Use of GIS in land resources management in the Colombian Orinoco Region

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Abstract

This article presents the use of Geographic Information Systems, or GIS, for land resources management with examples of various inter-linked applications in the Colombian Orinoco region. These applications are part of a project initiated in January 1999 and entitled "Exploration of opportunities for land use and agricultural development in the Colombian Orinoco". In nested test sites, they involve partnerships with the decision-makers at four different administrative levels, i.e. the village, the municipality, the department and the region. This project is also part of the savanna component of CIAT's ecorregional approach. We are diffusing the use of GIS at each of these levels as a tool for planning but also as a means to facilitate information transfer between levels. The determination of the biophysical restrictions to agriculture is an important step in the land use planning process. We are presently exploring different approaches to land suitability evaluation to determine which are most suitable at different levels or scales. In this context, we present the results of an evaluation based on an existing soil study for the municipality of Puerto López. An approach based on landscapes mapped from satellite images would be suitable for regional and departmental levels. If supported by adequate field characterization of soils and land use, as well as a good understanding of how these landscapes were formed, such an approach could be used by municipalities where semi-detailed soil studies have not been conducted yet. Land suitability maps explicitly presenting the topographic variations within landscapes are mostly useful for planning at the village or farm levels.

Introduction

Management of land resources is a complex issue. It involves different resources, a variety of users and decision-makers at different administrative levels, from the individual farmer or land-owner to national and international policy-makers. It therefore requires a multi-resource, multi-scale and multi-stakeholder approach. GIS plays an important role in such an approach, because it allows users to share information and visualize scenarios for discussion with the public. Moreover, GIS enables to display the results of simulation models and other decision-support tools, visualize land suitability schemes, market accessibility, and planned activities in space and time.

In the Colombian Orinoco region, our aim is to collaborate with decision-makers at different administrative levels and jointly develop GIS applications as well other decision support tools. We hae been pursuing this objective through a project entitled AExploration of opportunities for land use and agricultural development in the Colombian Orinoco region", which is a component of the agreement between CIAT and the Colombian Ministry of Agriculture and Rural Development since January 1999. These activities are also part of the savanna component of CIAT's eco-regional approach. We have chosen nested test areas that correspond to the different decision-support levels: the entire region, which includes 7 departments, the Meta department, the Puerto López municipality and five small villages within Puerto López. These are presented in figure 1. Other projects in CIAT are addressing the decisions taken at the farm level.

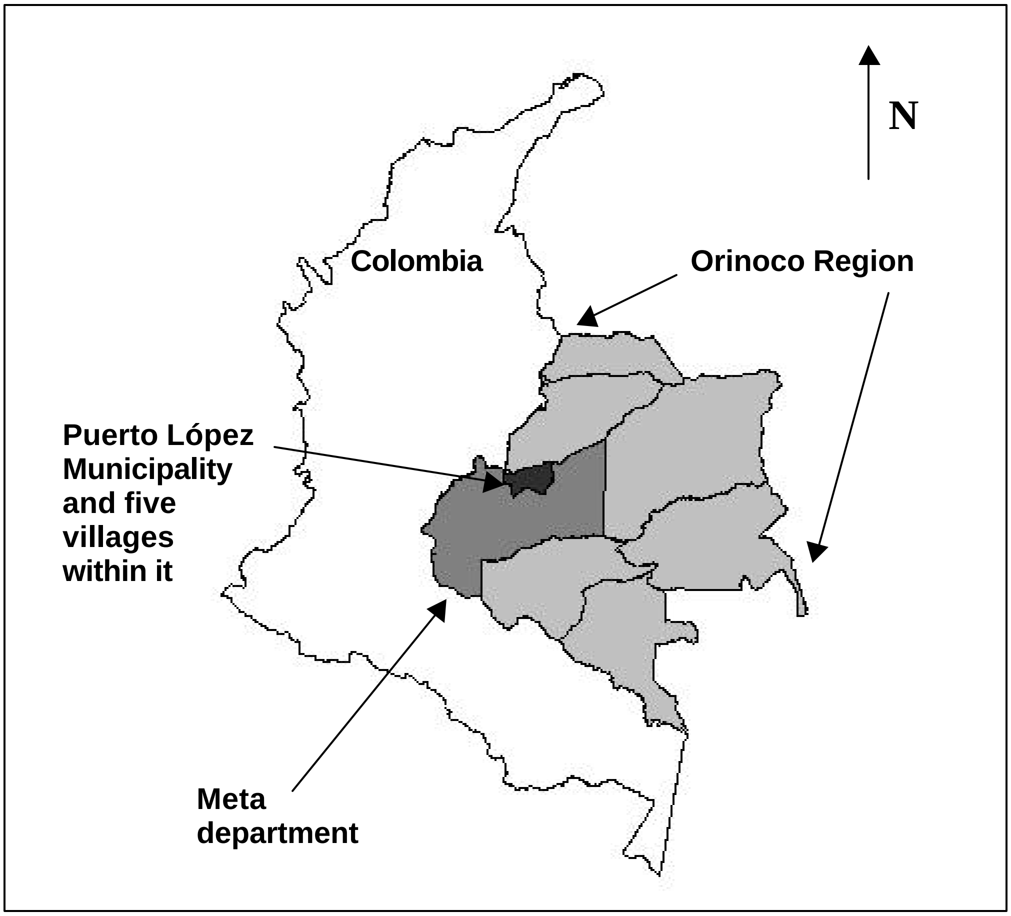

Figure 1: Nested test sites in the Colombian Orinoco region, within Colombia.

Partnerships and activities at the different administrative levels

At the regional level, we are participating in the formation of a planning network. While still in its formative stage of development, this network is enhancing the linkage between the regional institutions and development corporations, the governments of the seven departments and their corresponding municipal governments. GIS software and training materials are presently distributed over the network to the various members. This includes the MapMaker Popular GIS program (Duddley, 1999), a basic Spanish version of MapMaker that is freely available to non-profit organizations. We are also gradually compiling spatial information for the region. The first GIS task will be to compile all the protected and restricted use areas in the region to avoid the attribution of mining, petroleum exploration, pesticide use and forest extraction permits in conflicting locations. Conflict tends to arise in cases when municipalities implement land use restrictions on their territory, and that these are not taken into consideration by the regional institutions that grant permits for the extraction of natural resources. But the network's general task will be to assist the regional and departmental organizations in the planning and monitoring of the use of land resources. In 1999, the municipalities of Colombia are completing their land use plans to comply with the new national law N. 388 (1997), and the departmental governments will have to compile the municipal plans to elaborate the departmental plans in the year 2000. CORPES-Orinoquia, the regional planning council, must periodically update its development plan (CORPES-Orinoquia, 1998).

In the year 2000, we will therefore be supporting the land use planning efforts of the Meta department. But in the meantime, we are working with the departmental government to develop meaningful spatial data sets as well as environmental and socio-economic indicators. These indicators will be used by the Department for the evaluation of the impact of land resources policies. Once we have jointly established these indicators, the regional network will help the other departments develop and integrate their own data sets.

We are presently helping the planning secretariat of the municipality of Puerto López (which covers 6,744 km^2) with the preparation of its land use plan. This plan includes mapping of desired and actual land use, the latter being conducted from a Landsat TM image of 1998. Desired land use will be determined in a participative way by the municipality, based on actual land use, local needs and preferences, market opportunities as well as land suitability. Even in areas moderately suitable for agricultural use, the comparative advantages of natural vegetation and unproductive agriculture will be considered. The land suitability evaluation consists of mapping the distribution of different levels of restriction, allowing either conservation, restoration of natural vegetation, extensive pasture, perennial crops (non-mechanized), agropastoril systems as well as annual crops. We are exploring different land suitability evaluation approaches, involving different data requirements and different levels of detail of representation.

We first evaluated the land's suitability for specific uses and crops whose climatic requirements were met in the area. This effort was based on the characterization of soils mapped in the 1:100 000 scale soil map by IGAC (1978), following the approach proposed by FAO (1976) and IGAC (1986). The requirements of the different levels of uses and crops were determined in terms of soil depth, texture, slope, fertility, flooding frequency and drainage capacity. These characteristics were determined for all of the soil types in the soil map from the data in the soil study by IGAC. They were confronted with the agricultural requirements in a spreadsheet linked to the MapMaker Geographic Information System. The requirement to conserve the gallery forest (INDERENA, 1978) was also applied. But the application of crop requirements to soil units is not straightforward. This soil map, as all soil maps at this scale, represents complex soil associations. Each polygon can contain more than one soil with potentially different land use restrictions. The different soils often correspond to different geomorphological positions that cannot be mapped at this scale, especially since the slope varies continuously in the dissected portions of the municipality. For example, in the dissected high plains landscapes, the soils are much deeper, more fertile and richer in organic matter at the bottom of hills and in valleys than on the slopes and the top of hills. The top of hills, sometimes represented as relatively wide and flat plateaus, has a limitation in soil depth, because of the presence of plinthite. We evaluated each of the soils in the soil units but applied a "suitability scheme" to the entire polygons. It is in the legend of the land suitability map that we take into account the variability of soils within the units, describing which parts of the landscape are most suitable.

We then prepared a more general map considering all of the land uses contemplated. Again, because of the variability in soil properties within the soil units, we grouped the latter into ten classes for which restrictions and suitability are explained in function of the geomorphologic positions within them (depressions, flat areas between hills, slopes and top of hills). Figure 2 shows the distribution of these groups within the municipality and Table 1 presents their soil limiting factors as well as the suitable land uses. These groups correspond very well to the different landscape types that one can observe in the area. This relationship between soil restrictions and landscapes was also described by Ribeiro (1989) for a site in Brazil. In Puerto López, the restrictions related to landscapes and landforms are known by the local farmers who have had to adjust to them. Most of the rural population is concentrated in the most suitable areas. These include the flat portion of the high plain (shown in green in figure 2), which is used for semi-intensive livestock grazing on introduced pastures and some annual crops. They also include the terraces of the rivers flowing to the Meta river from the foothills of the oriental cordillera (blue tones in the left portion of the municipality), where rice is cultivated abundantly. Population is extremely sparse in the dissected portion of the high plain (orange to brown tones) which is used for extensive livestock grazing on the regrowth of natural savanna grasses after burning.

We also wish to provide a simple land suitability evaluation approach for the regional and planners as well as for municipalities which do not have semi-detailed soil studies. An approach based on geomorphological landscapes appears very suitable because, although there are many definitions of the term "landscape", it is a concept that can be shared by professionals of different disciplines as well as by the local population. The landscapes of the Colombian Orinoco region are described in IGAC (1999) and Ross (1997) gives methodological advice on how to use geomorphological analysis in environmental planning. We are therefore exploring how land use recommendations can be related to landscape types, drawn from satellite imagery and field surveys, complemented by soil sampling in the field or use of a soil map, without the necessity of representing the latter in detail.

Figure 3 shows a generalized map of landscape types, overlaid onto a portion of a JERS-1 image mosaic produced by the Japanese National Space Development Agency (NASDA, 1998). A more detailed version of this map was first derived from a RADARSAT-1 SAR image (Rubiano y Beaulieu, 1999), which unfortunately did not cover the entire municipality. We then completed it by using a Landsat TM image and the soil map mentioned earlier. We found that most of the features visible on the high resolution Landsat TM or RADARSAT-1 images were also visible on the JERS-1 mosaic, which covers the municipality as well as 5 of the 7 departments under study. We therefore decided to derive interpretation keys from the Puerto Lopez municipality to help the department of Meta to map the units in the neighboring municipalities from the JERS-1 mosaic. Although this mosaic, with a pixel spacing of approximately 100m, allows a less detailed analysis than the full-resolution JERS-1, RADARSAT-1 or Landsat TM images, it is presently the best data set we have in order to appreciate forest cover and geomorphology in the region.

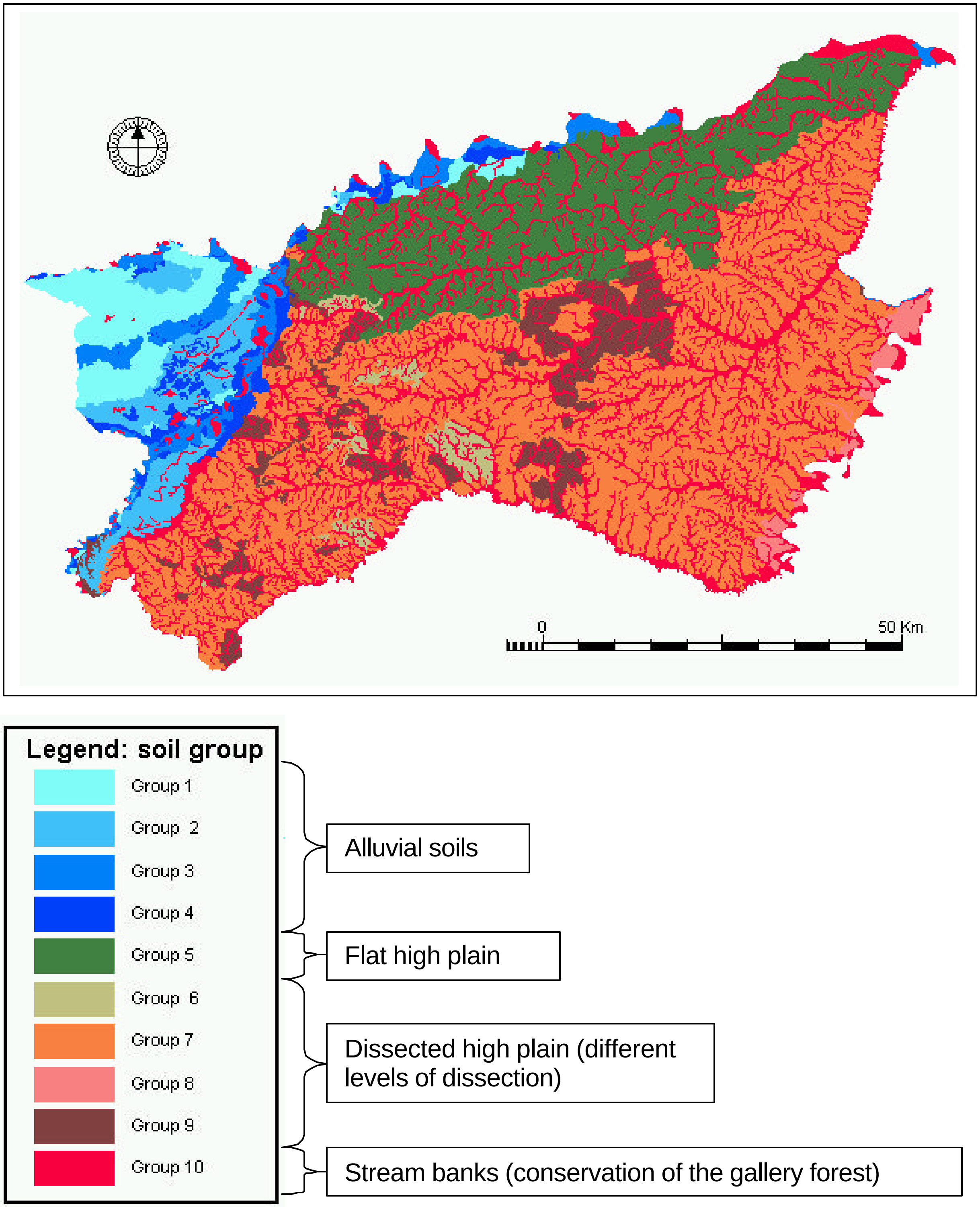

Figure 2: Land suitability soil groups defined from a 1:100 000 soil map (IGAC, 1978). Soil limiting factors and suitable land uses for these groups are given in Table 1, in function of the position within the landscape.

Group	Soil limiting factors	Suitable land uses
	Imperfect drainage, moderate depth, varying fertility.	Mechanized annual crops or semi-intensive livestock grazing, perennial crops such as fruits, rubber or African palm. Crops with deep roots require drainage.
	Imperfect to poorly drained, moderate depth, varying fertility.	Mechanized annual crops or semiintensive livestock grazing, perenial crops such as fruits, rubber or African palm. Crops with deep roots require drainage.
	Poorly drained, occasional flooding, low depth, varying fertility.	Difficult mechanization because of superficiality of soils and water saturation in a large part of the year. Localized use of annual crops (rice, sorghum, soya), semi-intensive or extensive livestock grazing in agrosilvopastoral systems.
	Very poor drainage, frequent flooding, very low depth, varying fertility.	Mechanization can only be performed in small, higher areas. Annual crops limited to varieties tolerant to excessive moisture (rice). Localized fruit plantations, cassava and pasture. Selective extraction and fishing
	Moderate drainage, moderate depth, low fertility, high aluminum saturation, crusting caused by iron oxides.	Annual crops adapted to the edaphic and climatic conditions. Easy mechanization. .Agropastoral systems involving semi-intensive livestock on introduced pastures. Fruit trees, rubber, oil palm or forest plantations
	Hills with slopes of up to 25% surrounding flat areas with moderate depth, well-drained soils, high aluminum saturation, low fertility.	The flat portions between hills are suitable for annual crops and introduced pasture but their mechanization is limited by accessibility. They are also suitable for fruit trees, rubber, oil palm, forest plantations and extensive grazing. Slopes are not suitable for any crop. Mechanization of flat hilltops is not recommended because of low soil depth and the presence of plinthite.
	Excessive drainage, slopes between 3 and 25%. Petroferric gravel pavement at the surface, low fertility. Narrow flat areas between hills.	The flat portions between hills are suitable for annual crops and introduced pasture but their mechanization is limited by accessibility. They are also suitable for fruit trees, rubber, oil palm, forest plantations and extensive grazing. Slopes are not suitable for any crop. Mechanization of flat hilltops is not recommended because of low soil depth and the presence of plinthite.
	Poor drainage in the low areas but excessive drainage, low fertility and petroferric gravel pavement on slopes and hills	The flat portions between hills are suitable for annual crops and introduced pasture but they tend to be poorly drained and their mechanization is limited by accessibility. They are also suitable for fruit trees, rubber, oil palm, forest plantations and extensive grazing. Slopes are not suitable for any crop. Mechanization of flat hilltops is not recommended because of low soil depth and the presence of plinthite.
	Pointy hills with very superficial and stony soils, surrounding limited flat areas with soils with moderate depth and moderate drainage	The flat portions between hills are suitable for annual crops and introduced pasture but they tend to be poorly drained and their mechanization is limited by accessibility. They are also suitable for fruit trees, rubber, oil palm, forest plantations and extensive grazing. Slopes are not suitable for agriculture. There are no flat hilltops in these areas.
	River and stream banks, subject to frequent flooding	Conservation of the gallery forest and natural vegetation Selective extraction and fishing.

Table 1: Soil limiting factors and suitable land uses for the groups defined in figure 2

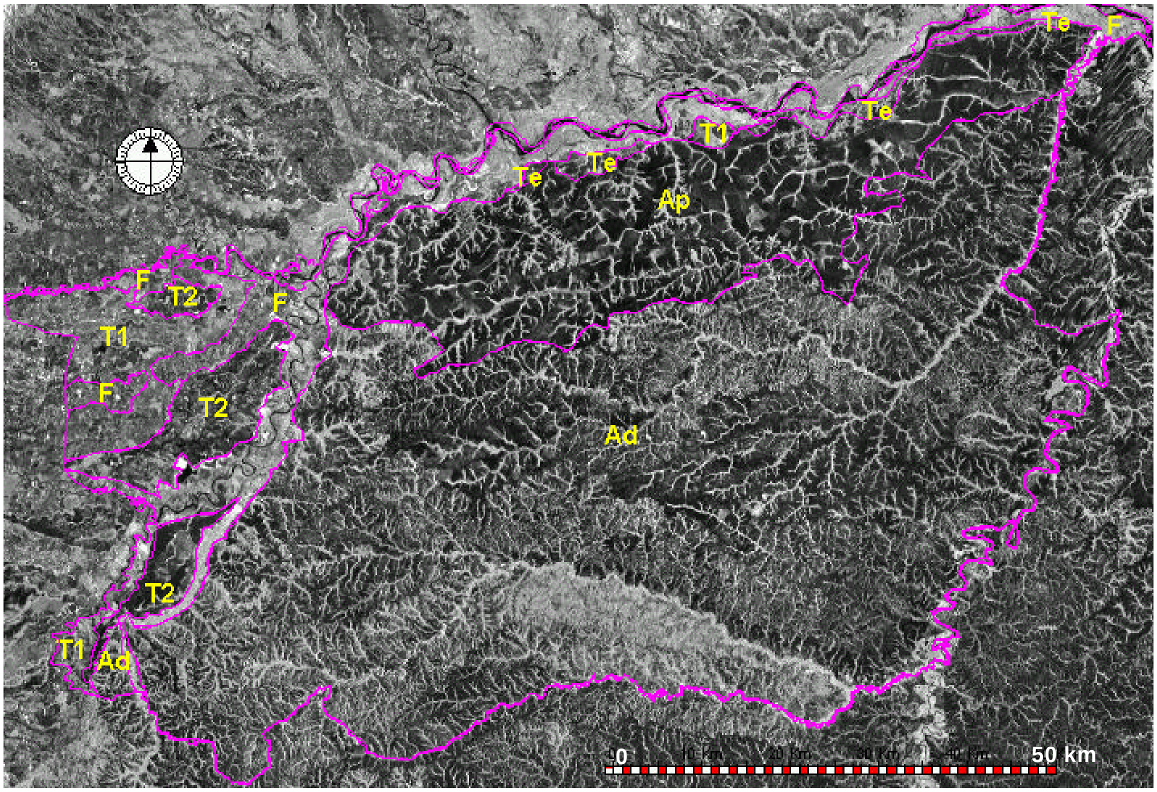

Figure 3: General map of landscape types ovelaid on a portion of a mosaic of JERS-1 images acquired in 1995 (©NASDA, 1998), over the municipality of Puerto López. Landscape types presented are the flat high planes (Ap), the dissected high plains (Ad), depositional alluvial terrasses (T1 and T2), floodplains (F) and erosional terrasses (Te).

In addition to our efforts towards simplification and generalization of land suitability mapping, we consider that a more detailed approach is required by farmers, agroenterprises and farmer associations. In many cases, they need to calculate the areas available to them for specific options, and to know exactly where they can implement them. For use at the village level, we are presently refining our land suitablilty analysis on the basis of slope calculated from a DEM that was developed from 1:25000 scale topographical maps. We are also incorporating soil erosion risk as an additional restriction. For the evaluation of the erosion risk, we are presently evaluating two approaches (Vrieling, 1999), a method developped at INPE (Crepani *et al*., 1999), which is based on an ecodynamic approach (Tricart, 1977 and 1992), and the Universal Soil Loss Equation (Wischmeier and Smith, 1978). We are also considering modeling soil properties as a function of topography. But we are very conscious that a DEM elaborated from 1:25 000 scale maps will not be useful for planning at the farm level, and that detailed soil characterization in the field cannot be replaced by modeling.

In collaboration with the Municipal Unit of Agicultural Technical Assistance (UMATA) of Puerto López, we are also supporting the planning efforts of the community action committes of five small villages. This study has started with an evaluation of potential markets for the crops and fruits in which the communities are interested. The GIS program is being used to draw field boundaries on scanned aerial photographs and digital Landsat TM satellite imagery, as well as to incorporate the location and results of soil quality observations in the field. The land units derived from this GIS analysis will be subjected to an evaluation of production costs and potential benefits for the different fruits and crops considered as well as their related value-added products. This will allow the communities to better choose and combine their options.

Interaction between the different administrative levels

For the planning effort now initiated in Colombia, each level has to provide information and plans to the level above where a synthesis is to be made. Conversely, each level has the responsibility of giving technical assistance to the level below. At the moment, this responsibility is not being fulfilled at its best by the institutions because of a lack of resources and a lack of technical capacity. This is where we feel that our project can have a significant impact, by providing simple tools and methods and by strengthening the links between the different administrative levels. GIS will be playing a very important role in these exchanges, provided that their use is disseminated. For example, the municipal units of agricultural technical assistance (UMATAs) are giving small farmers and communities support with specific agricultural production projects. With the use of GIS, aerial photographs, satellite images and thematic data provided by the regional network, they will better be able to help the communities to plan the location of their crops. On the other hand, the regional institutions will be able to more easily take into account the conservation areas defined by the municipalities when they issue Natural Resources extraction permits.

From the descriptive to the prospective phases

Planning projects often start with a very intensive descriptive phase leading to a diagnostic, and efforts often get drowned in a tendency to characterize the present situation in great detail. With the use of GIS, it becomes difficult to resist the temptation of accumulating large quantities of georeferenced data. But it is often very difficult to reach the prospective part of the planning, which addresses the questions "what will we do?" and "where?" We find it important for the planners to first define the desired situation with the population and stakeholders, evaluate the present situation on the basis of its comparison with the desired, and identify the means to reach the goal. (Shree *et al.,* 1999). With this approach, problems are seen as obstacles in this path and are not the main focus of the analysis. Indicators are used to monitor progress from and after the implementation of the actions planned. The evaluation of land suitability is necessary to determine whether the desired land uses are suitable for the area. It also enables to identify most fragile areas that should be devoted to conservation or recuperation of natural environments. But as we mentioned before, planning of land use must not be based solely on the analysis of land suitability. For example, Sanchez (1991) deplores the fact that large areas of the Brazilian Amazon forest have been converted to agriculture on the basis that the soils beneath the forest had been evaluated as suitable. Desired land use should be determined in function of local needs and potentials, as well as opportunities and restrictions both in the socioeconomic (market and labor) and environmental contexts.

In the municipality of Puerto López, it would be beneficial to intensify areas that are more resilient and to conserve the most fragile areas. For example, the dissected portion of the municipality is regularly being burnt for an extensive cattle ranching that allows very low stocking rates. This area could be better "used" if allowed to be recolonized by natural vegetation, assuming that the same number of cattle could be raised on much smaller areas in the more suitable zone shown in green on figure 2, on improved and well managed pastures. In this zone, there are extensive areas of degraded introduced pastures that could be much more productive if adequately managed. Conservation of the dissected portion of the municipality would be possible because presently, the municipal population density is low and there is no pressure to produce large quantities of food. But some perceive the Colombian savannas as an underdeveloped territory with great potential for producing food for the urban sectors of the country. National agro-industrial policies could induce pressure on the area if policy-makers are not well informed of the restrictions. These restrictions must also be considered in the eventuality of a land reform to avoid unsuitable land from being given to small farmers.

A discussion on land suitability approaches

In Latin America, the main limitation to the evaluation of land suitability is the availability of data, especially on soils. Generally, the biophysical suitability for different levels of land use is determined in function of soil properties, topography and climate. Very few areas have detailed soil surveys, and the units in the soil maps usually correspond to complex associations of diverse soil types, with different properties. When land suitability evaluation methods are conducted, a representative soil property is often applied to the entire unit. Some of the properties needed in land suitability evaluation, for example slope, can be calculated from a Digital Elevation Model (DEM), if a DEM showing more detail than the soil map is available. In certain types of landscapes, some of the other soil properties could be predicted on the basis of parameters extracted from a DEM, based on experimental data. But for planning of agriculture at the municipal level, it is not necessary to explicitly portray the variability of soils and slopes within the territory if it can be described logically. In the dissected portions of the landscape, having a multitude of small polygons or pixels with different classes of land suitability is confusing, and will certainly not ease the monitoring of the implementation of recommendations. This variability would be expressed much more meaningfully with soil longitudinal profiles along representative transects.

In the case of savannas, for the departmental and regional levels of planning, we feel that recommendations can be made respectively to geomorphological landscape types. This approach encourages an understanding of the restrictions to land depending on the position within the landscapes. But these levels also require an analysis of climatic variability within the study area. For the municipal level, a landscape approach can be complemented by explicit land suitability maps, portraying recommended land uses or levels of suitability of a given crop or use. But users have to interpret these maps knowing that at scales such as 1:100 000, they do not satisfactorily take into account the variability of the terrain for the characterization of soils. A more detailed analysis, explicitly presenting the topographic variations and their related factors, is recommended for the village and farm levels. Since the municipalities have (up to a certain point) the responsibility of helping small communities and farmers to plan their land use, it is pertinent for them to have a detailed GIS database of the entire municipality. In the case of Colombia, topographic maps are available at a much larger (detailed) scale than the soil maps. A good understanding of how soil properties vary with topography in the different types of landscapes is necessary to be able to express the variability within the units of the existing soil maps. This variability can be either expressed as descriptions associated with generalized mapping units (as in Table 1 but preferably supported by typical longitudinal soil profiles) or by further detailing the cartography. The level of detail in the explicit representation of variability should depend on the scale used for the study and also on the specific questions that need to be answered with the maps.

Conclusions

The interactions between the decision-makers of the different administrative levels can be very much enhanced by the use of GIS for organizing and sharing information as well as discussing scenarios among stakeholders. In addition, GIS can be used to evaluate land suitability for different uses, combining thematic information of different sources, using different approaches. Distinct approaches, corresponding to different levels of representation, should be used for different levels (or scales) of planning. We consider that a description of restrictions in landscapes mapped from satellite images is suitable for regional and departmental levels. If supported by adequate field characterization of soils and land use, as well as a good understanding of how these landscapes were formed, it could be used by municipalities where semi-detailed soil studies have not been conducted yet. Land suitability maps explicitly presenting the variation of topography within landscapes are mostly useful for planning at the village or farm levels.

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