GIS: A Window on Tropical Agriculture and Natural Resources

The Importance of GIS

Geographic information systems (GIS) are a relatively new set of scientific tools—powerful hybrids born of the marriage between modern disciplines, especially electronic computing and remote sensing, and more traditional ones like cartography and geography.

Simply put, a GIS is a computer-based framework that allows different kinds of information to be geographically tagged ("georeferenced") and displayed together on a single map. Users can then combine two or more distinct data sets to view relationships between selected social or biophysical factors—crops, livestock, forests, soils, waterways, climate, topography, population distribution, income patterns, education levels, roads, land tenure, administrative boundaries, and so on. GIS thus provides dynamic tools for analysis and reanalysis, making and remaking maps, mixing and matching different kinds of information depending on what is of interest.

During the past two decades, GIS applications have revolutionized how scientists use spatially oriented information. Around the world these tools are now in daily use by diverse specialists: meteorologists, geologists, hydrologists, economists, demographers, disaster relief workers, wildlife conservationists, ecologists, foresters, botanists, and plant breeders, in addition to cartographers and geographers. GIS tools allow these users to rapidly organize, integrate, and visualize various kinds of biophysical and socioeconomic data. The resulting electronic maps serve as a workspace for creative analysis and problem solving.

Agriculture and related natural resources, being spread over a multitude of locations and elevations around the globe, are intensely spatial in nature, lending themselves well to GIS analysis. Such analysis helps scientists, planners, policy makers, and others grasp the complex links between farming and environmental health.

The information used in land-use research and management usually comes from multiple sources. Typical among them are scientific databases, technical papers, census surveys, satellite and other remote-sensing images, economic forecasts, and reports of specialized agencies. Formats are often incompatible, though, or the data may be at different time and space scales, making comparative analysis difficult. One major strength of GIS is its ability to integrate and graphically represent such data.

GIS also allows users to push analysis beyond the current "real" state of the landscape. With modeling tools linked to or integrated with GIS, researchers can simulate and investigate alternative future states. These may be based on government policy options, economic growth projections, climate change scenarios, or other variables. Much of the strength of GIS, then, lies in its ability to tackle questions that begin with "What if ...?"

CIAT's GIS Laboratory

CIAT is a leading proponent and user of GIS as tools for untangling the web of social and biophysical causes and effects at work in the tropical rural landscape. The Center began assembling its GIS capacity in the mid-1980s. Fortunately, at that time it already possessed valuable assets with which to build: comprehensive databases on climate, soils, crops, genetic resources, pests, diseases, and socioeconomic factors in agriculture.

Today, CIAT operates a major state-of-the-art GIS laboratory that brings together, under a single "virtual roof," three types of resources: trained staff, databases, and the latest hardware and software. The GIS staff of about 40 scientists, technicians, and support personnel produce CD-ROMs and provide Internet-based information products and analysis for agricultural researchers, policy makers, and development planners around the world. The Center shares information with hundreds of organizations and works directly with national agencies in Latin America and the Caribbean to build and apply local expertise in GIS.

Behind the scenes specialists provide a range of technical support services for CIAT's GIS applications. These include:

- Management of a large computer infrastructure (spatial databases and state-of-the-art software and hardware in both Windows NT and UNIX operating system environments)
- Web integration of client services and implementation of data standards
  - Map digitizing and scanning
  - Photogrammetry, including extraction of digital elevation models (DEMs) from radar satellite imagery and stereo aerial photographs
  - Orthophoto production
- Field surveys and establishment of ground control points, using high-precision global positioning systems

Laboratory staff work directly with the Center's other scientists to adapt and apply GIS tools to diverse areas of research. While some staff are trained in GIS foundation disciplines like geography, remote sensing, and computer science, others have migrated there from areas such as ecology, agronomy, forestry, crop physiology, and soil science.

This wide mix of scientific expertise, combined with that found among non-GIS staff, allows for innovative synergy in CIAT's research. Visitors to the Center are just as likely to find a bean breeder and a crop physiologist working together on a GIS application as they are to find a geographer sharing a computer screen with a remote sensing specialist.

Applications of GIS to agricultural research and related areas of rural development are limited only by the human imagination and by the quality and resolution of available data. CIAT is actively developing and using GIS for diverse purposes:

- Mapping poverty and its social and environmental cofactors

- Environmental monitoring, assessment, and application of sustainability indicators
- Land-use planning at several political levels and geographic scales
- Predicting locations of wild relatives of cultivated crops and other organisms
- Analyzing genetic variation in plant species
- Disaster relief
- Crop modeling
- Germplasm targeting
- Mapping crop pests and diseases
- Research impact assessment

In addition, CIAT collaborates with other international networks and centers to implement spatial information standards and share GIS methods.

Integrating GIS into R&D

This section profiles selected GIS applications by CIAT, recent or on-going, under five themes: (1) poverty mapping and disaster relief, (2) environmental monitoring, (3) land use planning, (4) bioprospecting and germplasm conservation, and (4) integrated pest management.

Poverty mapping and disaster relief

Understanding poverty—especially who is poor and why—is a critical first step in designing development services for those most in need. In Peru CIAT has worked with the country's National Statistics and Census Institute (INEI) to make agricultural and census data more useful in the fight against rural poverty. Using data from a Peruvian survey of 5,000 households in the Ucayali region of the Peruvian Amazon, collaborating specialists created a GIS that allows users to analyze causal links between poverty ("unmet basic needs"), agricultural production trends, and the state of the environment.

With support from the Inter-American Development Bank (IDB), CIAT has also worked with national authorities in Honduras to design poverty indicators based on data from a national census covering 900,000 households. The indicators were linked to a socioeconomic and biophysical atlas of the country that CIAT released on CD-ROM in 1998. The results was a detailed picture of the spatial distribution of poverty—right down to the municipal level.

Going a step further, CIAT staff have used GIS techniques to help add a new dimension to poverty profiling, namely incorporating poor people's own perceptions of their "well-being" into indicators. In this case GIS analysis identified a cross-section of poor Honduran communities in which participatory research could be carried out with local people. This ensured that a sample of villages with contrasting biophysical and socioeconomic traits was selected for the study so that results could be extrapolated to the national level.

When Hurricane Mitch struck Honduras, Nicaragua, and other parts of Central America in late 1998, CIAT's databases, familiarity with Central America, and GIS expertise were quickly pressed into service in the relief effort. Radar satellite images of the devastated areas were processed by Canadian experts using CIAT ground reference data. Center scientists then loaded the resulting information into the Honduras electronic atlas for use in damage assessment. They also added pertinent data on crop production, locations of institutions, and sources of drinking water. Within a week Center staff had a set of emergency maps for use by relief agencies. Several weeks later, the "Mitch Atlas" was widely distributed on CD-ROM in collaboration with the US Geological Survey (USGS) and Environmental Systems Research Institute (ESRI). CIAT staff also contributed to a second GIS tool with wider geographic coverage, the *Digital Atlas of Central America: Prepared in Response to Hurricane Mitch*, which was copublished by the USGS, ESRI, and CIAT.

An indispensable task in hurricane relief was rapid multiplication and distribution of seed to farmers. Some 60 percent of the combined farmland area of Honduras and Nicaragua was severely damaged by the flooding and landslides. Many communities lost entire crops of beans and maize, threatening their livelihoods and food security. In response CIAT and three other international research centers launched an emergency project called Seeds of Hope for Central America. The Mitch Atlas, with its detailed data on crop types and locations, proved highly valuable in targeting seed distribution to the neediest agricultural communities.

Environmental monitoring, assessment, and use of indicators

This is an area of intense CIAT collaboration with numerous partner organizations. One recent product of the work is a powerful information tool kit, featuring a CD-ROM called *Rural Sustainability Indicators for Central America*. The first product of its kind for any region of the world, the information package gives decision makers an unprecedented ability to analyze problems in development and the environment, determine their causes, and weigh the consequences of different courses of action.

Published in a bilingual English/Spanish version, the product resulted from a 2-year project carried out jointly by CIAT, the World Bank, and the United Nations Environment Programme (UNEP). Financial support was provided by the governments of Denmark, Norway, and Sweden. The indicators tool was developed through a collaborative process, involving 6 regional and 50 national institutions. All took part in extensive consultations, workshops, and training events.

The indicators tool includes 11 indices that help analyze development and environmental problems; 68 "core" indicators for determining the causes and effects of these problems; and 114 "complementary" indicators that help apply the analysis to decision making. The tool will enable decision makers not just to analyze past and present problems but to explore future possibilities. With a "spatial land-use model" developed at Wageningen University in The Netherlands, users can explore the potential impact of specific policies, strategies, and actions under different scenarios, such as "business as usual," "natural disasters," or "sustainable rural development."

The new product for Central America builds on the foundation laid by a previous CIAT/UNEP project, which led to Latin America's first computerized environmental and sustainability indicators atlas in 1998. Like that product, the Central America tool kit draws largely on information already available, though its level of detail and power of analysis are greater.

Participatory land-use planning

A related domain of GIS work is the exploration of new land-use opportunities, especially for agricultural development. CIAT has worked intensively at five reference sites in Central and South America, representing three different agroecosystems: savannas (the Orinoco region of Colombia), hillsides (Honduras, Nicaragua, and southwestern Colombia), and forest margins (Peru). Here we look at recent work in the Colombian savannas.

In the expansive Orinoco region, CIAT has established partnerships with decision makers at four administrative levels of government: the region, department, municipality, and village. The work started in January 1999 and is funded by the Colombian Ministry of Agriculture and Rural Development.

Colombia's official land-use planning process is an interlocking exercise. Each administrative level, starting with municipalities, submits its plans as an input to the next level up. While the CIAT project makes GIS tools and expertise available for individual planning exercises, it is also encouraging the overall flow of spatial information, in compatible formats, between the various planning levels.

The approach promoted by CIAT begins with the formulation of a common vision for the area targeted by the planning exercise—what various stakeholders would like to see in 5 to 10 years. A diagnosis is then made by comparing actual conditions with desired ones and attempting to explain why there may be gaps between them. Next, collective actions, including adjustments in current land use, are planned. At this stage goals must be made more precise and adjusted in light of the land's suitability for the intended uses as well as socioeconomic factors like accessibility to markets and labor availability. Once the desired land use has been mapped out and the planning is complete, progress is monitored via a set of measurable indicators. These are used to track actions and any changes in the conditions that were described at the beginning of the exercise.

GIS analyses contribute to several aspects of the planning and follow-up work. They are used to describe actual conditions, to fine-tune goals through land suitability and constraints analysis, and to monitor progress. The planning approach is not based solely on land evaluation techniques; rather, these serve as an intermediate step.

The approach has been developed with decision makers in Orinoco and is being tested in their land-use planning exercises. Some GIS tools have been developed and are progressively being improved; others are still under development. A planning exercise has been successfully completed with the municipality of Puerto López. The *Plan de Ordenamiento Territorial* (POT), which is required by law and serves as the municipal-level policy on land use and municipal development, is now entering the monitoring phase. Planning exercises with five villages within the municipality are also well advanced.

Since the cost of GIS software can be a real obstacle to the adoption of GIS-related tools and methods at all administrative levels, CIAT helped fund the production of a simplified, Spanish-language version of MapMaker Pro, a low-cost British commercial software program. Called MapMaker Popular, the Spanish version is now distributed free of charge over the Internet, from CIAT's Web site. An accompanying Spanish-language training guide, developed by the CIAT team, is likewise available.

The CIAT project currently benefits a specific group of Colombian land-use planners and communities. But it is also generating valuable knowledge about which mixes of data, GIS tools, and conceptual approaches work best for land-use analysis at various geographic scales, from the village on up. Other countries and regions thus stand to benefit from the pioneering GIS work being done in savannas of Colombia's Orinoco.

Bioprospecting and germplasm conservation

Collecting, describing, and preserving specimens of wild plants and other organisms is a venerable art requiring meticulous attention to detail. It has been practiced for centuries by itinerant or curious farmers, traditional healers, and explorers. More recently, it has become a domain dominated by biologists, horticulturalists, herbarium curators, pharmaceutical companies, and plant breeders.

Bioprospectors, whether they are interested in mammals, insects, plants or other organisms, have traditionally needed strong legs and enormous patience to cover vast tracts of land in the pursuit of elusive quarry. Their success has often been based on educated hunches and sometimes on serendipity–being in the right place at the right time to make an unexpected discovery.

FloraMap® is a CIAT-designed software tool that eliminates much of the guesswork, legwork, and costs typically involved in tracking down wild plant species and other organisms of potential use to researchers. Developed, tested, and refined over the past two decades, this Windows-based tool relies on climatic data to predict promising collection sites.

Now available on CD-ROM, FloraMap is designed especially for situations where a wild plant or other organism has already been collected from multiple sites but where little is known about its physiology. All that is needed to run the program is the latitude, longitude, and altitude of each site from which the original set of specimens (or "accessions") was collected. These are the raw data that FloraMap uses to produce probability maps showing where else in the tropical world the species might be found.

Agricultural scientists are increasingly interested in the wild relatives of cultivated crops, because they harbor genes that could be useful in breeding better crop varieties. Disease and pest resistance, drought tolerance, and better yield are just a few of the traits that wild plants may have to offer their domesticated cousins. But scientists are also interested in other life forms, such as insects, fungi, and viruses. Studying their physiology, life cycles, and genetic makeup can furnish important clues as to how such organisms help or hinder crop growth and health.

FloraMap is predicated on the idea that climate is a robust indicator of the environmental range of plants and other organisms. Likely alternative sites for finding a particular species are those whose climate profiles closely match those of the original locations where the wild accessions were collected. FloraMap predicts these sites with the aid of an extensive, georeferenced tropical climate database compiled over many years by CIAT.

In one recent application, a Mexican researcher investigating passion fruit (*Passiflora*) as part of an international project found a wild species in southern Colombia based on a prediction from FloraMap. The species had not previously been identified and recorded in that region by scientists.

While FloraMap is mainly a tool for predicting new collection sites to provide raw material for plant breeding, it has other important applications. For example, it can be used by plant genetic resource specialists to plan more efficient *in situ* conservation programs. Or it can identify locations where promising species might be cultivated by farmers or tested in field trials. Both these alternatives are currently being examined in relation to tropical grasses and legumes.

CIAT tropical forage scientists have built up a considerable germplasm bank and database. They are now using FloraMap in combination with road maps to determine climatically suitable sites for conserving forage species in convenient locations—close to roads. They are also exploring the suitability of FloraMap and other tools to target promising forage species, such as the legume *Arachis pintoi* (a wild Brazilian plant in the peanut family), on suitable farming communities. The latter work takes into account both biophysical and socioeconomic factors, such as adaptation of various species to local climate and soils, milk and meat marketing opportunities, and the potential benefits to poor people. Central America is the initial focus of this work, with Africa to follow later.

The aim here is provide national research programs, development projects, and NGOs with a menu of forage technologies useful to their client farmers. Interactive tools to analyze germplasm options will eventually be available both on CD-ROM and directly on the Internet. In the same vein, CIAT scientists are using GIS methods to target bean varieties to farming communities in Latin America, based on the results of regional trials.

Integrated pest management

GIS tools have also proved valuable in studying whitefly, one of the most serious and growing threats to tropical agriculture. One species in particular, *Bemisia tabaci*, not only directly damages crops by sucking sap from foliage but also transmits geminiviruses that cause devastating diseases in many crops.

Soybeans, tomatoes, and cotton are especially vulnerable to whitefly. While common beans, an important protein-rich staple in Latin America, are not a primary host crop of the pest, they are especially vulnerable as secondary targets on mixed farms where different crop species are grown in close proximity. The same holds for increasingly important cash crops like squash, watermelon, cucumbers, and peppers.

As part of the global Whitefly Integrated Pest Management (IPM) Project, CIAT researchers are using FloraMap and other tools to learn more about the whitefly's distribution, by species and biotype, and about the topographical and climatic conditions that favor outbreaks. By assigning more or less weight to recorded whitefly infestation sites, depending on the severity of the outbreak, IPM specialists can use FloraMap to predict future hot spots.

CIAT scientists note that easier visualization of whitefly-related data in space and time, made possible through GIS maps, is helping to ring alarm bells in the international development community about the global threat posed by this pest. Recent mapping of geminivirus outbreaks in tomatoes clearly traces a dangerous pattern of whitefly penetration in Latin America and the Caribbean over the past 25 years. In the 1970s only a few areas, especially southeast Brazil, western Mexico's coastal region, and southern Chile, were seriously affected. By the mid-1990s, the situation had worsened considerably, with outbreaks also being recorded in Venezuela, Guatemala, Honduras, Nicaragua, Costa Rica, some Caribbean Islands, and the southern US state of Florida. While GIS tools can help scientists make better predictions, they also serve to raise public awareness about the whitefly menace and add a measure of objectivity to the task of selecting priority research sites.

Partnerships

As described above, CIAT works closely with national agencies in developing and applying GIS tools. In an effort to systematically build local GIS capacity in Central America, CIAT coordinates a major project, called "Pro-SIG," with funding from the InfoDev program at the World Bank. Our main partner in this work is the Tropical Agricultural Center for Research and Higher Education (CATIE), based in Costa Rica.

Despite the growing complexity of agriculture in Latin America and the Caribbean in response to the forces of globalization, countries in the region lag behind other nations in the use of georeferenced data for agricultural planning. The Pro-SIG project aims to improve the situation by helping government information providers to create new products and services for sale to the agricultural user community and to set up information-sharing networks. Participating countries link their census and other statistical data on agriculture to digital maps using GIS programs. The idea is to enrich these information sources and make them more user-friendly for market research, economic analysis and planning, and environmental impact assessment.

Consultation and training are integral to the project. CIAT has helped national participants assess their hardware and software needs, advised them on equipment importation, and surveyed their core data sets. In September 1999 a training workshop at CIAT brought together 18 professionals from six countries. Participants learned about Web site development, spatial data standards, GIS software options, mapping technology, data capture, relational databases, geoprocessing, three-dimensional terrain modeling, and remote sensing. They also got hands-on experience with CIAT-developed GIS tools.

Participants from each country are now planning new products and services for their client, such as population and environmental atlases, project databases, and planning tools.

In another effort to foment international cooperation in GIS, CIAT plays an active role in the Consortium for Spatial Information (CSI). Founded in 1999, the consortium is a global network of 12 research centers and laboratories that use GIS technologies for land management, sustainable agriculture, and poverty alleviation. Like CIAT, most of the other participating organizations are supported by the Consultative Group on International Agricultural Research (CGIAR).

Major aims of CSI are to standardize data sets within the CGIAR centers and to collaborate on methods and solutions in GIS-based agricultural research at the global, regional, and local levels. For each of six themes, a CSI member is designated as the coordinating center. These themes are data management and tools; geographic dimensions of crop varieties; impact assessment; degradation of natural resources; training of national-level agricultural researchers; and poverty mapping.