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APPLICATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM TECHNIQUES TO EVALUATE AGRICULTURAL PRODUCTION POTENTIAL IN DEVELOPING COUNTRIES

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ABSTRACT

The Comprehensive Resource Inventory and Evaluation System (CRIES) project uses a multidisciplinary approach to (1) assist developing countries to analyze their agricultural production potential, and (2) enhance their capabilities to conduct such analyses for policy formulation and evaluation. The project staff has collaborated within their respective disciplines with counterparts in the Dominican Republic, Costa Rica, Nicaragua, Syria, and Honduras to enhance each country's capacity to analyze agricultural production possibilities. The technical assistance provided has been in one of four functional areas. These are: (1) data acquisition; (2) information management and analyses; (3) analyses of policy alternatives; and (4) technology transfer and training. The paper emphasizes the use of remote sensing in data acquisition and the decision analyses followed in deciding the appropriateness of alternatve geographic information systems for use in developing countries.

I. INTRODUCTION

A. SCOPE OF PROJECT

The Comprehensive Resource Inventory and Evaluation System (CRIES)[1] project uses a multidisciplinary approach to assist developing countries to analyze their agricultural production potential and to enhance their capabilities to conduct analyses of production potential for national-level policy evaluations. The project provides technical assistance to developing countries in four functional areas. These are: (1) data acquisition; (2) information management and analyses; (3) analyses of policy alternatives; and (4) technology transfer and training. The emphasis given to each function depends on the agricultural production potential issues of the country and upon each country's indigenous capacity in each functional area.

The overall intent of the technical assistance to developing countries is to provide a means for each country to evaluate, at the national planning level, policy alternatives directed towards realizing the country's agricultural production potential. The CRIES staff has collaborated within their respective disciplines with counterparts in the Dominican Republic, Costa Rica, Nicaragua, Syria, and Honduras to enhance each country's indigenous capacity to perform the functions necessary to conduct policy evaluations.

B. SEQUENCE OF ACTIVITIES

The CRIES project staff initiates its activities by identifying the agricultural production problems of the country with special emphasis on those problems that are natural resource or resource use related. Problem identification is carried out through reconnaissance visits with participating country policy makers and technicians, through a review of planning and policy documents available from the participating country and international sources, and through interactions with USAID Mission and international agency personnel. As part of this problem identification procedure, the participating country's capabilities in data acquisition, information management, and analysis are evaluated; this assessment of capabilities puts specific emphasis on personnel computer systems, (both hardware and software), and remote sensing and cartographic capabilities.

Subsequent to the project identification activity a scope of work is developed by members of the CRIES project staff and personnel from the participating country and the US AID Mission. Within this scope of work and the existing fiscal constraints, a plan of work is developed for the technical assistance activities. In the five countries to which technical assistance has previously been provided a logical sequence of technical assistance has developed. This sequence constitutes technical assistance in data acquisition, information management, analysis, and technology transfer and associated training. Depending upon a country's priority problem issues and existing indigenous capacities, particular activities may receive greater emphasis than others and/or particular functions may be offered concurrently, i.e., data acquisition and information management.

Data acquisition methods stressed by the CRIES project are those to obtain relevant information on land resources, land use, and agronomic and economic characteristics. To assure that this information can be related for evaluation of policy alternative to achieve agricultural production potential, it is referenced to the agro-ecological zoning of the land resource base. Existing data sources are used to develop agro-ecological zones of the land resource base through reinterpretation of existing studies using the USDA's Soil Taxonomy; this information is augmented through limited fieldwork and the incorporation of pertinent annual and seasonal climatic data. Existing data sources and/or primary data capture techniques using Landsat imagery are used to estimate major land use by agro-ecological zones. When problem issues so require, refinements of the major land uses by agro-ecological zones can be made by a variety of techniques including aerial sampling methods. Estimates of crop yields, area planted, total production, production costs, and other agronomic and economic factors that are pertinent to the evaluation of agricultural production potential in the agro-ecological zones are derived from secondary sources and/or through field surveys.

The CRIES project offers technical assistance in geographic and agro-economic information management and analysis. Geographic information systems have been developed and modified for use on in-country computing facilities to capture, store, and analyze geographically-referenced information. Training in their use has been provided to selected analysts and technicians. Similar activities have been conducted for the agro-economic information systems designed to provide data management capabilities for tabular and statistical agronomic and economic information. Agro-economic information systems encompass linkages to the geographic information system needed to input information into the agro-economic information system's analytical routines, such as linear programming, goal programming, and basic statistical and econometric models.

The project has conducted a variety of applied analyses. The two information systems have capabilities that have broadened the range of analyses conducted. Analytical interpretations have been made from the agro-ecological zoning of the land resource base to specify land resource suitabilities for general agricultural uses and for crop recommendations. Analyses of the incidence of crop diseases have been made through the use of remote sensing techniques to specify related canopy stress levels. The geographic information system has been used to cross-reference the agro-ecological zones with major land use to identify additional areas suitable for the expansion of agricultural production, etc.; additional capabilities, such as multi-dimensional scaling can be applied to achieve suitability ratings of the agro-ecological zones for particular agricultural purposes. The agro-economic information system has been used to statistically evaluate crop area responses to government-announced prices, to evaluate comparative advantage for land use in meeting food and export crop demands, and other economic analyses of agricultural policy alternatives.

Subsequent sections of this paper discuss selected issues and elements of the technical assistance offered by the CRIES project in each of the four functional areas. The data acquisition section will stress the project's use of remote sensing techniques. The information management section that follows stresses geographic information system considerations. The final section discusses applied analyses that have been conducted.

II. DATA ACQUISITION

A part of the sequence of activities outlined above relates the assessment of physical components of the land resource base to evaluate crop production potential versus the actual production status of agricultural land (such as the percentage of the land resource in agricultural production, intensity of agricultural land use, mono- and mixed cultivation, crop type composition, etc.). The specific purpose of the initial stage in land evaluation is to assess to basic physical crop production potential of the resource base without considering major technology or socio-economic constraints. This physical analysis component is only useful if a comparative framework is defined allowing grouping and/or classification to derive a capability/suitability rating.

A. LAND RESOURCES

Providing an analytical framework to assess the comparative advantage of competing land use options by location requires the development a consistent, timely, and spatially defined land resource inventory. This presents the need to inventory various resource parameters, to interpret and aggregate this information to define relatively uniform areas for which estimates on crop suitability under various management practices, current land cover/use composition, and intensities can be made to support subsequent evaluations of alternative resource development options.

A typical CRIES approach uses a reconnaissance level survey to identify agro-ecological zones. Existing information on soils, climate and vegetation is used to form the basis for field surveys to refine secondary data and define map zone boundaries. This zone identification is accomplished to provide for agricultural production analysis by location.

The type and detail of available secondary data, project time, and budget constraints will determine which level of zones can be geographically defined and which sub-level areas can be identified through proportional allocation within the larger resource zones. This approach has evolved into a two-level classification system. The smallest homogeneous resource unit is called a Production Potential Area (PPA). The larger zones that is geographically and cartographically identified are called the Resource Planning Units (RPUs).

In the context of national/regional analysis, RPUs and PPAs are defined as follows:

Resource Planning Unit -- a RPU is a geographically delineated unit of land that is relatively uniform with respect to land forms, soil types and patterns, climate and natural vegetation.

Production Potential Area -- a PPA is an aggregate area of individual soil types and associated climates within a RPU which is sufficiently homogeneous with respect to plant adaptability, management requirements, and potential productivity to be reliable depicted by unique estimates of those parameters to serve as an analytical reference for national or regional analysis and planning.

The RPU and PPA concepts reflect the relationships among soils, climate, and plant growth necessary for agricultural production. Soil characteristics such as broad moisture and temperature regimes, the presence or absence of diagnostic horizons and soil properties, and other factors such as parent materials and relief give rise to differences among soil types. These factors differentiate unique characteristics of the various soil types, which in turn, affect plant adaptability. Variations in climate caused by such factors as altitude and seasonality are reflected in the distribution of specific plant species within broad vegetative patterns. Climatic factors considered important to crop adaptability and productivity are annual temperature, annual precipitation, seasonality of precipitation, intensity of precipitation during the wet season, and mean monthly temperature during the wet season.

The creation of RPUs, and PPAs, is largely a matter of the underlying taxonomic principles and of judgement. Knowledge about the kinds of soils, climate, natural vegetation, and their distribution are combined to create broad segments of the landscape that are relatively uniform with respect to the agro-ecological conditions for which specific management practices may result in certain crop yields.

The information on RPU/PPA's is summarized for each country in a report that includes a nation-wide RPU map and detailed descriptive information on the RPUs and associated PPAs. An Honduran example of a selected RPU (#12) and its component PPAs is provided (Table 2).

B. LAND USE

To fully evaluate the difference between general land resource potential and the current use status of the resource base, timely and accurate information is needed on the land cover/use at the national level. The resolution of existing satellite-sensors available for civilian use is generally sufficient to differentiate between major land cover/use categories. The current resolution of the operational Landsat series (approximately 0.4 hectare) poses some limitations for some tropical agricultural areas where small scale subsistence, farming, intercropping and relief induced spectral variation makes it difficult to derive use/cover data categories with a consistent high accuracy. In general, however, in many regions in the world where, comprehensive, multi-seasonal and timely aerial photographic coverage is incomplete or non-existing, it provides an excellent data acquisition alternative for reconnaissance level or even semi-detailed surveys. Needless to say that the improved resolution capabilities to be realized in the early eighties, such as the large format camera on future space shuttle missions with an optical resolution of $10m^2$, the thematic mapper with a $30m^2$ resolution for 5 of the 6 bands and the linear array detectors of European and U.S. Space Agencies Satellites (MAPSAT with a $100m^2$ resolution and a stereoscopic mapping capability of 1:50,000 scale maps with a 20 meter contour interval) will by far surpass current spatial and spectral signature definitions and applied use potential.

Land Cover/Use data acquisition, as carried out under the CRIES project, is generally approached from a low cost, appropriate technology perspective. That is, visual interpretation and low cost imagery enhancement techniques allowing high classification accuracy are used to train host-country technicians and facilitate the installation of an operational remote sensing capability adaptable to multi-purpose inventories. Image enhancement is frequently carried out through color additive or subtractive (diazo) techniques followed by visual interpretation of image products transferred to a stable, topographic mylar base. Final interpretation is usually accomplished after a detailed field survey of representative sites. Final verification of map delineations is carried out by means of low level aerial reconnaissance flights while simultaneously vertical and/or oblique photography is acquired to document detailed site conditions. The final land cover/map (scales 1:250,000-1:500,000) incorporates differences between level I/II categories. A typical example of the Land Cover/Use category definitions used in the Dominican Republic is included (Table 1).

Table 1. A Typical Example of the Land Cover/Use Category Definitions Used.

1. Urban and Built-Up: Man-made structures for residential, industrial, commercial and transportation-related land uses in contiguous areas of more than 1 km^2.
2. Agriculture: Land use for the production food and/or fiber.
   - 2.1 Sugar: Major agricultural areas of land planted predominantly to sugarcane interspersed with few other major crops except improved pasture.
   - 2.2 Intensive Agriculture: All other major agricultural areas with predominantly 75% or more of the land used for field and tree crops usually associated with prime agricultural areas.
   - 2.3 Marginal Agriculture: Less intensive, agricultural areas of a predominantly subsistence nature with 25 to 74% of the land used for field and tree crops. Usually characterized by smaller field interspersed with unimproved pasture, range, trees and open land in hilly terrain and foothills.
   - 2.4 Pasture: Predominantly improved pasture used for grazing.
3. Rangeland: Areas with a predominant brush and grass vegetation cover. Limited potential for grazing. Presence of Xerophytic plants common in the foothills.
   - 3.1 Limited Rangeland: Areas with major limitations for grazing caused either by steep slopes or heavy brush cover.
4. Forest: Forest lands predominantly with a crown closure of 75% or more.
   - 4.1 Predominantly Deciduous
   - 4.2 Predominantly Coniferous
5. Wetlands: Areas with a hydrologic regime accommodating aquatic or hydrophytic vegetation. Excluded are areas in rice production.
6. Barren/Open: Areas with exposed soil and little or no vegetation cover. Surface mining areas are included in this category.
7. Water: Inland water surfaces.
8. Cloud Cover: Areas where from August, 1972 to February, 1979 cloud free satellite imagery could not be obtained.

Mapped information on RPUs, land cover/use and national and internal political boundaries is geocoded for input into a geographic information system to provide cross-tabulations of mapped factors for the analysis of land use and associated production in a spatial context.

C. AGRONOMIC AND ECONOMIC DATA.

The two prior sections discussed the processes for defining agro-ecological zones and estimating their current major land uses. In order to complete the baseline data sets necessary for comparative analyses of agricultural land uses under alternative policies for

Table 2. A Typical Resource Planning Unit (RPU) and Potential Production Area (PPA) Description From a Central American Country.

RPU 12

GENERAL DESCRIPTION

RPU 12 consists mainly of the Nombre de Dios Mountains (Atlantida) and a westward extension of the area lying east of the Ulua Valley and southward around Lake Yojoa. This area of 602,000 hectares ranges in elevation from sea level to more than 2,000 meters. Soils are shallow to moderately deep. Warm temperatures prevail all year. Annual rainfall is high with less rainfall in the west and minimum rainfall occuring between November and April. Three PPAs are distinguished on the basis of differencs in soils and slopes.

PRODUCTION POTENTIAL AREAS

PPA 12-1, nearly 90 percent of the area, is a complex of shallow (lithic) and moderately deep soils, all of which occupy the steep slopes of mountains and hills. Most prominent are Lithic Eutropepts, Lithic Rendolls, Typic Tropohumults and Typic Dystrandepts. Because the soils are shallow and stony and all are steep and erodible, this PPA is most suited for forest use.

PPA 12-2, about five percent of the RPU, has two principal soils, Typic Tropohumults and Typic Dystrandepts that are not so shallow and steep as those of PPA 12-1. Because of their hilliness, however, their use should be limited to tree crops and pasture, to avoid severe erosion.

PPA 12-3 makes up the remainder of the RPU. Chief soils are Typic Dystrandepts, Typic Tropohumults and Fluventic Eutrochrepts. These undulating to rolling soils can be reasonably productive with row crops on the gentler slopes and hay and pasture or tree crops on more rolling areas.

PPA PROPERTIES	12-1	12-2	12-3
GENERAL			
elevation	0-2175 m	100-500 m	70-750 m
dominant slope	30%	16-30%	3-15%
portion of RPU	90%	5%	5%
CLIMATE			
- Annual wet seasons (no.)	1 (in some areas there is no distinction between the rainy and dry season)		
average precipitation	(1300)[2] 1550-3550 mm.		
average temperature	23-27°C		
- Wet Seasons			
average monthly precipitation	150-300 mm.		
average monthly temperature	23-26°C		
months	From May through October; from May through December, January or February		
- Dry Seasons[1]			
average monthly precipitation months	Very variable due to the variability of the wet season.		
SOILS			
principal components	Lithic Eutropepts Lithic Rendolls Typic Tropohumults Typic Dystrandepts	Typic Tropohumults Typic Dystrandepts	Typic Tropohumults Typic Dystrandepts Fluventic Eutrochrepts
depth to bedrock	50-100 cm.	50-100 cm.	50-200 cm.
texture	mod. coarse/fine	mod. coarse/fine	mod. coarse/ mod. fine
coarse fragments	non-stony/ very stony	non-stony	non-stony
permeability	moderate	moderate	moderate
available moisture capacity	moderate	moderate	moderate
drainage class	well/somewhat excessively drained	well drained	mod. well/well drained
flooding	none	none	none
INTERPRETATIONS FOR AGRICULTURE			
soil potential for cropland	Management Type I II III IV poor poor poor poor	Management Type I II III IV fair fair poor good	Management Type I II III IV good fair fair good
factors limiting land use	slope; shallowness; stoniness; erodibility	slope; erodibility	slope; erodibility

[1] Dry season data are residually estimated by subtracting wet season data from annual data.
[2] Data in parentheses are relatively minor in extent; they are transitional to adjacent RPUs.

achieving agricultural production potential, it is also necessary to associate agronomic and economic data with these agro-ecological zones.

The spectrum of agronomic and economic information needed for policy evaluations is dependent on the nature of the agricultural production potential issues. Generally, however, the need exists to analyze comparative advantage in the use of the natural resource base. As agricultural production processes encompass a wide array of natural resource - product combinations that are managed under a variety of technological, institutional, and marketing conditions, there is a need to obtain agronomic and economic information by the agroecological zones to facilitate the analysis of alternative policy options. Data are needed on crop area, yield, and production levels and on productive input use levels and production costs. In certain instances similar information is needed on the livestock industries, i.e., feed supplied to support livestock inventories, rates of off take, etc.

In countries with ongoing agricultural statistics programs, agronomic and economic statistics are generally collected by internal administrative units, not agro-ecological zones. If such programs are the only sources of data to establish baseline information on the country's agricultural production, allocative procedures are used to redistribute these data to the agro-ecological zones. Often the allocators are ratio estimates of land in a particular crop to total cultivated land in an agro-ecological zone, etc.

Occasionally, a country will have an annual agricultural statistics survey program employing field survey techniques that can be drawn upon to obtain agronomic and economic characteristics by agro-ecological zones. Data collected can be summarized by these zones through the inclusion of a zone code on the field survey forms.

If secondary data sources and/or an annual agricultural statistics program are unavailable, agronomic and economic data by agro-ecological zone must be obtained through a special survey. Such a primary data collection effort in a developing country is a large undertaking. Considerable care must be taken to design a survey instrument that fits the cultural attitudes of the country. Additionally, the cost of conducting the survey can be considerable.

III. INFORMATION MANAGEMENT

A. OVERVIEW

The information management systems are designed to store, update, retrieve and analyze the information sets developed to conduct analyses of agricultural production potential for national-level policy evaluations. These systems are modified to fit the existing needs of the country, its existing personnel capabilities, and its computer hardware configurations as closely as possible within the limits of budgetary and time constraints.

The components of the CRIES information management system are displayed (Figure 1). The actual computer systems used to actualize the components vary from country to country depending upon the conditions that prevail. Particular care is taken to minimize the personnel training need and computer time usage. As much of the computer processing of initial information sets as possible is done in the developing country to facilitate training in information management.

B. GEOGRAPHIC INFORMATION SYSTEM

The Geographic Information System (GIS) is used to store and analyze RPU and land use maps. Other agricultural and natural resource maps, interpreted airphotos or satellite imagery, and the map of country administrative boundaries (country, regions, provinces) are also incorporated in GIS.

System Design Considerations. The development of a GIS for resource inventories and evaluations depends heavily upon developing country's objectives, existing capabilities, and transferability of the methods and technologies employed. The first consideration is the level or levels at which analyses are to be conducted. Although the CRIES project looks primarily at national-level policy evaluations, GIS is designed to accommodate both national and regional level analyses. The GIS must be able to handle the quantity of geographical data at the detail required for the initial national-level study and be flexible enough to accommodate subsequent regional-level analyses.

Existing Capability. The developing country's capabilities in information management pertinent to system design are personnel capabilities, software/hardware availability, and fiscal support for information management activities. A series of questions pertinent to personnel resources are: How busy are counterparts? Will counterparts be able to modify the system to suit their needs? What computer languages are familiar to counterparts? What is the turnover rate among the technical staff? What support does the technical staff have (keypunchers, systems analysts, consultants)? How familiar are the counterpart groups with the management and analysis of spatially-referenced data? Is there a cartographic unit which could service the counterpart group?

With respect to hardware/software availability, the following issues need to be addressed: What computer(s), operating systems, core sizes, peripherals (disks, tapes, digitizers, plotters, printers, terminals) are available? What support do computer companies provide in-country? What editors, stat packs, etc. are available?

Fiscal considerations that need to be addressed are: What is the financial capability of a country (in light of its other demands for scarce resources) to purchase or lease hardware/software? What are the lease charges for software relative to computer programmers' salaries?

Transferability. In transferring a GIS to a developing country attempts should be made to provide a system which not only fulfills the objectives of the initial national-level analyses for policy evaluation, but also will be easy to use and modify by developing country counterparts for subsequent uses. Moreover, the system ought to minimize technical and financial

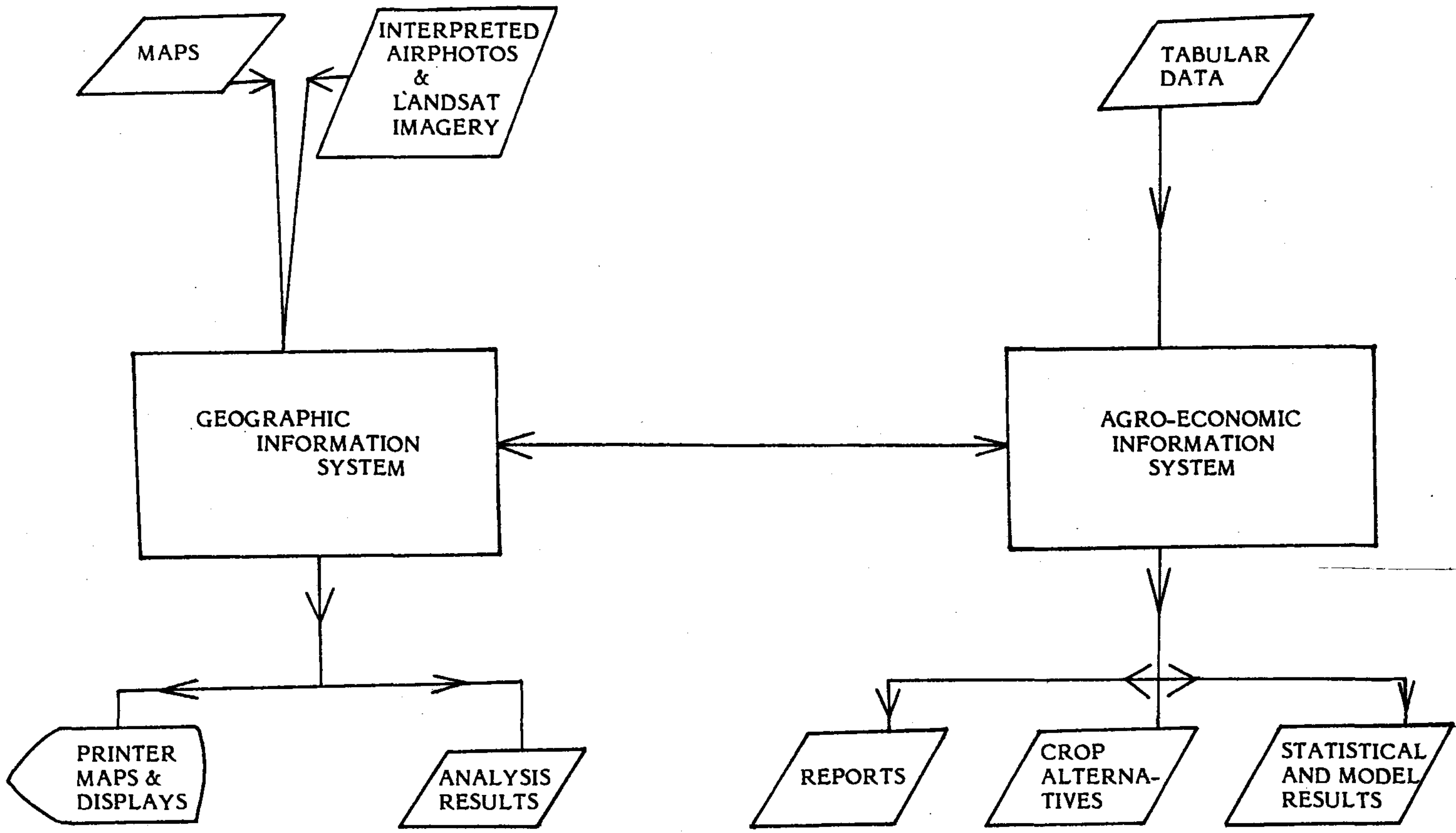

Figure 1. Major Components of the CRIES INFORMATION MANAGEMENT SYSTEM

dependency of the participating country upon "outside" resources.

The complexity of the system and its data structure are important issues. The availability of readable manuals, in-country training, consulting and maintenance services are crucial. The ease with which country users can begin obtaining timely, realistic results from the system has a positive correlation on its transferability. In-country users must have a basic understanding of what the inputs and outputs of the system are necessary. This often points to the developing of a simple but modular system.

A decision analysis for determining a GIS design for a developing country would embody several factors. High scores relative to these factors would indicate use of existing mainframe computers, manual geocoding, line printer maps/displays, and a grid data structure. Low scores would indicate use of dedicated computers, scanners, plotters and polygonal data structures. The measurement criteria for each factor below is meant to go from high to low scores.

1. Size of study area -- Small (below 100,000 km^2) to Medium (100,000 -250,000 km^2) to Large (over 250,000 km^2)
2. Projected financial resource availability in the long run -- Low to Medium to High
3. Critical nature of problem(s) the system is supposed to address -- Low to Medium to High
4. Quantity of data to be inputted and updated -- Little to Medium to Large
5. Quality of computer maps and graphs essential in the long run -- Low to Medium to High
6. Quality and quantity of systems (hardware/software) support in-country for system to be installed -- Low to Medium to High
7. Does the downtime at times experienced within the country offset any throughput efficiency statistics quoted by the system's manufacturers/designers? -- Yes to Maybe to No
8. Availability of in-country semi-technical persons (keypunchers, coders, etc.) at low costs -- High to Medium to Low
9. Availability of in-country systems analysts and programmers -- Low to Medium to High
10. Turnover in counterpart technical staff -- High to Average to Low
11. Financial resources of the project available for acquisition or development of a GIS -- Low to Medium to High

C. THE CRIES PROJECT'S GEOGRAPHIC INFORMATION SYSTEM

The GIS developed by the CRIES project is designed for use in countries that would score high in the preceeding decision analysis. It is portable, modular, and emphasizes analysis as opposed to display. It consists of two software programs --the Geographic Master File Creator (GEOMAST), and the Geographic Resource Analysis Program (GEORAP). GEOMAST checks, edits, updates and creates geographic data bases. GEORAP analyses and displays the geographic information. The modularity of the programs allows new routines to be added or deleted easily and routines to be overlayed in the computer's central processing unit. The GIS comes with user's guides, training manuals, and slides and illustrations in English and Spanish.

For countries with medium ratings in the previously-described decision analysis, the CRIES project could transfer an uncopyrighted geographic information system that requires a digitizer and a compatible plotter. For countries with low ratings in the decision analysis, the CRIES project recommends that commercially available hardware and software be purchased.

Data Capture. The GIS used by the CRIES project captures data by grids other manually or with a digitizer. The manual process requires at least one two-person geocoding team. Usually, a 100 by 100 grid block can be geocoded (capturing only the boundary changes of the map) in one hour by a two-person team with two or three hours of training in geocoding techniques. The geocoded data are recorded in a fixed format. Once checked, edited and updated by GEOMAST, the output file is in a fixed format. GEORAP accepts four types of gridded formats, either from coded or binary files, including the raster format. Thus gridded data files from other sources can be used. In addition, if within GEORAP, derivative maps have been created, these can be saved in any of the four gridded formats.

Data Processing. The way that GIS is used by the CRIES project process mapped data is illustrated (Figures 2 & 3). The GIS is designed to be run interactively or in batch mode. The processing is more convenient and timely if used interactively.

Analysis and Display. The analytical capabilities of GEORAP allows the user to perform descriptive statistics (frequencies, crosstabulation), delineate area a given distance from a grid cell, overlay maps, develop suitability indices, and perform suitability analysis. The user has the capability of developing a series of derivative maps which can be used in other analyses.

The display capabilities of GEORAP are limited by the output peripherals (in many cases only a line printer). However, line printer maps and histograms are the usual routines used for data display. Printer maps can be scaled with overprint options. There are also routines which facilitate the use of plotters and graphics terminals.

D. GEOGRAPHIC INFORMATION SYSTEM TRANSFER

The transfer of the GIS consists of installation of the system and training. The first part of the training is a two day overview of natural resource inventories and planning. The audience for these presentations is

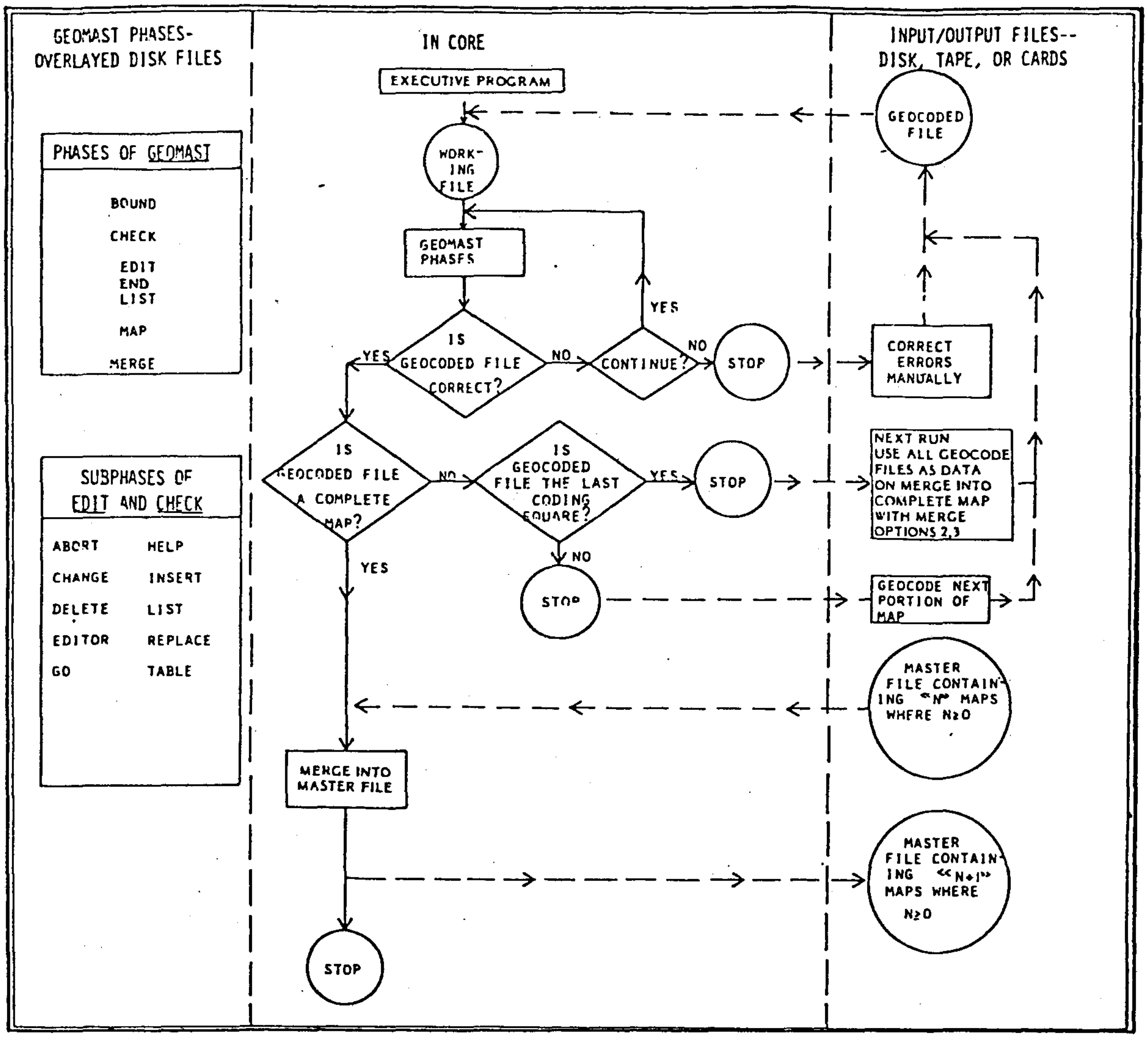

Figure 2. Schematic Diagram of the Geographic Master File Creator Program

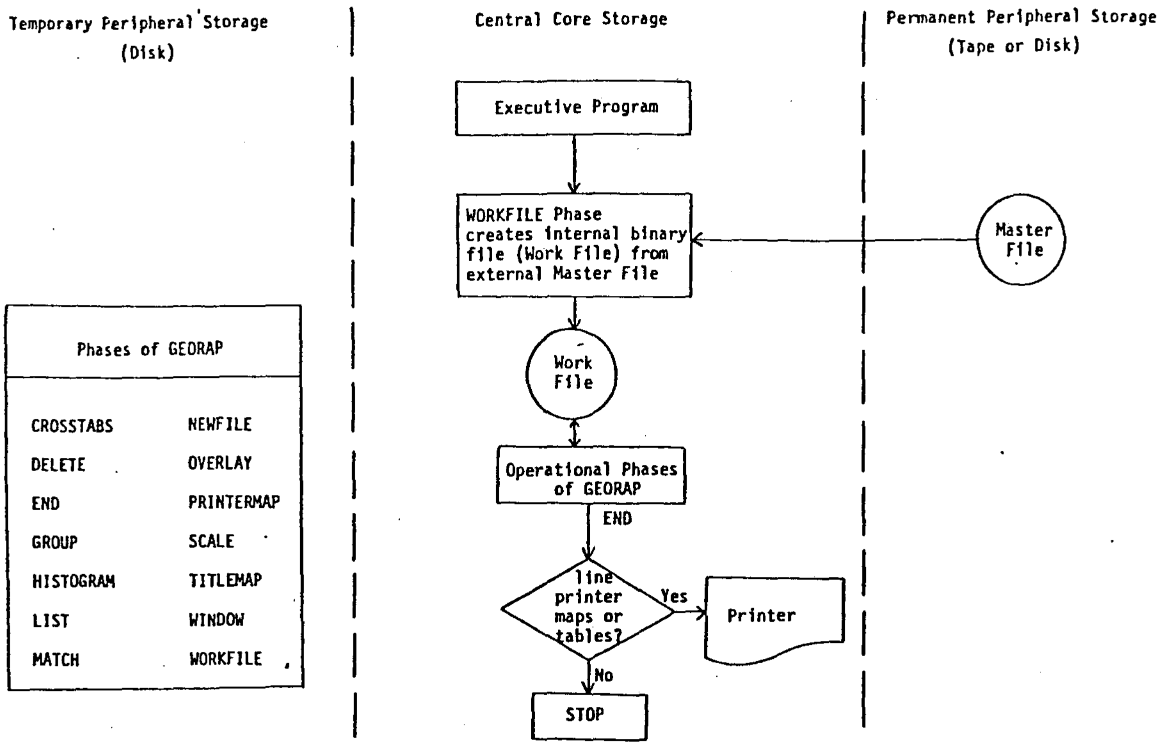

Figure 3. Schematic Diagram of GEORAP (Geographic Resource Analysis Program)

usually in-country project leaders and systems analysts who work with natural resource information.

The second part of the training consists of one day of geocoding training for technicians. The third part of the training program provides two to three weeks training in the operation of GEOMAST and GEORAP to users. Manuals and seminar outlines are provided to participants. Exercises are completed as part of this training. Where possible a small area within the country that has sufficient map coverage is chosen for analyses of agricultural resource problems. A data base and set of analyses are developed as part of this exercise. Additionally, the geocoding of a country map is included so that the counterpart group has some experience of developing a country level geographic data base.

Installation, testing and modification is done with collaboration with counterpart programmers. This provides the opportunity to train counterpart programmers in the internal operation of GEOMAST and GEORAP.

E. THE AGRO-ECONOMIC INFORMATION SYSTEM

A brief sketch is provided of the Agro-Economic Information System (AIS) since it is largely falls outside the main theme of this conference session. The AIS is designed to operate on tabular information to create data bases, update data bases, display (report), and analyze agro-economic information. The AIS designed by the CRIES project is suited for countries that would typically fall in the high range of the decision analysis described previously.

The AIS consists of data input, data verifiers, data editor; report writer, statistical analysis (descriptive and inferential), econometric models, and mathematical models (linear programming, multiobjective-goal-programming and optional control). The AIS, except for the econometric and mathematical models, is modular (linked); these models are separate and independent programs.

As some agro-economic data have spacial components and some spacial data are agro-economic, linkages between GIS and AIS are established to utilize the display and analytical capabilities of both.

The sources, structures, quality, quantity and types of data which a particular country collects and uses are so varied that is renders almost infeasible the design of a generalized AIS system. Therefore, the AIS is usually redesigned to accommodate the data structure and analytical needs of each country provided technical assistance. The design considerations for AIS tends to be more dependent than the GIS on the computer systems and personnel within the country, especially for the mathematical and econometric models.

IV. APPLIED ANALYSIS

A. RESOURCE INVENTORY

Agronomic interpretations can be made for the PPAs. They provide the homogeneity of land form, soil, and climate to make interpretations useful for assessing development priorities at the national-level. Two levels of interpretation can usually be made. The first is general interpretations for agricultural land use. The second more detailed interpretation are the crop or crop group recommendations.

The general interpretations provide indications of the potential of the physical environment for supporting agricultural endeavors. Economic evaluations of the relative practicality of various management practices and kinds of land use are not considered; such evaluations require additional information on the capital outlay requirements for the variety of alternative resource treatments, the operating costs associated with various management practices, the associated value of the increased production achieved.

The first general interpretation relates to soil potential. Soil potential is an expression of the expected performance of a soil for crop production under particular types of management.

Four types of cropland management might be defined as:

- I. Very limited use of inputs and no land preparation.
- II. Some input use and use of animal power.
- III. A high level of input use and use of mechanical power for land preparation and cultural practices.
- IV. Tree crops.

Ratings of soil potential are used for planning purposes and are not intended as specific recommendations for soil use. Interpretations of soil performance for crop production could be assigned one of three ratings such as:

A good rating implies high production potential at low long-term risk to the soil and for the expected crop. Limitations of soil and climate are minor or nonexistent. If necessary, soil limitations are easily correctable by manipulation of the surface soil.

A fair rating implies average production potential and some risk to the soil resource. Soil limitations present some difficulty in the use of equipment and require special management practices to produce above average yields naturally occurring in a PPA rated good. These limitations include moderate wetness, low available water capacity, erodability, slope, subsoil restrictions, salinity, and poor physical conditions for tilth. In those areas where soil limitations are minor or nonexistent by seasonal dryness is important, a fair rating is also used.

A poor rating implies low yields or unacceptable production potential and/or high risk to the long-term productivity of the soil resource. Either severe climate or severe soil limitations include slopes (greater than 30 percent), extreme droughtiness, drainage conditions (poorly or very poorly drained, or excessively well drained), long periods of flooding, high salinity, and shallow rooting depth (less than 50 cm).

The second general interpretation concerns limiting factors affecting land use. Limitations and restrictive features of the physical environment, principally those related to soil and climate, affect either directly or indirectly the use of land and the production of crops. Those attributes of the soil and climate which to some degree, either singularly or collectively, adversely affect the soil potential ratings are:

Soil Features: shallowness to bedrock; depth to restricting layer; wetness; susceptibility to flooding; steepness of slope; texture--sand; clay; stoniness; extreme acidity; extreme sodicity; extreme salinity; and erodibility.

Climate Features: duration of dry season; length of growing season; and distribution of rainfall.

The more detailed interpretations made from the production potential area descriptions are crop recommendations. Crop recommendations denote where major crops or major crop groups are adaptable and provide some indication of yield potential under alternative management levels. Ratings are qualitatively expressed as "high", "medium", and "low". Explanations of these ratings are provided:

High: When a crop or crop group is rated "high" conditions in the PPA are compatible with the known requirements of the crop or crop group. It may be inferred that a "high" rating implies a passibility of yield comparably to the upper values reported in the agronomic literature for a given level of management.

Medium: When a crop or crop group is rated "medium", what is meant is that one or more of the known crop or crop group requirements will not be fulfilled due to conditions that prevail within the PPA. A "medium" rating implies that crop yields will be less than the upper values reported in the agronomic literature for a given level of management.

Low: When a crop or crop group is rate "low" conditions in the PPA are incompatible with several of the known requirements of a crop or crop group. Yields of crops under such a rating can be expected to be highly variable from year to year. Additionally the "low" rating is used to acknowledge that crops with highly variable yields are traditionally cultivated within the PPA (under circumstances that the matching of crop requirements with PPA conditions would with such cultivation not to be advisable).

It should be noted that these crop recommendations are generalizations most suited for initial screenings for national-level planning purposes. In the case of single crops these qualitative rankings generalize requirements as though all varieties were similar. In the case of crop groups, the rating applies across all species included in the group.

B. REMOTE SENSING

In addition to the Landsat - derived land cover/use mapping a number of other applications have been evaluated and demonstrated.

Area Stratification for Sampling Survey Design. The successful application of an area-frame sampling design depends largely on the appropriate stratification of the landscape. Sampling efficiency and the associated accuracy of estimates on agronomic and socio-economic parameters at the national-level is greatly influenced by optimum stratification procedures. Landsat information can, based on experience in the Dominican Republic, replace or supplement aerial photographic information. It appeared that aggregation and adaption of certain categories in a nation-wide land cover/use mapping effort could greatly benefit area-frame design.

Multi-Stage Sampling. Landsat-derived categories are commonly too general to quantify in detail significant differences between agricultural production systems. Aerial sampling techniques have been successfully applied to refine landsat information and to produce estimates on crop composition in areas in intensive agriculture. Modified-systematic aerial sampling designs and associated intensities have been tested in their capacity to provide land cover/use area estimates. Four of the five major categories representing more than five percent of the surface area of a region in mixed agriculture in a tropical country, were accurately predicted at the 95 percent confidence level with a sampling intensity as small as 4.8 percent.

Crop Stress Analysis. Light aircraft, large scale, photography was used to test the cost and feasibility of quantifying canopy stress levels of sugarcane caused by a rust fungus (Puccinia kuehnii). Color infrared and multi-band imagery was acquired over areas infected at different intensities. Correlations of ground and image interpretation data, using a classification scheme based on five infestation levels and three growth stages appeared to vary from .86 to .66 at the 0.01 significance level for Color Infrared Imagery (CIR) scales of approximately 1:10,000 - 1:30,000. Result of the study indicated that use of CIR photography is a cost effective method for assessing the status and areal extend of infested sugarcane crops.

Evaluation of Imagery Parameter for Agricultural Inventories. A test was conducted to evaluate interpretation accuracies and, to some extent costs, associated with detailed agricultural inventories in a selected tropical country using various imagery types and scales. Generally it was found that good quality Pan chromatic photography at the scale of 1:30,000 (the smallest scale tested) provided a cost effective means in crop/area classification. Overall classification performance for seven classification categories with the use of a well-developed classification key, was 83.8 percent for CIR film versus 76.9 percent of PAN chromatic imagery.

C. GEOGRAPHIC INFORMATION SYSTEMS

The majority of the applications of the GIS has been in the area of inventory. The primary data developed by the CRIES project are a RPU map and a current land use map. The crosstabulation of land use by RPU is used to determine how land is being used relative to its potential use for crop production.

One country has combined social-economic indicators with natural resource data within the GIS to look at affects various policies on natural resources and visa versa. In this instance SAS (Statistical Analysis System) was linked to the GIS to provide increased capabilities.

Another application is a suitability analysis. To locate areas in Central America suitable for experimental farms/plots where corn/sorghum, corn solo, sorghum solo, or corn/beans can be tested. In this particular analyses the GIS is being used to identify those areas unsuitable for the experiments; researchers will conduct their field studies in the areas which remain.

In another country, statistics of the geocoded land use map by administrative region was checked against published totals.

Footnote:

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