the users of the land resource evaluation study, including:

a) Printouts of the land resource information for individual land systems.

b) Lists of comparative data for selected characteristics over any specified geographical area.

c) Areal totals for any recorded characteristic.

d) Map printouts of the land systems, Fig.6.

e) Thematic map printouts of the parameters evaluated according to their classification.

In addition, the system has capacity to:

1) Identify possible correlations between any of the characteristics described, and

2) Permit the analysis of the land resource data in the light of information obtained from independent agronomic and economic studies.

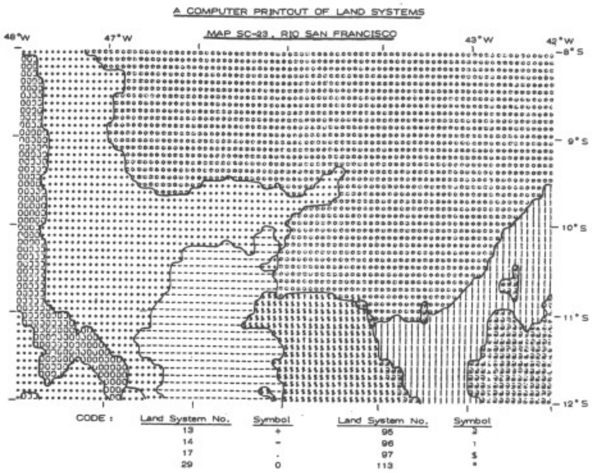

Figure 6. Land system map SC-23

III. APPLICATION

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

1. An analysis was carried out to see if climatic parameters were related to differences in the natural vegetation throughout Central-west Brazil, some 243 million ha of territory[1]. The native vegetation was compared with a number of climatic variables. Fig.7 summarizes the computer printout comparing vegetation classes with the total wet season potential evapotranspiration, TWPE. TWPE was calculated from the climatic data by totalling the potential evapotranspiration figures for those months with a MAI greater than 0.33; for soils with favourable moisture holding capacities, it is a proxy statement of the amount

TWPE mm	Seas. In.P.	Cl+ CS	CC	C	CD	TRF	SESF	SDSF	CAAT	OTHER	TOTAL
650– 699	0	0	0	0	0	0	0	0	2	1	3
700– 749	2	0	0	0	1	0	3	7	3	2	18
800– 849	1	0	0	0	0	0	0	1	3	0	5
850– 899	3	2	3	3	4	0	0	4	0	1	20
900– 949	8	13	17	20	10	1	6	5	0	3	83
950– 999	5	5	13	21	17	0	4	9	0	1	75
1000–1049	6	6	11	14	9	0	3	5	1	1	56
1050–1099	2	8	5	3	1	0	3	0	0	2	24
1100–1149	9	4	8	10	7	0	1	7	3	9	58
1200–1249	0	0	0	1	0	0	0	1	1	1	4
+ 1250	1	2	0	0	0	0	0	4	0	3	10
TOTAL	37	40	57	72	49	1	20	43	13	24	356

Native Vegetation Classes Code:

Seas.In.P. = Seasonally Inundated Pampas; CL+CS = Campo Limpo + Campo Sujo (grassland); CC = Campo Cerrado (open savanna); C = Cerrado (savanna); CD = Cerradão (closed savanna); TRF = Tropical Rain Forest; SESF = Tropical Semi-Evergreen Seasonal Forest; SDSF = Semi-Deciduous Seasonal Forest; Caat = Caatinga (Shrubby dry woodlands).

Figure 7. A comparison of the frequency of occurrence of native vegetation classes with total wet season potential evapotranspiration TWPE, regimes.

of energy available for perennial crop growth under natural, non-irrigated conditions. As can be seen, the area within the box on Fig.7 indicates that there is a much greater frequency of occurrence of savanna or, to use a Brazilian term "cerrado" type vegetation between the 900 and 1050 mm range of TWPE.

This observation was followed by a detailed study throughout the whole of lowland Tropical America by Cochrane and Jones[21], which showed that the native vegetation could be discriminated on the basis of TWPE and the mean monthly wet season temperatures. It has led to the separation of the region in terms of climatic subregions based mainly on TWPE for CIAT's work in evaluating forage germplasm[22 23], and provides a fresh approach to defining agricultural climates in the tropics.

2. The aereal totals and distribution of the percent Al saturation levels in the soils of Central-west Brazil, were needed to indicate the magnitude of potential Al toxicity problems, in order to establish preliminary guidelines for selecting forage germplasm tolerant to soils with varying levels of Al throughout that region[3]. With the appropriate computer program, the aereal extent of the soils percent Al saturation levels were quickly obtained as a printout, Fig. 8. The term "frequency" used on the printout multiplied by 10,000 will give the areas in ha.

LAND RESOURCE STUDY OF TROPICAL AMERICA
PERCENT AL SATURATION Central—west Brazil.

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 8. % Al Saturation, Central-west Brazil.

Further , thematic map printouts of the several levels of percent Al saturation of the soils were made for the region; Fig.9, provides an example of topsoil percent Al saturation levels for Map SC-23, Tocantins. The levels represent those of the principal land facets of each land system, as the smallest mapping units are the land systems. In contrast, the figures given in Fig.8 result from calculations made on a land facet basis.

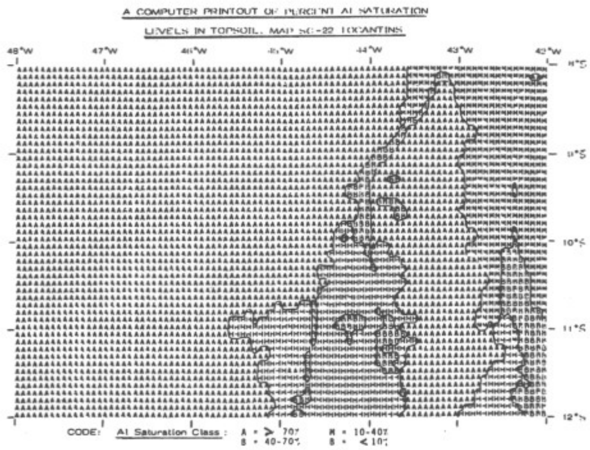

Figure 9. Topsoil % Al saturation values, map SC-23.

IV. SUMMARY AND CONCLUSIONS

The methodology has enabled the speedy and relatively comprehensive coverage of a large part of the land resources of lowland Tropical America. Satellite and radar imagery have made quantification to a common geographical base a reality, and computerization has provided a powerful and flexible analytical tool. The two examples of the application of the study in helping to define climatic and soil characteristics of agro-ecosystems over extensive regions, provide but a glimpse of the use to which the study in now being put. It is available to agricultural organizations as a series of computer tapes.

The work is already helping to focus CIAT's research endeavors for pasture germplasm improvement and selection in terms of the realities of the different ecosystems of Tropical America. It is envisaged that it will play an increasingly important role in the successful development and application of germplasm based technology for Tropical America's expanding agricultural frontiers. Perhaps it could serve as a model to update and extend land resource assessment studies throughout the tropics generally.

ACKNOWLEDGMENTS

The study is an exercise in technology development between CIAT scientists and scientists in the many countries comprizing Tropical America. In Brazil, it was carried out as a joint project with CPAC-EMBRAPA (Centro de Pesquisa Agropecuária dos Cerrados, Empresa Brasileira de Pesquisa Agropecuária) and with the Ministries of Agriculture and Natural Resources of the other republics.

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Thomas Cochrane joined CIAT in June 1977 as a visiting scientist to initiate land resource studies. Past positions include consultant, Tate and Lyle Technical Services, London and Miami, and soil scientist, Ministry of Overseas Development, Gt. Britain. Academic qualifications include B Ag Sc (N.Z.), AICTA and PhD.

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