CHARTING A NEW COURSE

CIAT's Initiative in Resource Management Research for Latin America and the Caribbean

A Review and Status Report, 1991 through 1994

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

CIAT, Cali, Colombia

Working Document
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Acknowledgements:

This document is a synthesis by Dr. Mark Winslow of a number of reports, analyses and graphics prepared during the course of CIAT's first four years of resource management research, including many passages copied verbatim. Major authors in those source documents included, in alphabetical order, Drs. Jacqueline Ashby, Gilberto Gallopin, Douglas Pachico, Joyotee Smith, Richard Thomas and Raul Vera, based on contributions of the scientific staff in CIAT's Land Management Scientific Resource Group, and Tropical Lowlands and Hillsides Programs. Thanks to Drs. Miguel Ayarza, Jacqueline Ashby, Myles Fisher, Samuel Fujisaka, Gilberto Gallopin, Ron Knapp, William Scowcroft, and Raul Vera for helpful reviews of the drafts. Photographs of field activities were provided by Drs. Jacqueline Ashby, Myles Fisher, Mark Winslow, Raul Vera, Mr. Mauricio Antorveza and Mr. Juan Carlos Quintana. Credits for the geographic information systems graphics are due to Drs. William Bell, Samuel Fujisaka, Peter Jones, and Ms. Elizabeth Barona. The collages and figures were prepared by Mr. Camilo Oliveros, and the text was formatted for printing by Ms. Alcira Arias.

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Executive Summary

The environment: a call to action, and CIAT's response

Global warming, destruction of the ozone layer, extinction of species, loss of tropical rainforests, soil erosion, air and water pollution - worrying reports over the past decade strongly suggested that global ecosystems were deteriorating in profound ways. Clearly, something needed to be done, and quickly. The whole world's attention was drawn to Rio de Janeiro, Brazil in June of 1992 as the United Nations convened a Conference on the Environment and Development, also known as the Earth Summit, which formed an action plan to confront these problems. Having made plans in broad terms, however, who could, and would effectively carry them out, and how?

Agriculture in Latin America, the area of CIAT's historical expertise, is fundamentally intertwined with many of the world's greatest environmental concerns, such as the loss of Amazonian rainforests, biodiversity and global warming. Notably, the Earth Summit focused particular attention on these as reflected in major agreements (Conventions) on biodiversity and global warming. Hearing the call to action even before the Rio Conference, CIAT had embarked upon an intensive, three-year strategic planning process, which culminated in early 1991. The process identified a number of comparative advantages CIAT could put to the service of this agenda. CIAT's impartiality, conveyed by its international, apolitical and non-profit status, make it a neutral broker in dealing with the sensitive trade-offs involved in environmental issues. Its credibility, built by a 25-year record of achievements and impact in agricultural research and development, has built a confidence that it delivers on what it promises. Many of the scientific skills, experiences and facilities built up over two decades at CIAT have direct utility in environmental sciences. And its linkages with many institutions, both within and outside of the tropics of Latin America enable it to convene the multiple partnerships that are essential to the complex task of changing how environmental resources are used.

The Strategic Plan became CIAT's blueprint for an initiative in the management of environmental resources, denoted as Resource Management Research (RMR). RMR would attempt to better understand how some agricultural practices affect the larger environment, and seek more sustainable technologies which simultaneously restore or improve the environment, enhance the quality of life of the poor, and increase regional food production. This pioneering document was a product of widespread external and internal consultation, and extensive environmental and socioeconomic data collection and analysis (Fig. 1). It was widely praised by scientific and donor communities involved in international agricultural development and environmental sciences.

A funding crisis

Just as the new initiative was launched, however a most untimely financial crisis hit the Institute. As a donor-funded institution, CIAT functions on annual pledges, depending on steady commitment from donors to fulfill long-term, strategic research thrusts such as the RMR initiative. However the fall of the Soviet Union and the end of the cold war suddenly turned the attention of major government donors to rebuilding Eastern Europe. At the same time, many had acquired debt loads which required cuts to be made to move towards balanced national budgets. As a result of these pressures, donations for development assistance aid fell sharply. CIAT's overall budget in inflation-adjusted dollars fell precipitously, to 15% below the planned level for 1992, and to 25% below it for 1993 and 1994. However, several donors began to specially earmark parts of their donations for use in RMR. This provided crucial support for the new initiative. Notably among these were Germany, Denmark, the Netherlands and Switzerland.

After a great deal of soul-searching, and buttressed by this special donor support, the Institute decided it must adhere to the priorities laid out by the Strategic Plan, carrying forward the new RMR initiative as vigorously as funds would allow. This decision was supported by the Technical Advisory Committee, the oversight committee of CIAT's parent organization, the CGIAR. By the end of 1992, the initiative had become operational, with key positions having been recruited. However, the 18.5 core scientific positions planned for RMR had to be reduced to 14, along with a number of support staff and operating budget cuts. Furthermore, recruitment of many of the 14 RMR scientific positions had to be delayed two years until 1994, when the budget appeared to begin to stabilize at the lower level. This delay postponed the onset of substantial parts of the RMR agenda.

RMR requires new strategies and approaches

The Strategic Plan laid the foundation for the RMR initiative. CIAT's contribution would be to act as a credible, effective agent in strategic regional research (with global implications); as a convenor and catalyst for multi-institutional research and development initiatives; as an advisor to governments and society at large concerning policies and technologies for sustainable development; and as a trainer of scientists in developing countries in the new methods of RMR.

Inducing individuals, communities and nations to change to more sustainable ways of managing the earth's natural resources, which is the ultimate goal of RMR, required a different set of research paradigms and perspectives from the prior crop commodity improvement approach. The crop commodity approach, which stemmed from the Green Revolution, had focused on increasing production, without great concern for the externalities this generated. Now, a much broader set of issues had to be tackled, affecting not only crop production but the health of the air, water, soil, and landscape, the livelihoods of communities, and national policies.

Clearly, changing practices that affected so many different dimensions of the larger environment would require engaging the participation and support of a wide range of individuals and institutions, many of whom were not the traditional clients of crop commodity research. To obtain sufficient perspective to identify regional and global priorities, and to engender joint commitment to those priorities, widespread consultations were undertaken. These resulted in the establishment of consortia, networks and other collaborative linkages necessary for RMR thrusts in particular areas (Fig. 2). The major committment of time and money which went into these consultations during the first four years of the RMR initiative were an essential start-up investment for this new type of research. Wide consultations must continue in the future, in the form of regular meetings of consortia and networks to review progress on the joint agenda, share results, standardize methodologies and a number of other important tasks essential to keeping these dynamic relationships effective.

The most intensive inter-institutional RMR linkages have been built around joint research projects in a few carefully-chosen strategic areas which are representative of major agro-ecosystems across Latin America, at present situated in Brazil, Colombia, Honduras and Nicaragua. CIAT's role in area-based research is to understand the more strategic, fundamental processes involved in environmental degradation and restoration, principles which can be extrapolated to many similar environments across the region. Local and national partners focus on generating nearer-term solutions to local needs. In this way, the work of both is highly complementary.

Another major task in the initial phase was to build the RMR capacity at CIAT - to recruit world-class scientific talent, and to upgrade the facilities and instrumentation for them to be maximally effective. While a great deal of strengthening is still needed and underway, by 1994 an impressive RMR capability was in place. Top scientific talent has been recruited in areas such as geographic and resource systems analysis, modelling, socio-economics, anthropology, plant and soil nutrition, and others. Superb facilities for geographical information systems and mapping, soil-plant analysis, scientific computing and database management, gene bank management, biotechnology and others have been installed.

Land management and agro-ecosystems perspectives

The Strategic Plan built CIATs' approach to RMR from two perspectives: land management and agro-ecosystems. Comparative studies of the native endowments of different land types, the effects of their uses and abuses on environmental degradation, and practices needed for more rational land management on a regional scale are the foci of land management research. CIAT now has the most sophisticated installation on the continent for geographic information systems, a key tool for these types of analyses (Figs. 7-11). An understanding of land management reveals policy and technology changes that will be necessary if more sustainable development is to be attained.

The agro-ecosystems perspective, in comparison focuses on in-depth studies of a few types of land which are especially strategic for environmental degradation, or which provide opportunities to counter it. By focusing on just a few crucial environments, more detailed studies can be carried out which can bring to light the mechanisms of degradation and rehabilitation, and reveal the motivations of the people whose decisions determine the present and future fate of these areas. Clearly, and even by design, there is complementarity and synergy between the land management and agro-ecosystem approaches, as attested to in practice from CIAT's brief experience with this model.

The focus agro-ecosystems

Three agro-ecosystems were chosen for focus following the in-depth analyses and consultations of the Strategic Plan: the tropical savannas, the well-watered hillsides, and the forest margins (Fig. 3).

The vast tropical savannas pose an opportunity to be the "escape valve" to meet peoples' need for steadily increasing food production and economic growth, but new technologies and policies are essential if these fragile lands are to be developed in ways which sustain their utility for the longer term (Fig. 4). The gentle terrain and minimal vegetation encourage expansive mechanical land-clearing and tillage, which erode the soil under the heavy rains and deplete the minimal nutritional reserves of these weathered, acidic soils. Overgrazing leads to degraded pastures which in turn stimulates even more land-clearing. Loss of native vegetation threatens an important biodiversity resource. Research is making exciting progress in better understanding the savanna's resource base and the effects of human intervention on it, and in developing improved agricultural systems which protect against erosion, enhance soil fertility, improve farmers' incomes, and increase productivity on existing cleared lands, countering a major motive behind social imperatives to further expand the agricultural frontier into virgin areas.

The hillsides are the basis of the livelihood of a large proportion of the region's rural poor, and the compelling need to meet basic food requirements drives many of these smallholders to use practices which erode the soil and destroy native biodiversity (Fig. 5). An understanding of the biophysical determinants of degradation and rehabilitation is fundamental to developing solutions in the hillsides, but there is an additional human dimension distinguishing this agro-ecosystem. Hillside communities, often marginalized by mainstream society, exhibit unique ethnic traditions and value systems often unfamiliar to outsiders, including researchers. These isolated communities must learn ways of engaging in group action to negotiate with downstream communities affected by their practices, finding "win-win" solutions that benefit both parties. CIAT is pioneering methods for involving farmers and communities in setting research priorities and objectives, and in forming consortia for community action to improve resource management. Research on this topic includes development and training in the use of computer-aided decision support systems and models to enable community organizations to analyze the implications of different trade-offs and reach mutually-beneficial solutions.

The third focus agro-ecosystem, the forest margins (Fig. 6), is well known in the international press. Immigration into the Amazonian rainforests has been supported by government policies aiming to provide opportunities for the unemployed urban poor to create a better life. Without much experience to draw upon, the settlers slash down and burn the forest, chipping away at the edges of one of the most biodiverse areas on the planet. Burning generates initially high crop productivity due to the release of nutrients in the ash and organic residues, but this is soon exhausted. The inherently nutrient-poor, acidic forest soils will not sustain agricultural production for more than a few years in the absence of fertilizer inputs, which the immigrants can rarely afford.

Once soil fertility is exhausted and weedy species take over, the only option is to sell the land to ranchers and speculators and venture further into the forest, clearing still more land. The land buyers often care less for maintaining the agricultural quality of the land than for its future resale value, allowing it to become overgrazed and eroded. CIAT is participating in a major global study to find alternatives to this vicious cycle of degradation. Clearly, government policies which encourage forest margin encroachment must be changed, and there is evidence that this is happening. At the same time, the needs of people already settled in these areas cannot be ignored. Research seeks to identify more sustainable farming systems which minimize damage to forests or even generate income streams by regenerating and protecting them. These should serve as an incentive for farmers to invest in the sustainable use of already-cleared lands, rather than clearing more virgin forest.

Results and achievements

The primary goal of these first years of the RMR initiative was to create an effective RMR capacity, and establish numerous linkages with other key institutions. This has largely been achieved, and sets the stage for a vigorous, shared future research agenda, one which addresses a top priority subject area for the CGIAR System, its donors and clients.

CIAT is now well positioned in particular research thrusts. It has conducted the world's most detailed biophysical and socioeconomic characterization of three major agro-ecosystems in Latin America, covering about 400 million hectares, and made several major advances in the methodology of characterization. In particular this characterization includes an innovative quantification of plant and soil fauna biodiversity as affected by land management practices. We have also developed or adapted workable models simulating the outcome of decisions affecting growth, equity and conservation, and assessing the effects exported to the larger external world from degradation within agro-ecosystems. The initiative has also identified valuable strategic principles behind more sustainable, regenerative farming practices, particularly in the savannas but increasingly in the other agro-ecosystems as well.

We do not engage in extensive characterization efforts as an end in themselves, but rather to ensure that the problems, and types of solutions we work on are relevant and appropriate to regional and farmer needs and resources. For example, our hillsides characterization in Central America in the La Ceiba, Honduras watershed found that farmers would in fact like to stabilize on existing cleared areas, if they could only generate sufficient income and food security to do so. At present a dominant food and income source is steep-slope bean cultivation during the first, heavy rainy season, which is undermining their soil resource base through massive erosion. We have identified the reasons farmers persist in this practice- it reduces bean heat injury and disease. We have also observed, however that some farmers attempt to grow limited areas of beans during the second, drier season (when erosion is much less likely), and they use mulch to conserve soil moisture which, incidentally, protects against soil loss. Yields are low in the second season, but prices are much higher at that time of year. A key leverage point, then for simultaneously increasing sustainability and income would be to increase bean heat and disease tolerance so that yields and income could be raised in the more sustainable, second cropping cycle as an alternative to first-season cropping. We and our collaborators are now attempting to identify varieties with these traits through farmer-participatory selection.

Normally a gestation period is required before a research investment begins to pay dividends, so it might seem too soon for the new RMR initiative to have begun producing major impacts of global significance. Nevertheless, two important achievements are already receiving worldwide notice. The potential benefits of these two innovations are manyfold greater than the costs of the RMR investment to date and indeed, greater than the cost of continuing the effort long into the future.

1. Reducing global warming: tropical pastures store global carbon emissions

CIAT's discovery of a previously-unrecognized major carbon "sink", the root systems of improved pasture grasses, could also help contribute to ameliorating the impending ecological disaster of global warming. Since the beginning of the Industrial Revolution, massive combustion of fossil fuels worldwide has caused major increases in atmospheric carbon dioxide, which could cause a warming of the atmosphere with potentially catastrophic results, such as the flooding of coastal cities and expansion of deserts.

CIAT-led studies in Colombia have demonstrated that the more vigorous growth of cultivated pasture species introduced into the savannas leads to the capture and storage of three to fifteen extra tons of carbon per hectare per year, compared to native savanna vegetation. Since there are a conservatively-estimated 35 million hectares of introduced pasture species in the tropical savannas of South America at present, it appears that from 100 to as many as 507 million additional tons of carbon are being stored annually, if our results are representative of that larger savanna area. This is roughly equivalent to the carbon waste spewed into the atmosphere by 215 million large automobiles each year. Dr. Pedro Sanchez, Director General of ICRAF has estimated a monetary value for the removal of one ton of carbon from the atmosphere at around US$100, which, extrapolated across the whole estimated area of improved pastures (35 million hectares) would indicate a value range from $10 to $50 billion annually.

This discovery implies an extremely powerful means through which sustainable agricultural development can simultaneously help improve the global environment. Increased vegetative growth, which is a basic objective of sustainable, more productive agricultural systems not only protects the soil surface and increases production but also increases carbon storage. The regeneration of degraded pastures through improved agro-pastoral systems, discussed below, could substantially increase pasture growth, and presumably carbon storage. Our results also indicate that another CIAT-led innovation, the introduction of legume forage species into tropical grass pastures, results in much larger amounts of carbon storage than in the grass-alone pastures which now predominate.

This recent CIAT RMR discovery has received global notice and acclaim (Fig. 12), and additional donor support is being sought to validate it over a larger area, and further explore its ramifications and the mechanisms underlying it.

2. *Reversing the downward spiral of degradation: improved agro-pastoral systems*

Degradation of pastures in the tropical savannas, mentioned earlier is a serious problem triggering soil erosion, the clearing of more virgin land, and low food productivity. It is known that regenerating grass pastures through tillage and re-planting, combined with modest fertilizer inputs and cattle mineral supplements can approximately double livestock productivity, and double it again if legume forages are additionally introduced, greatly increasing farm income.

The problem has been in starting up the improved system. Many farmers particularly smaller producers could not afford it, considering the requisite seed purchases, land preparation and weed control, and the year-long wait before the pastures became sufficiently well-established to be able to be grazed. RMR collaboration between CIAT and EMBRAPA-Brazil is now developing a prototype system which can overcome this bottleneck, with huge potential impact (Fig. 13). Referred to as "improved agro-pastoral systems", acid soil-tolerant cereal crops are simultaneously planted with better pasture species, providing farmers with quick income from the crop which also covers the cost of pasture establishment. The crop acts as a "nurse" to protect and enhance the rapid establishment of the pastures, keeping a constant vegetative cover to protect the soil (Fig. 4). The pastures establish well enough to be grazed shortly after the crop is harvested (about 6 months), accelerating the income stream generated from pasture regeneration, thus providing a second motivating element to farmers.

CIAT-led studies are showing that, by increasing the economic feasibility of pasture regeneration, the system generates large sustainability benefits in terms of improved soil fertility and physical structure, soil surface protection, carbon storage (as explained above) and increased soil fauna biodiversity. Of course, it also yields the major indirect effect of releasing pressure on land expansion further into native savanna areas and other sensitive agro-ecosystems to attain national food production and meet farmer income needs. It should be emphasized that by relieving the cash constraints to pasture regeneration, this system is particularly advantageous to smaller producers.

The imminent impact of improved agro-pastoral systems is enormous. In Meta, Colombia, despite security difficulties in the savannas the area sown to improved pastures increased by 14% annually between 1979 and 1992, and agro-pastoral systems are used on about 4,500 hectares annually, largely due to the stimulus provided by CIAT, CORPOICA, and local government collaboration. In Brazil, CNPAF-EMBRAPA estimates that there were more than 50,000 hectares sown to the upland rice-pasture variant of the prototype in 1993, expecting this to double to 100,000 hectares in 1994 and more than a half million hectares within five years. Venezuela is expecting to have 25,000 hectares sown to the system annually within five years. CIAT is catalyzing the international dissemination of this new technology through a savannas research network which it convened with special donor support, and training courses which it designed (Fig. 15).

The development of improved agro-pastoral systems has revealed principles which may have wider application, and are being tested in CIAT's other focus agro-ecosystems, the hillsides and forest margins. These principles include: plant species and management practices which increase the amount and rate of accumulation of vegetation, to increase productivity and prevent erosion, and efficiently store and recycle nutrients; successional species replacement to restore the landscape to a dense cover by adapted, biodiverse plant species; improved farm productivity; semi-colon and, perhaps most importantly, a steady income stream throughout the process, to stimulate farmer adoption of the improved technologies.

Outlook for the future

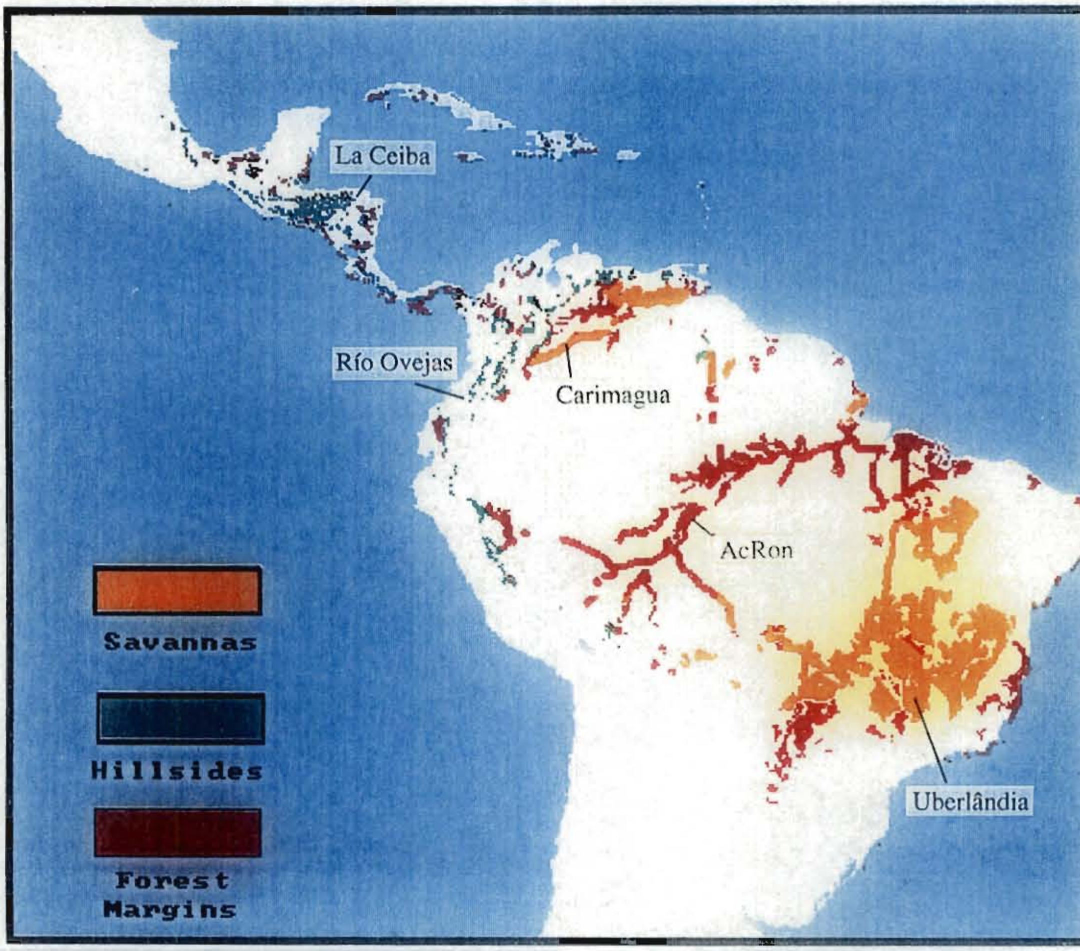
CIAT has become a leader in the CGIAR System in serving the new resource management agenda. In 1994, it was chosen to act as the "ecoregional convenor" to convene Latin American RMR for all of the 17 CGIAR Centers, a reflection of the confidence which the rest of the system places in it. CIAT was also chosen by its sister Centers in 1994 to be the convening Center for a new, System-wide initiative in soil, water and nutrient management research, as well as the convenor of a global consortium for research on managing acid soils. CIAT was also recently recognized by the Earth Summit convenor - the United Nations Environment Program - being invited to become a UNEP Collaborating Center for International Environmental Assessment and Forecasting. This may soon result in the creation of a Data Center on Sustainability Indicators for Latin America and the Caribbean at CIAT.

One feature of the RMR initiative has been an effort to build upon and realize synergies with CIAT's pre-existing strengths in crop commodity research, and to re-shape those efforts towards a resource management direction. Vegetation, including crop species is of course a key environmental resource, and the conservation and management of its diversity is a central issue in most concepts of RMR, as clearly reflected in the Biodiversity Convention emerging from the Earth Summit. One example mentioned earlier was the construction of agro-pastoral systems around improved, acid-tolerant crop varieties and leguminous pasture species. A second interesting example has been the application of geographic information systems technology, a key tool of RMR, to identify sites for potential new collections of genetic diversity of crop species and their wild relatives (Fig. 11).

Although the RMR initiative is just four years old, and donor cutbacks have substantially constrained its implementation, it has laid the foundation - building the capacities and institutional linkages which now set the stage for future success. Laying this basic groundwork has been a satisfying accomplishment for such a short and difficult period, yet there have been some highly significant scientific achievements, too. With continued and even stronger donor support in the future, these accomplishments could augur well for improving the sustainability, equity and productivity of agriculture in the tropics of Latin America, with enormous additional benefits to the global environment and society as a whole.

Figure 1. Major documents recording the information-gathering and analytical processes led by CIAT in the development of the RMR initiative.

Figure 2. Research consortia and networks linking CIAT with regional, national, and local partners, both in and outside of government, to execute the joint RMR agenda were documented in the proceedings of key meetings and workshops.



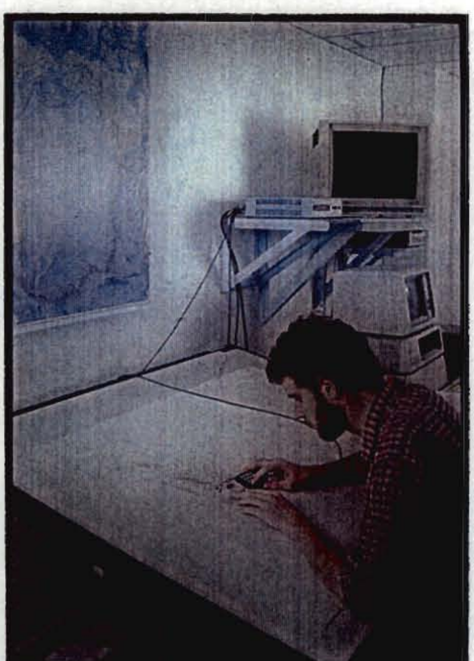


Figure 3. The geographical locations of CIAT's three priority agro-ecosystems: the savannas, hillsides and forest margins of Latin America and the Caribbean. Locations selected for area-based research efforts in each agro-ecosystem are also identified.

1 

Figure 4.

The tropical savannas of South America are a vast land resource of 250 million hectares, only about one-quarter of which is in use at present. They are characterized by grasslands intertwined with gallery forests (1). They are ideally suited for rangeland and pasture grazing, but overstocking and under-investment in land improvements have caused about 60% of the occupied lands to be in a degraded state, as illustrated by poor forage grass growth and termite mounds (2). Degradation causes farmers to clear more virgin land, whereas pasture improvement (3) could increase productivity on existing land by 30-60 fold, decreasing the need for expansion. Improvement is through the planting of more vigorous grass and legume species, together with modest fertilizer inputs and proper managment of stocking rates. Planting of improved pastures, however is expensive and involves a long time period with limited ground cover which can increase erosion (4, right side). CIAT and EMBRAPA are researching improved agropastoral systems, in which a cash crop like upland rice is intersown with more productive pasture species (4, left), acting as a "nurse crop" which provides good soil cover and a favorable microenvironment for pasture establishment, as well as cash income to cover the costs of the regeneration process. Well established Brachiaria forage grass can be seen emerging above the mature rice crop (5), which does not impede the rice harvest operation.

2 

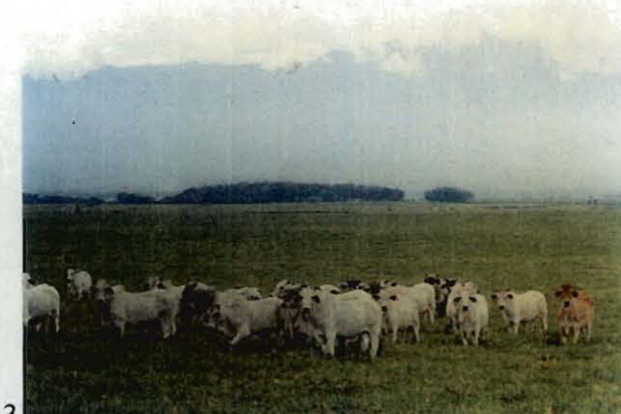
3 

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Figure 5. Many hillsides in Latin America and the Caribbean are intensively farmed by smallholders using manual methods (1). Tillage of sloping soils, however can lead to massive erosion over a few decades (2). However, the overriding concerns of these poor and often indigent farmers is to feed their families in the days and months to come. Meeting their needs while conserving the soil resource base (societies' long-term need) requires community action (3), and the negotiation of "win-win" solutions with the larger society, particularly downstream communities affected by siltation, pollution, flooding and drought. More sustainable farming systems and soil conservation must take into account the special needs of poor smallholders through participatory research methods, including farmer involvement in the selection of improved crop varieties (4). The ultimate goal is sustainable, productive use of this major land resource (5).

3 

4 

5 

1

Figure 6.

Most farmers in the forest margins are poor immigrants from overcrowded urban slums, seeking a better future and control of their own destiny through agriculture (1). However, the resource base is less productive than might appear from the lush growth of tropical rainforest. The forest is first slashed (2), then burned (3) and the nutrient-rich ash and good level of soil organic matter from decaying roots will support a reasonable first crop of cassava, upland rice, corn and other staple food species (4). However, soil fertility is ephemeral; nutrients soon leach and organic matter oxidizes, and farmers cannot afford fertilizers to replace them. They often sell their cleared lands to ranchers and speculators, who use them for poor quality grazing (5) while consolidating their landholdings. As the forest recedes, humanity loses valuable biodiversity, soil protection and a global store for carbon and source of oxygen.

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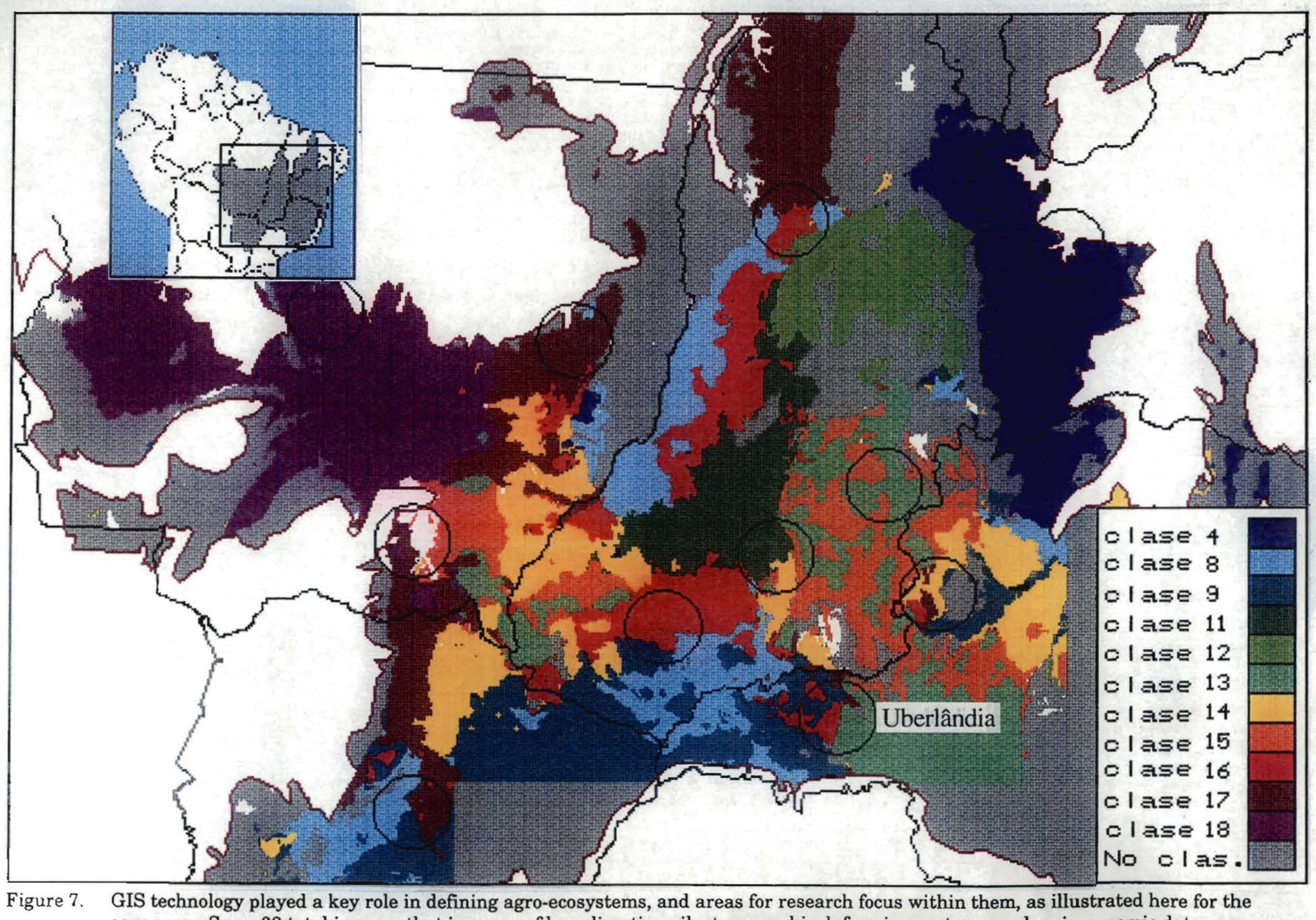

Figure 7. GIS technology played a key role in defining agro-ecosystems, and areas for research focus within them, as illustrated here for the savannas. Some 38 total images, that is, maps of key climatic, soils, topographical, farming systems, and socioeconomic data, were integrated using principal-component analysis and clustering techniques to produce 11 distinctive agro-ecological classes representing key characters of relevance to sustainable agricultural development across the Brazilian tropical savanna, shown here in different colors. The study was a critical resource used in a major Workshop held in Brasilia in 1992 to select candidates for the final study area. The final outcome was the selection of the area around Uberlandia for area-based research, because it has access to most of the savanna diversity clusters within the 60-kilometer radius.

Monitoring Land Use Dynamics in Acre and Rondonia, Brazil Using Satellite Imagery and Geographical Information Systems

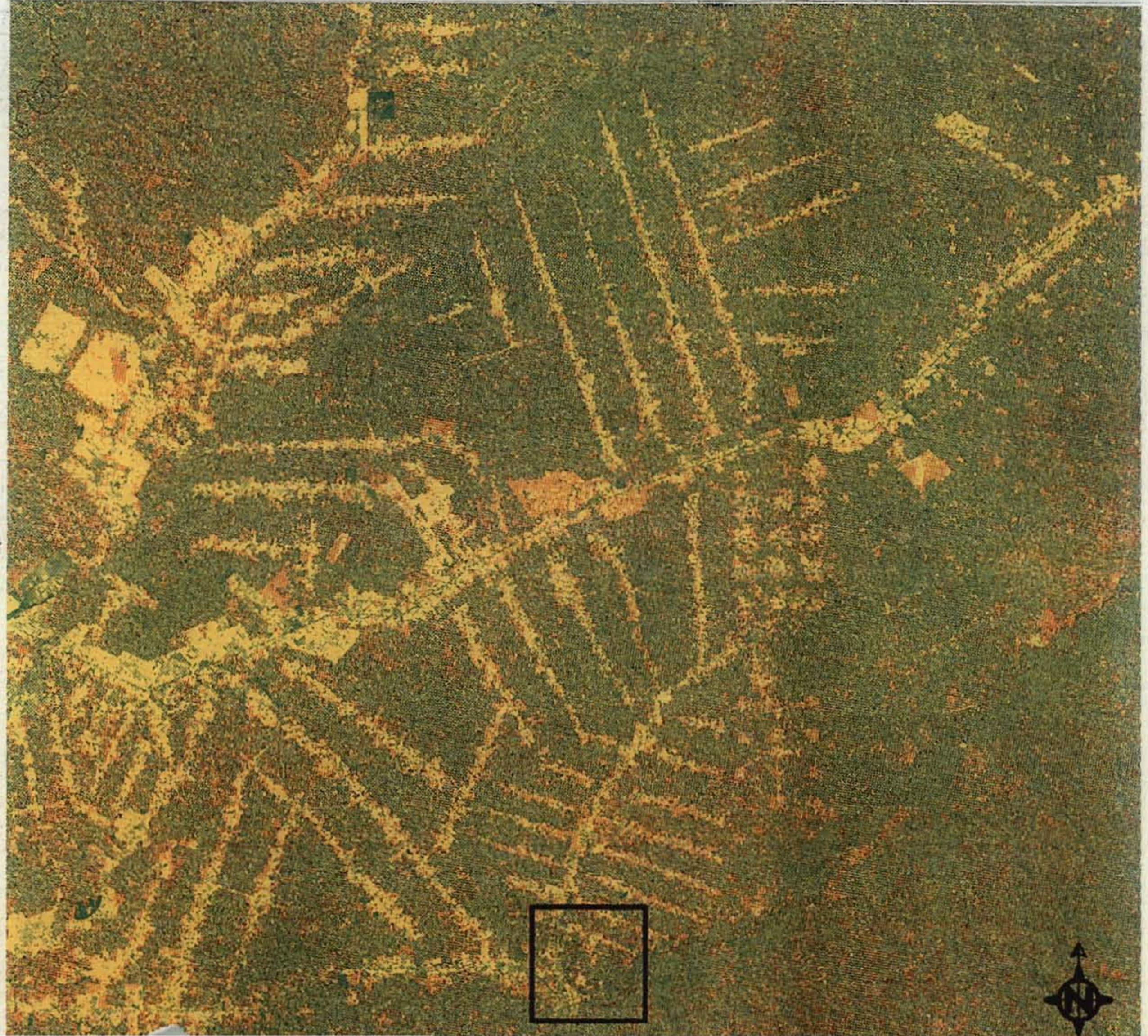

Figure 8.

The adjacent image, taken on January 2nd 1992, by the landsat thematic Mapper (TM) has been spectrally enhanced to create a colour composite using bands 4, 5 and 3.

TM images, covering 185km squared, have a nominal ground resolution of 30 metres and a "site re-visit" time of 16 days making it a valuable resource in temporal landuse characterization.

Clearly defined patterns of development, and associated deforestation, can be seen. The Brazilian-Bolivian border is defined by the river in the south eastern quarter of the image. Evidently Bolivia has not initiated development in this zone.

Scale

Kilometers

10 0

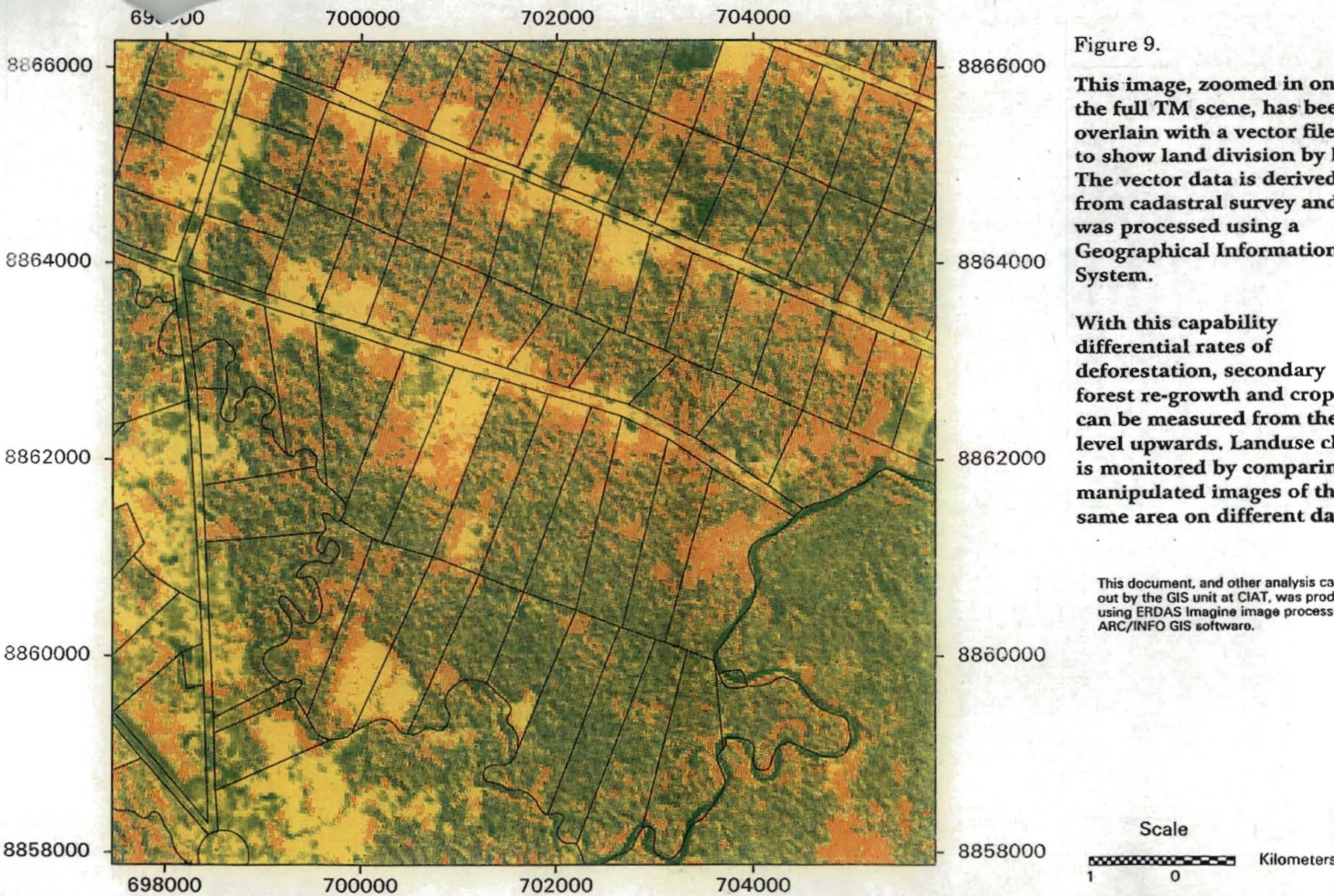

Figure 9.

This image, zoomed in on the full TM scene, has been overlain with a vector file to show land division by lot. The vector data is derived from cadastral survey and was processed using a Geographical Information System.

With this capability differential rates of deforestation, secondary forest re-growth and cropping can be measured from the lot level upwards. Landuse change is monitored by comparing manipulated images of the same area on different dates.

This document, and other analysis carried out by the GIS unit at CIAT, was produced using ERDAS Imagine image processing and ARC/INFO GIS software.

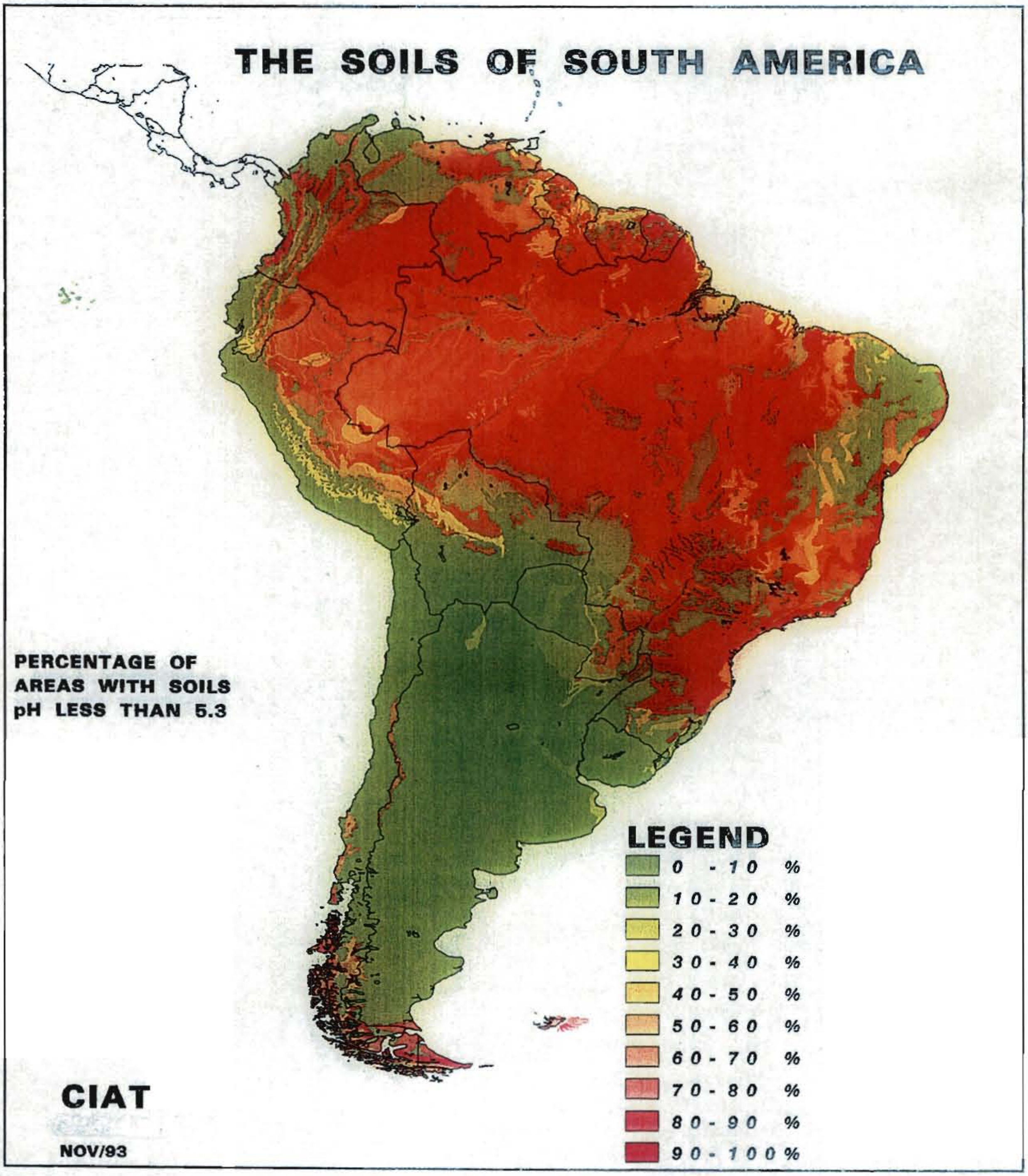

Figure 10. GIS map indicating the probability of encountering acid soils across Latin America. The enormous significance of soil acidity and its related constraints (highly weathered soil clays, aluminum toxicity, deficiencies of P, Ca, Mg, and other nutrients) is apparent on a continental scale.

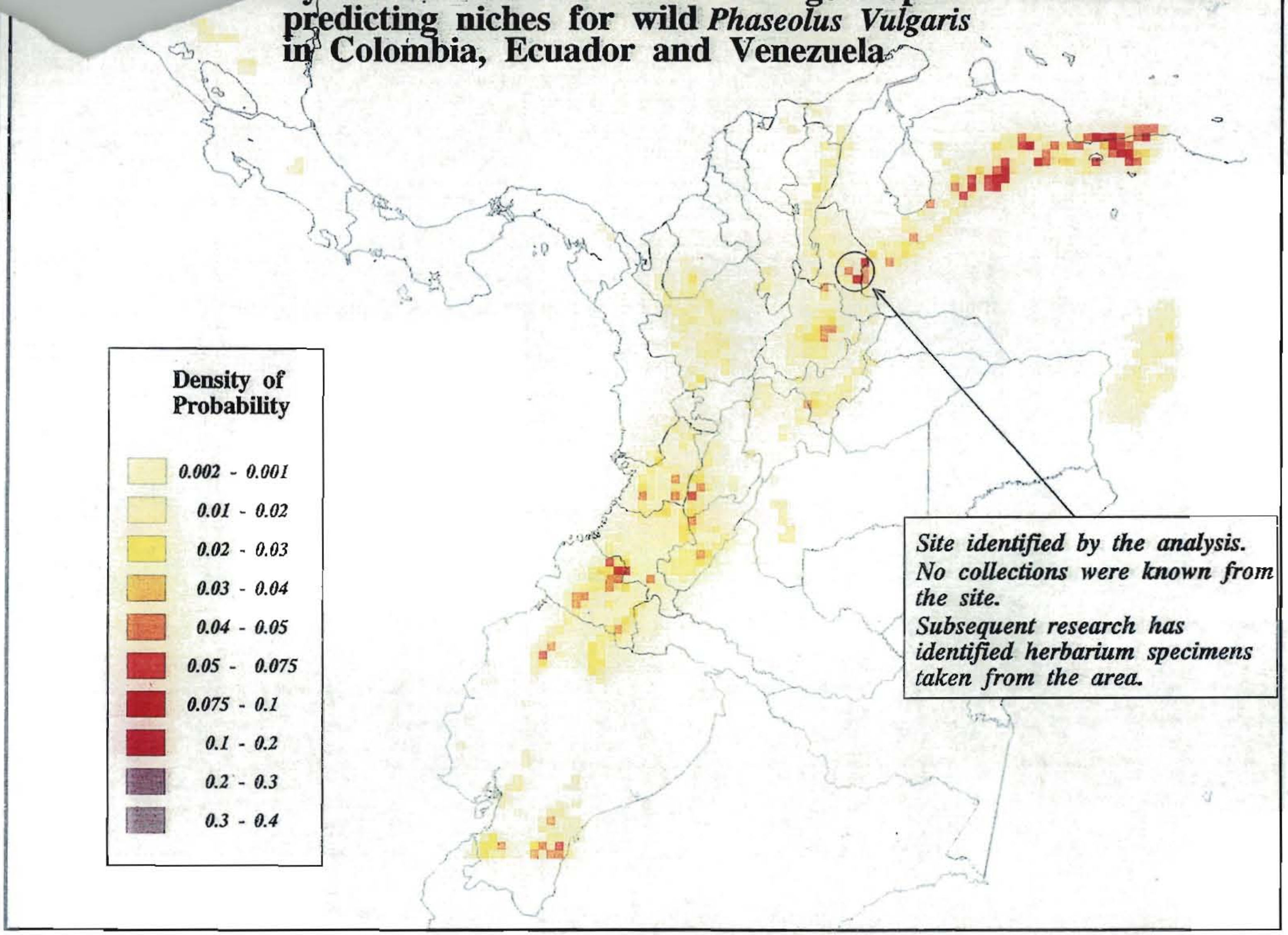

Figure 11. GIS map of the likely distribution of different ecotypes and species within the common bean genus (*Phaseolus*) based on known affinities for certain climates and soils. This technique helps researchers identify areas most likely to contain valuable new biodiversity.

Emissions Must Be Cut to Avert Shift in Climate, Panel Says

Capping carbon is not enough, U.N. advisers warn

A potential warming of the planet by 3 to 8 degrees Fahrenheit.

THE HINDU, Wednesday, December 7, 1994

Grass to counter global warming

Pasture grasses planted to increase beef production in the South American savannas are countering the doomsday predictions of global warming, say scientists at the International Centre for Tropical Agriculture.

The deep-rooted grasses may remove as much as two billion tonnes of carbon dioxide, a greenhouse gas, from the atmosphere yearly, says Dr. Myles Fisher, CIAT ecophysiologist.

"Green plants are small factories that use CO_2 and sunlight to produce organic matter. The perennial grasses *Andropogon gayanus* and *Brachiaria humidicola* convert as much as 53 tonnes of CO_2 per hectare yearly to organic matter," Fisher says. "That's as much CO_2 as a gas-guzzling car emits in 213,000 kilometres." The storage of organic matter was not noticed earlier because the extensive roots of these grasses deposit it as deep as a metre in the savanna soil, Fisher explains.

The burning of fossil fuels pumps about 20.5 billion tonnes of CO_2 into the atmosphere yearly, scientists estimate. Burning of tropical forests releases another 5.5 to 11 billion tonnes. But scientists have measured a yearly increase of only 18 to 25 billion tonnes of CO_2 in the atmosphere.

The ocean, tropical wetlands and green plants absorb some atmospheric CO_2. But scientists cannot resolve the fate of several billion tonnes.

"Improved savanna grasses must explain part of this difference," Fisher says. "Brazil alone has at least 35 million hectares of introduced pastures — enough to fix two billion tonnes of CO_2 per year."

The pasture grasses fix more CO_2 when planted with the legumes *Arachis pintoi* or *Stylosanthes capitata*, both from South America.

Because *Andropogon* and *Brachiaria* adapt well to acid soils, national programmes have released one or both of the grasses to farmers in at least 12 Latin American countries, says a press release from CIAT.

Carbon storage by introduced deep-rooted grasses in the South American savannas

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Ecology: Carbon Storage and Global Warming

Deep-rooted grasses planted on the savannas of South America may be playing a crucial part in combating global warming by storing carbon underground, a group of scientists has found.

The team from Colombia's International Centre of Tropical Agriculture reports that perennial grasses of African origin introduced to the area in recent years store significant amounts of organic carbon in their long roots.

The scientists write in the Sept. 15 issue of the journal Nature that this could explain a scientific mystery: why the amount of carbon dioxide produced by burning fossil fuels is not fully reflected in the atmosphere. "Improved pastures . . . may play a vital part in stabilizing the global carbon cycle and minimizing the greenhouse effect of atmospheric CO_2," the scientists write.

They said pastures—particularly in Brazil, Colombia and Venezuela—introduced in the last 30 years now cover about 86 million acres. The researchers analyzed the amount of carbon stored by plants in such pastures and estimated that the process could account for the "sequestration" of between 100 million and 500 million tons of carbon per year.

—Reuter

Rooting Around for Missing Carbon

Greenhouse solution may lie underground

Figure 12. CIAT in the news: the discovery that improved tropical pastures can act as a major store of global carbon, helping counter a major cause of global warming.

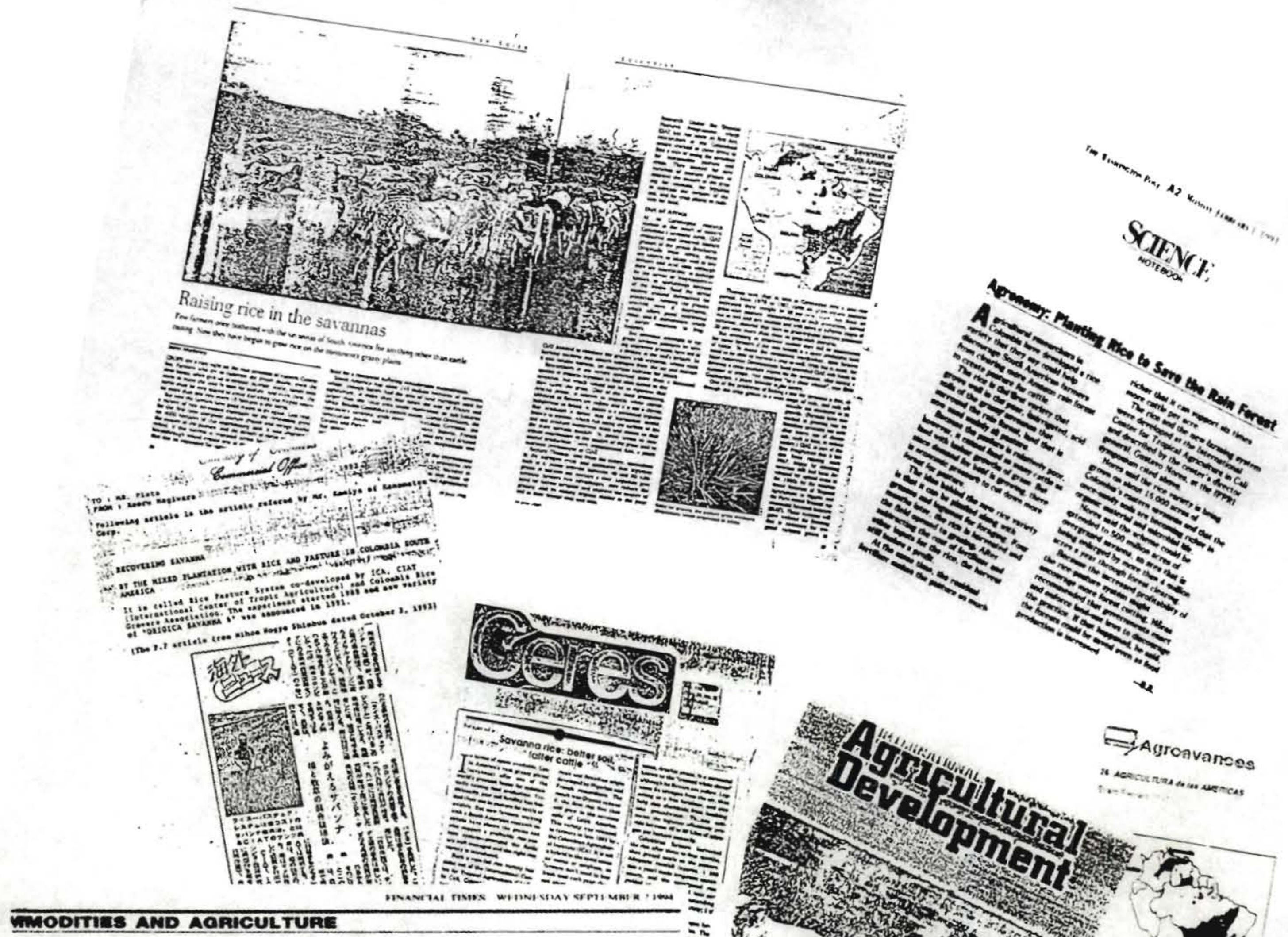


Figure 13. CIAT in the news: the promise of improved agropastoral systems to help reverse the downward spiral of degradation in the savannas.

Figure 14. Proposals under consideration or approved for special-project funding by various donors, to further build upon the RMR initiative underway at CIAT.

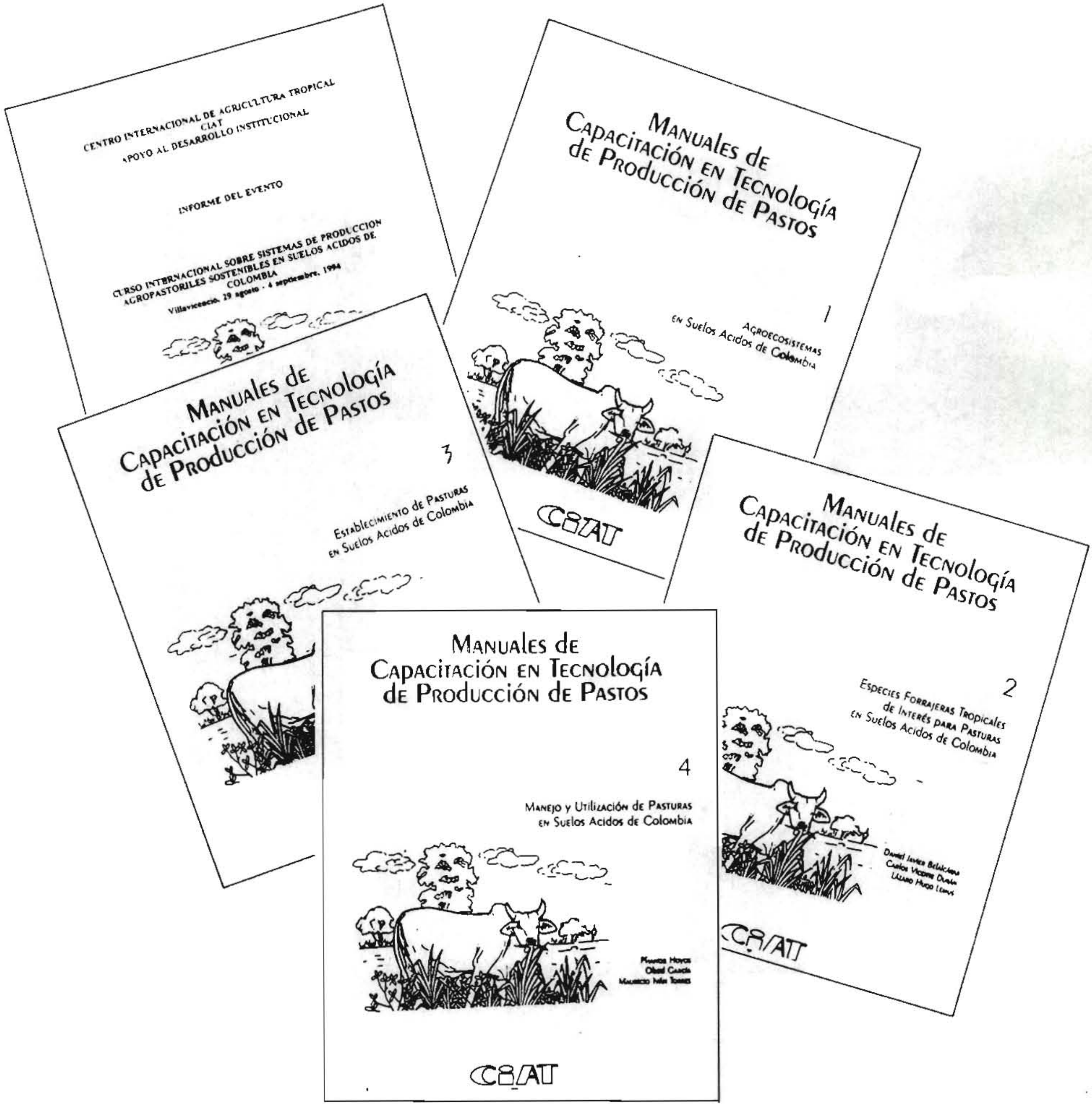


Figure 15. Despite its short time span, RMR is beginning to develop training courses in more sustainable agricultural systems. A course was recently held on improved agropastoral systems, including the development of a number of training manuals focused on specific aspects.

I. Facing the Challenge: CIAT and the Resource Management Imperative

The global environmental crisis, and CIAT

By the late 1980's/early 1990's, the need to inculcate a concern for the environment in mankind's development activities had become urgent. Alarming reports about the rapid loss of the ozone layer, global warming, loss of biodiversity and extinction of species, destruction of tropical rainforests, pollution of air and water resources and more had become recurring headline themes.

CIAT listened to these concerns, and began to look for solutions. Located in perhaps the world's most ecologically strategic and fragile zone, where agriculture and environmental degradation are causally interrelated, and with a mandate and expertise on researching agricultural development, it appeared that CIAT could indeed contribute. The Institute embarked on an intensive, 3-year effort to re-examine its goals and objectives (Fig. 1), and in April, 1991 the outcome was formally documented in 'CIAT in the 1990's and Beyond: A Strategic Plan'. The Plan outlined the role CIAT should play in sustainable agricultural development, seeing the following as its comparative advantages:

- Region-wide perspective, as an international organization;
- Impartiality, due to its apolitical nature and nonprofit status;
- Credibility built through a 25-year history of proven impact;
- Location in the South American tropics;
- Skills in relevant areas: germplasm conservation and improvement, geographic information and land classification systems, farming and cropping systems methods, soil science, client-participatory research and others; and
- Linkages and rapport with a many key organizations, in and beyond Latin America, including active networks for information and training.

These advantages could be effectively applied in the following general roles in RMR for CIAT:

- Strategic research with a region-wide focus (and global implications);
- Policy analysis and advice to decision-makers;
- Training in advanced research skills;
- Convenor and catalyzer of multi-institutional research initiatives; and
- Regional information resource.

Accordingly, the Plan elaborated three key goals towards which the Institute should strive to contribute, the last referring specifically to the RMR imperative:

- Economic **growth**, not as an end in itself but because it raises incomes;
- **Equity**, emphasizing research that specifically benefits the poor; and
- **Preservation and enhancement of the natural resource base**, the basic capital upon which future growth depends.

It sees these three goals not as conflicting, but rather as mutually interdependent and synergistic (see box).

Are CIAT's goals compatible?

The question is often raised as to whether growth, equity and preservation of the resource base are even compatible goals, or whether instead they are conflicting. Some forms of economic growth could create incentives to exploit natural resources. High prices for export crop production have sometimes caused entire countries to have negative nutrient balances. Many large-scale farmers and ranchers in the Latin American savannas and forest margins have cleared huge areas, then farmed them with minimalist techniques that basically "mine" the soils of their fertility, and lead to serious erosion and loss of biodiversity.

On the other hand, there are numerous examples where a **lack** of economic growth opportunity encouraged destruction of the environment. Much frontier development in the Latin American hillsides and forest margins has unfortunately reflected this dynamic. Subsistence farmers struggling to feed families slash and burn more and more native lands, impoverishing the soils they leave behind. Haiti is a dramatic example currently in the news, but there are many other examples.

The studies of CIAT's strategic planning process concluded that environmental destruction is not fundamentally caused by economic growth. Where these two have sometimes been associated, the linkage usually traces to policy incentives which do not forsee the totality of their effects, particularly on environmental degradation. Often, as in the savannas case, a lack of appropriate technology for sustainable development contributes to unwise management.

For example, during the 1970-80's policies in Brazil had the inadvertent secondary effect of encouraging destruction of irreplaceable rain forests while plenty of more productive lands in the savannas lay idle or were being abused. Recent policy changes and the removal of subsidies has dramatically slowed the clearing of these forests. At the same time, CIAT and EMBRAPA are making a major contribution through the development of improved agropastoral systems. These enable savanna farmers to achieve the same levels of cattle productivity as before but using just a fraction of the previous land area, while soil fertility and erosion control simultaneously improve. The profitability of the technology is based on more productive varieties of upland rice, maize and potentially other crops, and better pasture grass and legume species, all of which respond efficiently to modest nutrient inputs. These serve as an incentive for farmers to invest in upgrading their existing land holdings, rather than clearing more virgin land. Together, these policy and technology changes should enhance both equitable growth, and sustainability at the same time.

A plan of action

The Plan then focused its message on RMR through a strategy statement: "Resource management research will focus on important tropical American agroecosystems which are threatened by increasing land use intensity or natural resource degradation, as well as on those which may have the potential for relieving such pressure. The aim of research will be to understand the basic processes within the agroecosystems for the purpose of making agricultural production more sustainable." An intensive study to prioritize agroecosystems for focus by CIAT culminated in a choice of three: the savannas, hillsides and forest margins (Figure 3) - as elaborated later.

In 1992, the rising environmental awareness converged on a global scale through the United Nations Conference on the Environment and Development (UNCED), also known as the Earth Summit. This landmark Conference produced an agreement among 179 nations on principles, directions and mechanisms for more sustainable development. It became the task of CIAT to ensure that its activities were in harmony with the UNCED agreement. The Earth Summit created a funding mechanism, the Global Environment Facility (GEF), which now contributes to some of the RMR agenda for which CIAT and its parters have assumed responsibility. (See the Slash and Burn Project in later sections).

The broad guidelines of CIAT's Strategic Plan were made more concrete through its Medium Term Plan (1993-98), including details of how the RMR initiative would be organized, executed and funded. Many of these operations had already begun during 1991 and 1992.

The financial crisis

At this point, however an unforseen financial crisis struck the institution, as donors began a wave of major cuts to agricultural development assistance worldwide. With the ending of the cold war, donor priorities had shifted to rebuilding Eastern Europe and cutting spending to balance their own budgets. However, it is notable that several key donors began to specially earmark parts of their donations for the RMR initiative notably Germany, the Netherlands and Switzerland. Nevertheless, CIAT had no choice but to undergo a wrenching series of analyses on how to cut back its plans. RMR research, because of its critical start-up status, received some protection but could not be implemented to the scale planned, and those aspects that could be implemented had to undergo delays due to the uncertainties of funding. The details of these adjustments are described in the last section of this document.

Global credibility, and responsibility

As part of a CGIAR-wide restructuring which is increasing the emphasis on RMR, and in recognition of CIAT's demonstrated committment to this new endeavor, CIAT was chosen in 1994 to act as the convening center for a CGIAR system-wide effort on ecoregional research in Latin America and the Caribbean. This means that in 1995 it will have the additional responsibility of bringing its sister institutions on-board the RMR initiative in Latin America and the Caribbean. This CGIAR recognition was further reinforced in late 1994 as CIAT was chosen to be the convening Center for a new system-wide initiative on soil, water and nutrient management. Within that initiative, CIAT also retains lead responsability for the component on acid soils a reflection of its global leadership in convening and coordinating the Managing Acid Soils consortium, described later.

As another recognition of CIAT's excellence in RMR, it was recently chosen (also in 1994) by the United Nations Environment Program (UNEP) to become a UNEP Collaborating Center for International Environmental Assessment, Reporting and Forecasting. This important development directly ties CIAT into a key part of the global Agenda 21 committments of the United Nations. This follows a number of contacts and exchanges of environmental databases between CIAT and the UN.

Conclusion

In conclusion, the RMR imperative, and CIAT's role in it remain as urgent as ever. The financial crisis has sorely tested CIAT's confidence and resolve, but the Institute is nonetheless forging ahead as best it can. The RMR agenda is now in vigorous operation, albeit at less intensive levels than planned. At present, there is a general feeling that the worst of the financial crisis may be over, and CIAT's committment to RMR throughout the crisis now positions it to experience rapid growth as donors increasingly recognize its credibility, the achievements and benefits it is beginning to deliver (Fig. 14). Since much of the start-up investment has now been made, these rewards will be increasingly realized at levels far beyond their costs.

II. Paradigms and Perspectives in Resource Management Research

The RMR Initiative began with, and continues to develop its approach based on a number of basic concepts, many of which are new to agricultural research and development. Borrowing freely from evolving global thinking in RMR and particularizing these concepts for the circumstances of CIAT in Latin America, these are part of the intellectual development of the Initiative. A brief outline of some of the key concepts will enable a better understanding of CIAT's approach to RMR.

CIAT's mission, and operating principles

CIAT's Strategic Plan for the 1990's and Beyond describes its mission as: "To contribute to the alleviation of hunger and poverty in tropical developing countries by applying science to the generation of technology that will lead to lasting increases in agricultural output while preserving the natural resource base."

The Plan elaborates four guiding principles concerning the way CIAT works:

- **Relevance/goal orientation:** concentrating on the most important rather than the merely interesting; prioritized problem-solving, output-orientation, with a sense of urgency.
- **Systems perspective:** steer clear of unidimensional approaches, while avoiding the pitfalls of endless system analyses and location-specific activities.
- **Multi-institutional approach:** most tasks are too large for any single institution. Pool resources based on shared vision and jointly-developed agendas.
- **Comparative advantage:** within a multi-institutional approach, each partner should do what it does best and at lower cost.

These themes surface again and again in the discussions that follow, and in the daily challenges posed in charting the course of the RMR initiative.

Multi-institutional approach, with CIAT as a convenor and catalyst

In providing a healthier, more sustainable use of the earth's natural resources, the results of RMR research will affect everyone, not just those engaged in agriculture. Of course, many of those who stand to be affected by it will not "buy into" the solutions unless they have the opportunity to participate in developing and executing the RMR agenda. Successful RMR thus requires the participation of multiple stakeholders: farmers, community members, national, regional and international agencies, donors, scientists, policy makers and more.

As an international, apolitical and nonprofit institution, CIAT is inherently well suited to function as a convener, to bring these diverse groups together around a common agenda. CIAT only convenes initiatives in areas in which it has or can obtain some in-house expertise, and will be able to proceed as a fully-engaged partner in carrying out the agenda. This active, catalytic role helps stimulate all the partners, and steers the execution of the joint research agenda towards focused ends. While several other institutions can play effective roles as either convenors **or** catalysts, a unique advantage of CIAT is that it has the skills, experience and facilities to do **both**, at high levels of excellence.

The section on Collaborative Linkages explains in detail the major effort and investment CIAT has made over the past three years in convening institutions and catalyzing focused RMR research in Latin America (Fig. 2). These multi-institutional linkage efforts are essential to the successful launching and execution of the RMR initiative.

Organizing RMR: land management, and agro-ecosystems

A key decision of the Strategic Planning process was to organize CIAT's RMR work from two vantage points: Land Management, and Agroecosystems.

Land is the basic resource of agriculture. The uses, and abuses of land are at the heart of issues surrounding sustainable agricultural development. A land management perspective enables CIAT to tackle these issues head-on. By studying the potentials of different land types and identifying their optimal and most sustainable uses, a vision is created which can be provided to policy decision-makers and technology developers, in order to better guide the paths of development and conservation.

In comparison, the agroecosystems perspective takes a more detailed yet wholistic look at just a few strategic agricultural environments. This perspective is critical in achieving real change, because it takes into account the needs and aspirations of the occupants and users of key parts of the landscape. They are the actors who will have to actually make the changes, if more sustainable agricultural development is to occur.

As expected, we are experiencing an enormous amount of synergy between these two perspectives. In fact, this was planned element in the construction of our RMR approach. The over-arching strategy was to integrate options of land use and farming systems that help relieve market and social pressures on the most fragile environments. Throughout this document there are many examples of how this synergy has been working in practice.

Scale

For some purposes, RMR is facilitated by viewing systems at different hierarchical levels, or scales. Levels of scale that are strategically important in agricultural resource managment include: region, landscape, agro-ecosystem, watershed, farming system, cropping system, and crop. Of course, sustainable systems involve interactions among levels, and a major current challenge is to develop the ability to link between these, for example by modeling the effect of a nutrient input (cropping systems scale) on pollution of runoff water into a catchment basin (watershed scale).

Different groups of stakeholders may be affected at the different scales, so studies are needed on how to effect change involving tradeoffs among groups with very different needs and motivations. Often, this leads to a need for policy changes, as well as technological ones. The focus should be on market-based solutions that minimize the need for external enforcement. Often, these can be based on opportunities posed by new technology.

Site-specific versus regional approaches

In the past, much work on agricultural resource management consisted of site-specific trials of particular combinations of inputs. For example, numerous local institutions are actively engaged in the empirical testing, validation and transfer of soil conservation techniques in the hillsides. There have been too few attempts to derive principles with strategic validity across a wider area, such as the agro-ecosystem. The benefits that such work could deliver to thousands of other sites possessing some degree of similarity for certain key parameters, are often missed.

CIAT's international character gives it a role to play in bringing together the large number of local experiences, past and present, and applying strategic research methods (such as geographic information systems, nutrient balance studies etc.) to derive principles which can reveal generalized effects that benefit a much wider area. Vigorous networking, training and publication efforts ensure that these principles are communicated widely. This is an important way in which CIAT complements and magnifies the benefits of local development efforts.

To capture strategic principles of wider validity, CIAT's approach is to conduct research across a range of conditions reflecting the variability of the target agro-ecosystem, rather than attempting to find one perfectly representative site. The locations chosen for our outposted research teams have been specifically chosen because of their suitability as "hubs", which are geographically close to a representative range of variability in the surrounding area. We therefore use the term "area-based research" rather than site-based research, because it is more descriptive of our approach to field work. Ideally these areas capture a representation of the major dimensions of variability for a given agro-ecology within a 60 kilometer radius, approximately the size of one LANDSAT image, a key resource for characterization.

Dynamism of systems

Besides ignoring systemic interactions, much past research has taken a static approach, with little attempt to determine the dynamics of processes. For example, soils research often restricted itself to identifying the amounts and types of inputs needed to achieve high crop outputs, almost ignoring the soil processes involved. This was acceptable as long as there was only secondary concern for reducing input usage, more sustainable crop managment practices, soil conservation, and groundwater pollution, but times have changed. To reach these new objectives requires an understanding the processes involved in nutrient transformation in soil with emphasis on soil biological activity which is highly dynamic. A static component technology approach is unlikely to capture where technology can intervene, and how.

The dynamics which drive farmers to change are also crucial to sustainable development. More sustainable agricultural systems will probably be reached through a process of gradual transition, rather than a single quantum jump to the "perfect" system. Experience shows that farmers are more likely to adopt changes which build on existing systems with which they are familiar ("technological grafting"), rather than entirely new systems. Improved agropastoral systems, described in detail elsewhere in this document, are a classic case of this type of innovation. A succession of such changes should eventually lead to the desired optimal system. Farmers do not all change in synchrony, however; at any point in time, different farmers will find themselves at different points along the transitional gradient. To be successful, then research and development will have to create multiple options ("technological pluralism") that allow farmers to accomodate the desired improvements in sustainability with their current circumstances and capacities at any particular point in time.

Sustainability indicators

Measuring sustainability means measuring changes over long periods of time and space, in large, complex and dynamic systems. This appears a daunting task. However, research could probably discover early-warning signs which could help predict whether a system may be heading in a sustainable direction or not over the longer term.

Biodiversity is often mentioned as a promising indicator of sustainability. Although the extinction of a certain species may not directly threaten mankind at the present time, it is suspected that this is an indicator of more fundamental problems in an ecosystem. In a similar agricultural context, we know that the activities of soil biota are extremely important in nutrient cycling and maintenance of soil conditions in agroecosystems, hence their sustainability. Research is needed to pinpoint which organisms are most critical, and exactly what it is that their appearance or disappearance is telling us. Other potential indicators include changes in soil chemical balances, vegetation types, total biomass, and system diversity as measured in a number of ways, including socioeconomic factors.

Rainforests on the Rebound?

Ecologists have traditionally regarded rainforests as highly fragile and difficult to rehabilitate. This dogma leads to the supposition that those areas already cleared are lost forever and can be "written off", so current efforts should to be geared at preservation of the remaining forest land. Recent advances have moderated this viewpoint, however and forest ecosystems are now being viewed as having an important degree of resiliency. According to this view, previously written-off areas can be regenerated, if appropriate technologies and incentives are put in place.

This paradigm highlights the possibility of stabilizing small scale agriculture in the forest margins, rather than allowing it to expand further and further into the forest. Supporting evidence for this hypothesis exists: many farmers are attempting to re-use areas that were once cleared and abandoned, and are now in secondary regrowth. For example, between 1988 and 1989 in Altamira, Brazil, 42% of new agricultural land was created by clearing secondary growth.

Can research enhance this promising alternative to further forest clearing? The mechanisms underlying the dynamics of secondary vegetation and forest regeneration following human intervention are under investigation in the Global Slash and Burn Project, in which CIAT is a key participant. Research is underway using satellite imagery analysis to understand land use trends, ground-based surveys to understand farmer perspectives, and experimental research on relay plantings of species which can progressively advance the vegetation to a forest state while generating the economic value necessary to motivate the users of the land.

The payoff to the new paradigm of resiliency may be high, because it is realistic: it acknowledges that people are living in the forest margins, and attempts to find ways to increase their viability on lands already cleared. By finding means for integration of appropriate land use with generation of economic benefits, those uses provide incentives for farmers to protect the land, their capital for the future. Furthermore, these technologies would provide governments with a reasonable alternative to policies that encourage further forest clearing to meet the needs of the poor.

Participatory methods

RMR research needs not only to be client-oriented but client-driven in order to ensure its continuous relevance. Client-driven implies that users of research need to be involved in decision-making with respect to establishing research priorities, planning and conducting trials, and evaluating results. Because recognition of the importance of non-economic objectives in farmer decision-making is in its infancy, understanding such objectives and how to translate these into criteria determining research priorities, necessitates substantial input from farmers. The methods and institutional arrangements entailed in this approach should be seen as a "social technology" which complements biophysical systems research.

The participatory approach requires finding means to organize the interface between farmers and researchers, and through which farmers can hold researchers accountable to responding to their needs. For most farmers, actively identifying needs and formulating demands rather than simply responding to opportunities presented to them by external research or development organizations is something new. Formulating problems in a non-opportunistic manner and perhaps even without having an idea of the contours of what might be a possible solution is a demanding exercise - even for researchers. To avoid being "supply-driven", a participatory approach requires a capacity for objectively analyzing the present situation including the farmers' viewpoint, then establishing clearly specified goals and objectives, and only lastly to search for the appropriate solutions that meet these criteria.

Win-win strategies

Many practices that would "win" from societies' point of view, i.e. by increasing sustainability, have not been adopted by farmers because they would personally lose, by increasing production costs and/or reducing productivity. An example is the case of soil conservation measures. At early stages of soil depletion the net returns without soil conservation in the hillsides exceed the net returns with conservation. It is often not until 40-60 years later that enough native fertility has been lost to make it economically profitable to apply conservation techniques, if farming is still practical at all at the consequent lower productivity levels.

The response of governments to this dilemma has often been to present inducements, either positive (subsidies) or negative (legal restrictions) to farmers to encourage adoption. However, subsidies are costly and usually short-lived, and often induce distortions in other sectors of the economy. Restrictions are extremely difficult to implement, and unpopular.

"Win-win" technology development implies a different type of incentive, such as income earning opportunities linked to soil conservation practices. Examples could include: downstream communities providing some key services to hillside communities in return for reduced silt loads entering the river due to conservation practices, thereby reducing siltation in the downstream users' water supply; or carbon dioxide polluters paying farmers for types of cultivation (such as forests) that absorb large amounts of carbon, i.e. "carbon storage services". Adoption is expected to occur because of farmers' opportunity to increase income, with soil conservation or reforestation occuring as a byproduct.

This concept has been validated. For example, in the few cases of successful adoption of soil conservation practices in the hillsides, the practices permitted the introduction of high value crops, supported the introduction of livestock, or generated income by being associated with value-added processes. Closely linking the income opportunity to conservation practices is vital, however, as the literature is replete with cases where the introduction of income-generating opportunities without any links to conservation have exacerbated resource degradation.

A Win-Win Market for "Ecological Services"

Developing countries may soon be able to benefit from a new comparative advantage: the provision of ecological services. For example, a company in a developed country, required to reduce its net carbon dioxide output so as not to increase the risk of global warming, might decide to purchase carbon storage services in developing countries, if these services were cheaper than at home.

Properly implemented, a market for ecological services should create a "win-win" opportunity not only for the companies and farmers involved in the immediate transaction, but for the larger society as well. A carbon market would benefit global sustainability not only through its direct effect in reducing net carbon dioxide emissions, but also in providing funds to encourage developing countries to protect high-biomass systems such as native forests. By increasing the value of native forests, these market instruments might also help reduce destructive logging practices. The forest, in essence becomes more valuable alive, than dead. A global market agreement could provide mechanisms and funds for enforcing frontier closure and for funding research on the modalities for maximizing and sustaining carbon storage, so that market development is knowledge-based and rational.

The tropics of Latin America appear to have a comparative advantage in this potential new enterprise. Brazil has 3.8 million square kilometers of closed tropical forest. This is a major carbon store, with estimates ranging from 136 to 225 tons of carbon per hectare. CIAT's new discovery of the ability of improved pasture species in the vast savannas to act as a net carbon sink, shows that this ecosystem could also function as an important carbon store.

Questions about this novel idea include concern for a theoretical loss of national sovereignty over large tracts of land, and the high transaction costs of implementing such mechanisms. Many of these problems can be overcome by having markets in short-term rental contracts instead of land purchases, or by franchising contracts between local authorities and the world community. The Costa Rican government is attempting, for example, to develop a market in government guaranteed carbon storage certificates. Land owners would have the freedom to select their own land use strategies, as long as they achieve the guaranteed rate of carbon storage. Research on ways to effect these win-win transactions, and on technologies to maximize sustainable high rates of carbon storage, falls within the remit of CIAT's RMR agenda.

Modeling, and decision-support systems

Achieving the potential impact of strategic information generated on natural resource management depends on the provision of this information in forms useful to stakeholders. Yet this information is often complex, technical, systemic and dynamic, i.e. containing many interactive elements which are difficult to comprend in totality, especially in a state of change. Computer models can help analyze this complexity and simulate the outcomes of resource management choices. The use of interactive decision-support systems which allow stakeholders to critically review and analyze their opinions and synthesize new positions are likely to be of considerable utility in obtaining more objective analyses of outcomes, and this will assist the process of changing perceptions and resolving conflicts.

A particularly interesting possibility for stakeholders, including policy makers, is the use of simulation models to predict outcomes of potentially costly decisions such as setting environmental quality standards or assessing tradeoffs for large capital investments in irrigation or conservation projects. Sensitivity analyses can identify model parameters which are most responsible for uncertainty in predictions. This type of *ex-ante* impact analysis will be used, for example by the hillside consortia in Colombia and Central America to assess the comparative advantages of well-managed pasture, annual crops intercropped with cover-crops, or sowing conservation barriers, relative to achieving reforestation. The models are built from data generated through prototype system trials conducted by the consortia.

Models also help researchers themselves handle the complexity of systems analyses, and reduce the costs of experimentation. Technology design and testing in the absence of modelling tools to assist screening large numbers of permutations for varied environments is likely to be costly, time consuming and inefficient. In many cases such experiments would even be impossible, eg. to examine the potential effects of changes in government policy on resource management practices.

The methodology and computer-based techniques for building models and interactive decision-support systems is a fast-moving technological frontier. CIAT intends to develop and maintain a core competence in these techniques.

III. Consultations to Set the Agenda, and Linkages Forged

Because of the wholistic nature of RMR research, CIAT realized at the outset that an effective RMR initiative could only be developed through a joint collaborative approach with a diverse array of international, regional and national institutions, both within and outside of government. CIAT intensively consulted with many such institutions during the three-year strategic planning process, as well as with current and potential donors. This set into motion a large number of collaborative alliances which currently execute the RMR agenda (Fig. 2). Some of the most important events of this process are highlighted below. Also, a chronology of these formative meetings is presented in Appendix A2.

LAND MANAGEMENT

The new land management perspective of CIAT was built upon prior land classification expertise, embodied within the Agroecological Studies Unit. That Unit had developed numerous linkages around the world for the purpose of exchanging environmental data sets. The expansion into a land management agenda necessitated the establishment of contacts beyond our traditional clientele of agricultural research and climatic data base institutions, particularly into the environmental conservation area. Towards this end, new or renewed contacts have been established with:

- The Inter-American Group on Sustainable Development of Agriculture and Natural Resources.
- The International Geosphere-Biosphere Programme (IGBP) and the Human Dimensions of Global Environmental Change Programme (HDP), in relation to their joint core project on land-use/cover change (LUCC), and IGBP/DIS on soils database.
- The Earth Council, Costa Rica.
- The New World Dialogue on Environment and Development.
- The United Nations University, Tokyo.
- The International Institute for Applied Systems Analysis, Austria.
- The Beijer Institute (The International Institute of Ecological Economics of the Royal Swedish Academy of Sciences).
- INDERENA (Colombian National Institute for Renewable Natural Resources and the Environment).
- The Ministerio de Agricultura, Colombia.
- The Ministerio de Medio Ambiente, Colombia.
- The Instituto Geográfico Agustín Codazzi, Colombia.
- The Colegio Verde (NGO), Colombia.
- The University of Kassel, Germany.
- The Hohenheim University, Stuttgart, Germany.
- The National Geophysical Data Centre, Boulder, Colorado.

Building on Institutional Change: New Directions in CIAT, NARS, NGO's and Universities Create New Opportunities for Collaboration

Environmental perspectives are becoming increasingly important not only in the world community at large, but also in national research systems in Latin America. NARS, like CIAT are new to the RMR scene, and are starting to develop the necessary skills and capacities. The Brazilian national system, EMBRAPA, has been reorganized to include a natural resource management program. EMBRAPA activities now include conservation technologies, characterization of native species, a germplasm bank of native vegetation, tree crops research, recuperation of degraded pastures and strategies to reduce fertilizer use. EMBRAPA has also developed a land use plan for the savanna. In Colombia, university level resource management courses are being developed in collaboration with faculties at universities in the USA. Organic agriculture, diversification and agroforestry are among the new activities of several national systems.

Non-governmental organizations (NGO's) are also key players in the new RMR agenda. They often have applied, in-depth, long-term committments to specific local areas, which can strongly complement the international and strategic responsibilities of CIAT. CIAT played a key role in convening several such NGO's towards an RMR objective in the hillsides of Colombia through the formation of the consortium CIPASLA, described later in a box article. In the savannas, CIAT's RMR effort builds on previous linkages with cattle rancher organizations such as Fondo de Ganado de Meta, and Asociación de Ganaderos de Puerto López in Colombia. As mentioned later, part of CIAT's forest margins characterization effort was an analysis of data contracted to a respected Brazilian NGO, the Instituto Sociedade, População e Natureza (ISPN). We are building on this beginning through close collaboration with Pesquisa e Extensão en Sistemas Agroflorestais do Acre (PESACRE), an NGO located near the research sites in Brazil. Many other examples could be cited.

Linkages with Latin American universities are also of growing importance in the RMR initiative. Collaborative analyses of satellite imagery are underway with the Instituto Geográfico Augustín Codazzi, Bogotá, and CIAT collaborates with the Universidad Technologica de Llanos and with the Departmento de Biologia of the Universidad Nacional, Bogotá and the National University of Colombia, Palmira in studies of how agricultural intensification affects plant and soil fauna biodiversity. One of the reasons CIAT chose Uberlândia, Brazil to serve as the hub for its area-based savannas research was access to a strong potential collaborator there, the University of Uberlândia. Research collaboration and joint writing of proposals is now underway with these colleagues. Besides Latin America, a large number of collaborative links have been built with universities in the developed world, particularly Europe, the USA, Canada and Australia. These are described throughout this document.

- The World Conservation Monitoring Centre, Cambridge, U.K.
- The University of Washington, Seattle.
- The University of Georgia, GIS Laboratory, Athens.
- The University of Guelph, Ontario, Canada.

Many of these contacts have led, or are leading to collaborative research activities and joint project proposals to carry out the priorities described in later sections.

SAVANNAS

Consultations were crucial in characterizing the savanna agro-ecosystem, and in choosing sites for collaborative research. In 1991, CIAT and EMBRAPA's Center for Agricultural Research in the Cerrados (CPAC) established joint, long-term trials testing different land use and cropping system alternatives at CPAC headquarters near Brasilia. (Since then other institutions have joined those trials, such as Cornell University and the University of Bayreuth, Germany). At the same time CIAT created a savannas working group, including representation from CPAC and also the Rice and Beans Center (CNPAF). The savannas working group met regularly, initially to discuss the methodology to be pursued in characterization studies and to identify relevant sources of secondary information, and later to refine the analyses as they began to be produced. This was a highly iterative process, resulting in a detailed characterization of the savannas of Brazil ('Cerrados'). CIAT additionally contracted a highly respected Brazilian NGO, the Instituto Sociedade, População e Natureza (ISPN), to conduct a major retrospective study of land use in the Brazilian savannas and forest margins (Mueller et. al. 1992). The review was based on existing information, including data on farming systems, land use, and censuses. A parallel and complementary study on the agroecological characterization of the Cerrados was also undertaken by CIAT's Land Use Working Group in cooperation with EMBRAPA-CPAC, and was published as a CIAT document, *Area Classification and Mapping for the Cerrados Region of Brazil*, in July, 1992. To obtain current perspectives, the savannas working group also conducted numerous rapid rural appraisals in Brazil and Colombia. Farmers perceptions and priorities were absorbed in the process.

The ISPN and Area Classification studies were the main subject of a week-long Workshop held in Brasilia in September, 1992 attended by Directors and/or Technical Directors of 6 EMBRAPA Centers, two State research organizations, ISPN and CIAT. The objective was to identify representative areas within the savanna for intensive study. The workshop examined the data against criteria of representativeness, intensity of land use, perceived demand for technology and relative strength of local institutions. This process reduced the initial set of twelve candidate areas to four (Uberlândia, in Minas Gerais state; Río Verde, in Goiás; Campo Grande, in Mato Grosso do Sul, and Rondonópolis, in Mato Grosso). The workshop also identified broad research priorities.

A consensus decision was also taken at the Workshop to carry out an inter-institutional rapid rural appraisal (RRA) in each of the four areas in late 1992, to identify demands for research, evaluate and classify existing farming systems, and to identify local institutions interested in sustainable agricultural development. The current research agenda was strongly influenced by the outcome of those RRAs' and discussions with national partners.

The area identification process concluded in late 1993 with the selection of the area surrounding Uberlândia for the research effort. One CIAT scientist has now been outposted to EMBRAPA-CPAC. He has established a number of on-station and on-farm experiments in collaboration with national scientists at Uberlândia. In addition, we have established regular contacts with other EMBRAPA Centers: CNPAF, the rice and beans center; CNPGC and CNPGLC, the beef and milk centers; CNPMS, the maize and sorghum center; CNPS, the soybean center; and CNPAB, the center for soil biology.

Currently, research priorities for joint projects at Uberlândia are being developed with EMBRAPA and with the University of Uberlândia. We recently learned that one such project has been accepted for funding by the German Government (BMZ). The project, a collaboration among CIAT, EMBRAPA, the University of Uberlândia, and the University of Bayreuth, Germany, will evaluate soil organic matter parameters that could be indicators of more sustainable agropastoral systems. Another project has been conditionally approved with Göttingen University, examining the impact of improved agropastoral systems on subsequent animal production volumes and economics.

The situation in the Colombian savannas was simpler due to the smaller set of institutions involved, and CIAT's close historical involvement with them. The process is well illustrated in several publications by Seré, Sanint and Rivas included in the 1990 through 1993 issues of *Trends in CIAT Commodities*, a major CIAT publication. The first planning session was held in December, 1992 including CIAT, ICA (now CORPO ICA), HIMAT and Instituto Geográfico Augustín Codazzi (IGAC). Close operational links have been forged with CORPOICA at both their Carimagua and La Libertad experiment stations, with the establishment of a number of collaborative trials. Active collaboration has also been established with the Department of Biology of the National University, Bogotá, with the Technological University of the Llanos, Villavicencio, with the Secretariat of Agriculture of the Meta Department, with FEDEARROZ (the rice growers' association), and with IGAC.

One example of active collaboration is "Culti-Core", a multi-disciplinary, long term field study established at CORPOICA's Carimagua station. This major study involves several institutions both in Colombia and the developed world, whose expertise complements the germplasm, crop physiology, nutrition, root dynamics and systems skills provided by CIAT. A major factor in the success of the project has been the active participation of CORPOICA, which, in addition to sharing responsibility for infrastructural and logistical support with CIAT, has assumed responsibility for crop agronomy, management and the monitoring of soil physical properties. CORPOICA also contributes technology components, such as acid-soil tolerant soybean germplasm, as does CIMMYT, with its acid-soil tolerant maize varieties. Another international institute, IFDC contributes skills on crop nutrient requirements, soil fertility, nutrient cycling and management. Additional support from IFDC will be provided in the use and adaptation of existing crop simulation models developed under the IBSNAT umbrella. A CIRAD-CA (France) ecologist is monitoring weed dynamics and native savanna biodiversity, and soil biologists from the Universidad de Complutense (Spain) and ORSTOM (France) are monitoring soil macrofaunal dynamics. Thus, Culti-Core is a truly collaborative endeavor.

We are also initiating collaboration in the savannas of Venezuela. We have established close links with the Experimental University of the Llanos, UNELLEZ and with FONAIAP.

Continuing consultations to revisit the feasibility of technological options as they evolve are necessary to maintain relevance to real-world needs and potentials. Collaborative reviews of the regional savanna research agenda are a continuing process, facilitated by annual workshops supported by the Inter-American Development Bank and involving representation from Bolivia, Brazil, Colombia and Venezuela. So far, workshops have been held in Colombia (1992), Brazil (1993) and Venezuela (1994).

Strategies for transferring improved technologies to end-users must be developed and implemented in close consultation with national and local agencies, and farmers. In 1991 and 1992, we conducted feasibility studies of the promising rice-pastures system using Delphi surveys and rapid rural appraisals in both Colombia and Brazil. In December 1993 CIAT and FAO jointly conducted a regional workshop on the transfer of improved agropastoral production systems to farmers. This has subsequently been merged with a related PROCITROPICOS initiative. The collaborative proposal, featuring partnership among CIAT and the NARS of Colombia, Brazil, Bolivia and Venezuela, has been submitted to UNDP.

Acid soils are a theme that cuts across all three agro-ecosystems (Fig. 10), although CIAT's effort is most advanced in the savannas. In late 1993 CIAT organized an international workshop on tropical acid soils, attended by 32 representatives from five USA and two German Universities, CATIE, CPAC-EMBRAPA, ICA, the Universidad Simón Bolívar, Venezuela, and IFDC. At the workshop, the participants decided to create a research consortium named MAS (Management of Acid Soils) to develop a joint research agenda for acid soils based in the forest margins, hillsides and the savannas. Since then the consortium has been joined by representatives from ICRAF, ORSTOM and IBSRAM. The consortium will emphasize strategic research, integrating soil and water management with improved germplasm to generate prototype technologies for sustainable agricultural production within a framework of appropriate socio-economic and policy considerations. CIAT functions as the secretariat for the consortium. MAS is now actively developing projects for the three agro-ecosystems.

HILLSIDES

The genesis of CIAT's hillside effort, as formulated in the Strategic Plan of 1991, was threefold: a major land-use and environmental classification study, described in the

Results section; consultations with regional partners through two hillside consortia, one for Central America and another for the Andean region, described below; and the deliberations of CIAT's hillside working group.

A very wide process of consultation was undertaken in Central America, a biophysically, politically and institutionally complex area. In early 1991 a regional Consortium for the Sustainable Management of Natural Resources was formed including CIAT, CATIE, CIMMYT and IICA. In August of 1991 the Consortium convened a large and successful workshop in Costa Rica, partially financed by the Swiss Government, to discuss a collaborative approach to RMR in the Central American hillsides. The proceedings have been published as *Agricultura Sostenible en las Laderas Centroamericanas. Oportunidades de Colaboracion Interinstitucional, 1991.* The workshop concluded with agreed-upon divisions of labor among the various international, regional and national institutions, and a prioritized plan of action for the future. It also created a "focal group" to continue working on a series of recommendations, including preparation of an interinstitutional data base and the selection of a watershed as a site for inter-institutional projects. Despite the ups and downs associated with the dynamic evolution of all the institutions involved, that plan of action has been followed.

The Consortium developed a draft proposal for work in Central America which was presented to donors in late 1992. The Swiss Development Cooperation (SDC) has generously supported the further development of Central American consortium activities, and they were formalized into a Central American Hillsides Project (CAHP), a collaborative effort among CIAT, CIMMYT, IFPRI, IICA, CATIE, DICTA (Honduras) and INTA (Nicaragua). The first official meeting of the CAHP steering committee took place in May 1994 with representatives from IARC, regional and national partner institutions. Research priorities were set and a six-month workplan was outlined. Guidelines for cooperation with national and local institutions were agreed upon.

In Colombia, another interinstitutional consortium (CIPASLA) was formed to enhance hillside cooperation (see box), with support form IDRC. Workshops with national, regional and local institutions with active programs in the Río Ovejas watershed identified problems and objectives for research which address the participants' interlinked needs for equity, economic development and resource conservation. CIAT also joined a consortium for the higher elevations, CONDESAN (Consortium for sustainable development of the Andean Ecoregion), convened by CIP. We took part in a planning workshop at which a joint benchmark site in Ecuador was chosen. A special project was developed to initiate research at this site. Partners in CONDESAN also have related projects for the Central American hillsides, which are coordinated through the consultative group of the CAHP.

Once the hillside experimental sites had been identified, efforts continued to examine priorities for research in the light of problems and strategic opportunities, in consultation with local NARDs, NGOs and various farmer's communities. In fact, this is an ongoing exercise for all of CIAT's agroecosystems.

From the Ground Up: The Andean Hillsides Consortium, CIPASLA

Under better circumstances, hillsides would not be cultivated at all. The people who farm them would be far more profitably occupied in the fertile river valleys below. With that option closed to them, however they have little choice but to increasingly intensify their cutivation of steep slopes, leading to severe erosion, declining crop productivity, loss of precious montane forest biodiversity, and pollution, flooding and shortages of water downstream.

The standard government approach to try and control resource degradation is regulatory and punitive. But such measures have not been enforceable in practical terms, and have done little or nothing to curb the relentless deterioration of the hillsides.

In search of a better approach, Consorcio Interinstitucional para una Agricultura Sostenible en Laderas (CIPASLA) was formed, a multi-institutional consortium for sustainable hillside agriculture. CIPASLA's approach is predicated on the belief that poverty of individuals and weakness of community organization are causal factors which must be addressed, if the historical pattern of failure in preventing ecological damage in the hillsides is to be changed. Towards this end, the consortium carries out projects aimed at commercializing traditional crops, introducing new agricultural enterprises, and diversifying the livestock and crops produced for home consumption, all linked to the introduction of soil conservation and other sustainable agricultural practices. The linkage is achieved through shared social values and consequent expectations, which are much more powerful forces in traditional, rural communities than government enforcement.

CIAT is playing a key role in this endeavor. It convened the meeting in November of 1992 which led to CIPASLA's creation, and continues to play an active and catalytic role towards the objectives of the consortium. It is also well situated to provide strategic research input related to both on biophysical and social technologies, and to identify principles which can be extrapolated to other hillsides environments.

CIPASLA works in the northern part of the Cauca department of Colombia, focusing on an area in the municipality of Caldono along the Cabuyal River, a part of the Ovejas River watershed in southern Colombia. The area is typical of hillside agro-ecologies throughout the Andean zone. CIPASLA consists of 17 institutions:

- Government: CVC and CRC (Cauca natural resource management), Secretaría de Agricultura del Cauca, SENA (training), UMATA de Caldono (agricultural extension), DRI (rural development), HIMAT (irrigation).
- Nongovernmental: Corportunía (rural credit, extension, training), CETEC (credit and agro-ecology research), FIDAR (production and agro-industry research), FEDECAFE (coffee growers' association), Sol y Tierra (local institutional development).
- Local: Junta de Acueducto (local potable water), CIALs (committees of experimenting farmers), ECONORCA (marketing and credit), Escuelas (local primary and secondary schools).
- International: CIAT (agricultural research for sustainable development).

FOREST MARGINS

CIAT became involved in the Peruvian Amazon in the early 80's, an involvement documented in *Amazonia: Agriculture and Land Use, Proceedings of the International Conference sponsored by the Rockefeller Foundation, GTZ, CIAT, NCSU and ICRAF (1982).* Work countinued thorugh the 1980's in the forest margins of Peru (Pucallpa area). In November 1989 CIAT and IFPRI, with support from the Rockefeller Foundation, organized a workshop that constituted a first attempt at "analyzing the causal relationships between ecology, technology, culture and economic aspects that affect patterns of land use and their environmental impact". The proceedings were published (W. L. Loker and S. Vosti, eds., *Desarrollo rural en la Amazonia Peruana,* CIAT and IFPRI, 1993). Several conceptual and methodological advances in relation to land use analysis and priority setting were made in preparation for this workshop, as reflected among others in Loker's and in Riesco's papers. It was unfortunate that having done all that preparatory work, the Peruvian forest margins could not be incorporated in CIAT's research agenda due to intense guerrilla activity throughout the country in the years that followed.

The focus quite naturally turned to Brazil. In February 1992, a Consortium formed by CIAT, CATIE and IICA formed a joint Mission to visit potential research areas in the Brazilian Amazon, with the participation of ICRAF and three EMBRAPA (Brazil) Centers from Belem, Rio Branco and Porto Velho. CIAT had contracted a land use study with a respected Brazilian NGO, the Instituto Sociedade, Populaçāo e Natureza (ISPN), to assemble and analyze available information on the forest margins. In parallel with this, extensive interinstitutional and multidisciplinary rapid rural appraisals (RRA) were conducted by CIAT with Brazilian institutions and staff of ICRAF, PROCITROPICOS, IFPRI, and IICA during the remainder of 1992. More details of the site selection process are given in the Results and Achievements section.

The Global Slash and Burn Project was subsequently initiated in the Acre-Rondonia region of Brazil as a major inter-institutional collaboration. Participating international institutions include ICRAF, CIAT, IFPRI, IFDC, TSBF, and the regional network PROCITROPICOS, sponsored by IICA and IDB. At the national level, two EMBRAPA centers (one each from Acre and Rondonia) are working in the project. NGO's are also active collaborators, namely PESACRE (an NGO in Acre, funded by USAID via the University of Florida), and IPHAE (an NGO in Porto Velho). This global project is led by ICRAF, coordinated in Latin America by CIAT, and funded by the GEF. The collaborating institutions jointly chose the research sites (Theobroma, in Rondonia; and Pedro Peixoto, in Acre) based largely on the CIAT-led characterization inputs mentioned above.

A final Planning Meeting for Slash and Burn was held in Rio Branco, and then completed in Porto Velho during October 1993, attended by four CIAT scientists as well as members of the above institutions, plus representatives from the University of Florida, EMATER, CATIE, WRI, and the Technical University of Göttingen, Germany. The meeting aimed to initiate the characterization stage of the project, plan the in-depth diagnosis phase, and agree on a common research agenda and budget. Two working groups were assembled: one to develop strategies for characterization and approaches to sustainability, and the other to develop questionnaires for system characterization in Acre and in Rondonia. Field trips were also undertaken, following which four hypotheses were generated. Working groups were assembled to work on one hypothesis each in order to generate lines of research and identify valuable outputs. Then the whole group met again and priorities were assigned to each line of research.

Specific research activities and institutional research responsibilities were agreed upon during that meeting. CIAT's current research activities in the Slash and Burn Project honor those agreements. CIAT is leading the site characterization together with EMBRAPA, CIAT, IFPRI and ICRAF. A CIAT agronomist is outposted to EMBRAPA-CPAF to participate in the project, evaluating germplasm of annual food crops and forages tolerant to acid soils with EMBRAPA. ICRAF and CIAT are evaluating potential agroforestry-based permanent cropping systems and improved fallows.

Conclusion

This brief review of the consultation process which launched CIAT's RMR initiative, and formed the active linkages that are now carrying out the investigations, illustrates the multi-institutional nature of the endeavor. While building linkages takes time and costs money, CIAT views this multi-partner approach as absolutely critical to the long-term success and impact of RMR in contributing to more sustainable development in Latin America.

IV. The Focus Agro-Ecosystems

The choice of a few agroecosystems for focus was a difficult one for CIAT, because there were a large number of important candidates. Intensive studies over the three-year strategic planning period (described in the Results section) identified three for priority attention: the well-watered hillsides, the forest margins and the well-drained savannas of Tropical America (Fig. 3). These were chosen based on the likelihood of CIAT being able to achieve the most progress towards the goals of equity, growth and sustainability of the resource base.

Besides being important in their own right, there are important unifying themes across these three agro-ecosystems. All three are characterized by low fertility soils, often acidic (Fig. 10), either due to their genesis or due to agriculturally-induced degradation. This shared characteristic makes possible comparative studies and economies of scale in developing biophysical mechanistic models. Secondly, there are strong political, social and economic interactions among them. Examples are: the policy-induced migration of settlers from the Andean hillsides to the forest margins and savannas of Bolivia, Colombia, Peru and to a lesser extent Venezuela; the colonization of parts of the Brazilian Amazon rainforest by homesteaders who originate in southern Brazil, traverse the savannas areas and eventually settle in the forest margins; and the well established connection between poverty and migration to the hillsides in Central America, resulting in land degradation.

In considering these interactions among agro-ecosystems, is useful to distinguish between two groups of countries: those favored with savanna lands, and those without. The first group has the opportunity for agricultural expansion in the savannas, which are potentially well-suited for the purpose; while the second has no option but to exploit the hillsides and forest margins, which are much less suitable for intensification.

Of the savanna countries, Brazil has had the largest absolute and relative area under cultivated crops and pastures. Nevertheless, Brazil still has the largest amount of savanna land still in undisturbed native vegetation. Notwithstanding that deforestation of the Brazilian Amazon has been massive, Brazil still has a relatively large amount of forest per capita, and a relatively low percentage decrease in forest land over the last three decades. Only Bolivia has a lower rate of deforestation and more forest land per capita. Like Brazil, Bolivia has also had a very significant increase in cropped area in recent decades. Thus, Brazil and Bolivia still have a greater endowment of undisturbed land despite having had a greater expansion of the frontier.

The second group of countries, particularly those in Central America do not have a savanna resource that might absorb future agricultural expansion. Population growth in their hillsides has led to increasing poverty and resource degradation. The only agricultural development alternative for these countries has been the settlement of the lowland forests. This group of countries has a greater dependence on agriculture, yet exhibit lower agricultural production per rural inhabitant and lower per capita nutrition availability, and lower, and slower growing, incomes. Poverty and food imports are higher while health and welfare indicators are generally less favorable.

SAVANNAS

The lowland acid-soil savannas of tropical America are a vast expanse of grasslands and mixed grass-shrub-woodlands, occupying about 240 million hectares. Their elevation is below 1100 meters. Soils are acid (pH<5.3) and the climate is seasonally wet, with mean rainfall exceeding 60% of potential evapotranspiration during 6-9 months annually. Population density is low.

The density of small trees is determined largely by local soil fertility; more densely-wooded areas are usually more fertile. One ecologically important (and picturesque) feature is the presence of dense tree growth concentrated along small watercourses, called gallery forests (see cover, and Fig. 4). The savannas house important reserves of biodiversity which should not be lost.

Norman Borlaug recently described the tropical savannas as "the last agricultural frontier in the world". They are regarded as having a high potential for crop and livestock production because of their suitability for mechanization due to the moderate terrain and ease of clearance of the low vegetation, and because much of the area has plentiful rainfall. However, the soils are weathered, nutrient-poor and acidic, requiring multiple nutrient inputs before they can reach commercially-attractive levels of productivity. Soil structure is considered good, but prone to serious erosion if not carefully managed.

Sustainable, more productive agricultural development on existing cleared lands in the savannas could remove one motivation for government policies which have encouraged the expansion of its frontier, as well as similar degradation in the more fragile hillsides and rain forests - namely, the need to increase national food production to counter imports. Recent policy changes have slowed down speculative frontier expansion in the savanna, particularly in Brazil.

Dynamic changes in land use have been a pervasive feature of the savanna as the settled frontier has expanded over the past three decades. About three-quarters of the savanna are still in native vegetation. The initial incursion at the edge of the frontier is extensive cattle grazing on this vegetation, a low-input, low-output strategy. As intensification proceeds, the land is cleared of trees and sown to an upland rice crop or, if liming is feasible, other crops such as soybeans. Thorough tillage for sowing these row crops during the onset of heavy storms often results in wind and water erosion. In following years, introduced grass pastures are often sown and more cattle are brought in for grazing. An estimated 35 million hectares are currently sown to introduced grasses. Finally, as urban development encroaches there is cultivation of perishable horticultural products and intensive dairying.

The technology of introduced pasture grasses has had massive impact. Most of these pastures are sown to the species *Brachiaria decumbens*, which was brought in by the private sector from Australia in the 1950's (Australian breeders had, in turn obtained it from East Africa in the 1930's). It tolerates poor soils, responds to modest fertilizer applications and produces a more digestible forage than native savanna species. Well-managed *Brachiaria* pastures can increase cattle live weight gains 30-fold on a per-hectare basis (which includes a higher stocking rate enabled by the more vigorous pasture), to about 300 kg/hectare-year, which is why the technology has been adopted on such a large scale.

Despite the potential of *Brachiaria* grass pastures, however many ranchers overgraze and provide little management, leading to a state of degradation on an estimated 60% of its planted area (Fig. 4). This reduces productivity on the order of 50% (to around 150 kg/hectare-year) and sets off a downward spiral of deterioration. As grass is weakened and grazed to the ground, soil is left bare and erodes, and the absence of sufficient root biomass results in soil compaction by animal hooves. These and additional degradative factors related to the expansion and intensification of use of the savannas are causing serious destruction of gallery forests, siltation and pollution of rivers, loss of genetic diversity, and out-migration of rural populations.

Agriculture in the savannas, however may also present some positive resource management opportunities. In an important new finding by CIAT, detailed in the Results section, the introduced grass pastures seem to be acting as a net sink for atmospheric carbon, sequestering huge amounts of this element below ground (Fisher et al., 1994) (Fig. 12). Also, CIAT research has shown that grass-alone pasture productivity could be doubled, to about 600 kg cattle live weight gain/hectare-year, if a legume is added to the grass system. The legume stimulates increased grass biomass through improvements in the structure, fertility and biological activity of the soil, which also benefit subsequent crops and in general set the system on a course of regeneration, increasing sustainability in both environmental and economic senses. At present legumes are rarely used by farmers, however because of a lack of suitable species which are easy to manage, particularly which have the required environmental adaptation plus are able to survive the competitive conditions and grazing damage encountered in a pasture.

The crops component may provide a strategic leverage point for stimulating pasture regeneration, including the adoption of legumes, through agro-pastoral systems (described in later sections). Crops have a major presence in the savannas: about 12 million hectares in the savannas of Brazil are sown to them annually. They supply about 40% of Brazil's total rice and soybean production, and 35% of its maize. Improved upland rice varieties based on CIAT germplasm and tested by EMBRAPA appear poised to double yields and increase grain market value over the next decade, and more acid-tolerant maize germplasm developed by CIMMYT may soon allow farmers to reduce liming rates for this important multi-purpose crop.

HILLSIDES

The total area in hillsides in Tropical America is estimated at about 96 million hectares. CIAT's environmental characterization identified a seasonally-wet subset, amounting to 30 million of the total, for focus in CIAT's RMR initiative because the reliable, well-watered growing seasons give it more options for agricultural development than do the drier areas. Even in these relatively well-watered areas, the erratic distribution of rainfall can lead to short but sometimes critical periods of drought stress, however.

Principal hillside countries in the South American tropics are those located along the Andean mountain range. The countries and their percentages of total area in steep-slope agriculture, where available include: Bolivia, Colombia (40%), Ecuador (65%), Peru (50%) and Venezuela. Another hillsides locus is in Central America, especially Costa Rica (70%), El Salvador (75%), Guatemala (75%), Honduras (80%), Mexico, Nicaragua and Panama (80%). Hillsides are also of major importance in the Caribbean, particularly in the Dominican Republic, Haiti and Jamaica.

The hillside agroecosystem in Latin America is the basis of the livelihood and food supply of a large proportion of the poor, numbering an estimated 20 million people (Fig. 5). Many of these are indigenous (pre-Colombian) ethnic groups, as well as destitute, landless immigrants lacking the means or opportunity to pursue an acceptable standard of living in the urban areas. World Bank data indicate that a high proportion of this rural population falls below the poverty line, ranging from 45% in Colombia to 80% (Guatemala). A significant portion of the population is considered indigent, i.e. lacking the means to meet minimal nutritional needs: 23% in Colombia, 46% in Peru, and 57% in Guatemala. Moreover, World Bank figures for the current decade indicate that rural impoverishment has recently increased in some of these countries. CIAT's work in the hillsides directly targets this equity need.

Agriculture in the hillsides is typically based on fallow-rotation systems in which forest or bush fallow is cleared for cropping with annuals (maize, beans, cassava, upland rice) and perennials, and returned to bush fallow or pasture once yields decline to a level that is non-economic for farmers to continue cultivation. In the more densely populated and drier areas, fallow periods have shortened or fallowing has been virtually replaced by organic or chemical fertilisers. When farmers cannot obtain or afford fertilizers, they work off-farm, leaving care of the crops to the females in the household, causing an increased "feminization" of hillside farming. Female-headed households are a high proportion of the indigent rural population.

A linkage between poverty and environmental degradation is plainly evident in the Latin American hillsides. Environmental degradation is driven by a compelling need to produce food in the short term, combined with a lack of incentives for hillside farmers to seek the longer-term benefits of soil conservation. Once one area becomes degraded, poverty drives farmers to clear more land and continue the vicious cycle of degradation. Income-generating activities which would ameliorate poverty while simultaneously rewarding sustainable uses of the land are the keys to ending this cycle.

About 25 million hectares of the hillsides are already considered to be highly degraded, and about 53 million hectares are experiencing rapid rates of degradation. Causes of degradation include deforestation (24,9 million ha), overgrazing (24.7 million ha) and agricultural activities or domestic use of vegetation (42.6 million ha).

Environmental degradation in the hillsides not only impoverishes the farmers there; it also affects others downstream. Deforestation results in reduced storage of water in soil profiles and aquifers, contributing to floods and droughts. Deforestation followed by heavy rainfall sets the stage for land slippage, and together with construction activities and tillage for cropping, causes soil erosion and siltation of watercourses which serve farmers and urban centers further down. Throughout the Andean region, a major portion of hydroelectric power is generated in the hillside areas, and these reservoirs are subjected to rapid degradation as they fill with silt from erosive activities upstream. Coastal estuaries, the nurseries which sustains ocean fisheries, bird life and other critical ecosystem processes, are also degraded when silt-laden water reaches its ultimate destination. These "external" affects are often overlooked in analyses of the hillsides.

The loss of biodiversity due to the clearance of montane forest, largely for agriculture, is also a major concern. These forests account for 15% (Bolivia) to 57% (Guatemala) of all forest areas in the region. Montane forest has very high biodiversity, possibly higher than lowland forests, especially with respect to herbs and shrubs found between 600-3000 meters elevation, which are considered strategically important habitats for ecotypes related to important food crops. The rate of deforestation in the hillsides is higher than in the lowlands: 90 percent of all native montane forests had disappeared by 1990.

FOREST MARGINS

Following its comprehensive Latin American environmental classification in 1990-92, CIAT defined the forest margins (Fig. 6) as "those areas that are tropical, lowland, seasonally wet with acid soils where the land use is some combination of slash and burn agriculture with extensive cattle grazing". Areas with nine months or more of heavy rainfall (including large areas of the Amazon basin) are excluded because burning becomes difficult. Since human access is required to clear forests, the definition includes only land within 30 kilometers of a permanent road or navigable waterway. Defined in this manner, there are some 44 million hectares in the forest margins.

The massive environmental problems that have resulted from deforestation in the forest margins have been widely publicized. Tropical deforestation is leading to irreplaceable erosion of biological and human diversity. The burning of tropical forests also contributes to global warming. Brazil is now the fourth largest contributor to atmospheric carbon, after the USA, the ex-Soviet Union, and China. Decreasing transpiration and precipitation both within and outside of deforested areas may also be caused by the loss of forests.

Tropical deforestation has been highest in Latin America both in absolute (43,000 square kilometers/year) and relative (0.64%/year) terms, compared to Asia and Africa. Twenty-eight percent of the Latin American forests standing in 1850 have now been converted to other uses: 44% to cattle pastures, 25% to cropland, 10% to shifting cultivation, and 20% has been degraded. Shifting cultivation often cleared the way for those uses; it was thought to account for 32% of all deforestation in 1980. Approximately 232,000 square kilometers of the Brazilian Amazon are now deforested, and 588,000 more are within one kilometer of a cleared margin, which subjects them to edge effects. Comparing the different states of Brazil, deforestation is most advanced in Rondonia and Mato Grosso, followed by western Maranhao, Acre, and northern Goias.

The root causes of deforestation (Figure 16) in the Brazilian Amazon include government policies favoring the incorporation of the Amazon into the mainstream of the Brazilian economy over the past few decades, and the responses these policies generated from the poor who were driven by aspirations for a better life, as well as more wealthy citizens seeking to protect their savings from inflation through land speculation. Roads were built, and settlements encouraged through a number of policies, such as: exemption of agricultural incomes from taxes; recognition of clearing as evidence of useful ownership; land taxes encouraging conversion to cattle pasture; credit schemes subsidizing corporate livestock ranches; and tax breaks for wood product industries.

Small-scale settlers escaping urban poverty attempt to use the abundant land resource of the forests to increase returns to their labor. Immediately after slashing and burning the forest, annual cropping with nutrient-demanding crops such as rice and maize is the most common practice because it captures some of the benefits of the temporarily-increased soil fertility caused by the ash deposition and high organic matter content of the soil. This is not sustainable, however once soil fertility is exhausted; in Brazil's forest margins, yields of rice, maize and cassava have decreased sharply over the 1984 to 1990 period, in contrast to significant yield increases at the national level. As fertility declines after a few years of crop cultivation, pastures, which are less nutrient demanding, are established, and new land is deforested for growing annual crops, thus expanding the frontier and shrinking the forests.

As the frontier matures, smallholders sell out to investors with larger financial resources who are driven largely by motives of land speculation. During the last two decades when the holding of cash was a sure road to ruin in Brazil due to out-of-control inflation, land was a hedge which showed good returns to the investment. Land ownership provided the additional benefit of access to credit at favorable interest rates. Government institutions were established to facilitate private investments through tax incentives, with most support being granted to large ranches and corporations. Title to public lands could be claimed if land could be shown to be used for productive purposes, spurring needless land-clearing. During the period 1980-85, it is estimated that about one third of the deforested area was not used, being burnt to demonstrate occupation (Mueller et al., 1992).

Cattle ranches soon covered 8.4 million hectares in the Brazilian Amazon, averaging 24,000 hectares each, employing just one cowboy per every 300 hectares, but even so were profitable only with full tax advantages. The environmental cost to economic benefit ratio was shocking: one ton of rain forest was sacrificed for each quarter pound of hamburger produced. Nor was it economically attractive, either: 22 out of the 26 US cents it cost to produce the quarter pound of hamburger came from subsidies. However, in recent years cattle ranching in some areas appears to have reached a critical mass wherein it is becoming economically viable on its own merits. This is because the necessary infrastructure and social systems (land titles, law enforcement etc.) are now in place which reduce risks and overheads formerly borne by frontier settlers.

Some of the major incentives provided to large corporations and cattle ranches were eliminated in 1985 as Brazil suffered from recession and hyperinflation. Presumably as a consequence, recent analyses of remote sensing data suggest that rates of Amazonian deforestation have been decreasing, from 8 million hectares in 1987 to 1.8 million in 1989, 1.4 million in 1990, and 1.1 million in 1991.

Nevertheless, major threats to forests remain, namely logging, mining and ranching. Logging may increase in importance as Asian wood supplies are exhausted. Gold mining in the tributaries of the Amazon continues unabated; in the Tapajos river area, it resulted in the spilling of 2,000 tons of mercury into watercourses between 1980 and 1990.

If policies which discourage clearing at the frontier continue in force, technologies to stabilize agriculture on existing cleared lands might take hold. Innovative strategies for sustainable use of forest products, in combination with institutional mechanisms for participating in global markets for environmental services such as carbon storage (see box in Paradigms and Perspectives section), could create incentives to protect and regenerate, rather than destroy the forests. Rainforests have significant “resilience”, and might even be able to regenerate in much of the forest margins, if enabled to do so.

V. Research Priorities

The priority-setting process for the RMR initiative began with the land classification analyses of the three-year Strategic Planning process (1988-1990) (Fig. 1). Geographic information systems technology was applied to make a thorough analysis of land uses across Latin America and the Caribbean, and the potential for research to contribute to their more sustainable development in the future. The entire region was mapped for a large number of key variables, both biophysical and socio-economic. In stage 1, all of Latin America and the Caribbean were mapped into broad environmental classes. In stage 2, a short list of classes was chosen according to their priority relative to CIAT's geographical mandate, the needs of its clients and its existing expertise in those environments. Stage 3 moved beyond environmental classification to add a systematic description of actual land uses and demographic data. Stage 4 involved a clustering of areas with similar characteristics, and a comparative analysis of the constraints and opportunities these agro-ecosystems present, searching for "best fits" to CIAT's goals.

This process resulted in the selection of the hillsides, savannas and forest margins as the three foci for CIAT's agro-ecosystems research (Fig. 3). The land management approach, which had been fundamental in carrying out this analysis, would continue as an over-arching theme in the new RMR initiative.

The Strategic Plan identified four objectives for each of the agro-ecosystems:

i) Characterization of the dynamics of land use and farming systems and their influence on the sustainability of the resource base;
ii) Strategic research to identify principles that would increase the sustainability of use of the resource base;
iii) Development and testing of more sustainable prototype technologies which could be tailored by national/local agencies for their particular needs; and
iv) Training and research partnerships to strengthen national capacity in RMR.

These generic objectives have been particularized for each agro-ecosystem, as described later.

Having determined the focus agroecosystems, more detailed GIS-based analyses were applied to identify representative areas for detailed study within each (Fig. 7). This process again utilized large amounts of detailed data gathered from the literature, from national and local collaborators, and in many cases from rapid rural appraisals and surveys mounted specifically for the purpose. More details are presented in the section on Results and Achievements.

LAND MANAGEMENT

CIAT's priority objectives in land management since 1991 have been to:

i) continue to help identify representative areas in which to focus agro-ecosystem research;
ii) understand and anticipate the dynamics of land management;
iii) understand interrelationships among different levels of scale (eg., farm, watershed, landscape etc.);
iv) analyze policy alternatives for improved land management;
v) assess the impact of new technologies and policies on land management; and
vi) strengthen national capacity to improve land management.

The types of activities these objectives require include:

- continuation and strengthening of earlier expertise in the mapping and analysis of data on the spatial distribution of agricultural land use, using geographical information systems technology;
- the development of a broader systems and resource management approach to tropical land management;
- the addition of new capability (including the recruitment of qualified scientists) in ecology and socio-economics;
- the expansion of contacts and cooperation with different types of research institutions, not only agricultural, but also including the broader issues affecting equitable, sustainable land use;
- the development proposals for new projects;
- convening meetings and other actions to catalyze new projects and draw attention to results to stimulate changes which improve land management; and
- publications, training courses, workshops, internships and other modes of information dissemination and skills enhancement.

Specific priority activities are outlined below.

Strengthening GIS facilities at CIAT

GIS is a core tool for land use analyses. CIAT is continually upgrading its a world-class facility so researchers will be able to carry out the most powerful analyses that this rapidly-developing field will allow. At present, CIAT's existing GIS datasets from older computer mapping systems are being converted to a newer, more powerful software and hardware system, with rigid quality control procedures.

The GIS laboratory is moving into the remote sensing/image analysis of satellite images through cooperation and technology transfer from the Universities of Leicester and Edinburgh. Air photos are being analyzed in detail to characterize land use and land use change for detailed site specific work for the agro-ecosystem and crop research teams. Initial work for the Andean hillsides is proceeding through cooperation with the CVC, the Regional Planning Authority for the Cauca Valley, Colombia and the University of Georgia.

Many of the areas of CIAT's work are covered by clouds throughout the year which makes them impossible to sample using air photos or normal (optical) satellites. To secure data in those areas, capability in radar imagery and differential interferometry is being built, which will permit detailed mapping, elevation extraction and calculation of slopes from ERS1 (Earth Resources Satellite) imagery. This work will be done in cooperation with the University of Stuttgart and Milan Polytechnic.

Normal air photos cannot be used to map mountainous regions accurately due to distortions in the imagery. A capability to map such regions using digital orthophotography with GPS (Global Positioning Satellite) position fixing on the ground is required for sloping areas in the hillsides and parts of the savannas. To improve this capability CIAT purchased two precise GPS receivers in late 1994.

Data restrictions in Latin America imply the need to produce our own elevation and slope data for detailed simulation modelling experiments. This necessitates the development of a capacity in the area of soft-copy photogrammetry with allows the construction of accurate and detailed three dimensional images of small study areas. The use of stereo satellite images, which allow larger areas to be mapped in three dimensions at reduced resolutions and cost, is also being explored. This work will proceed in cooperation with the University of Georgia.

In 1995 we expect to move further into complex GIS analysis integrating crop growth, hydrological and erosion models (TOPOG, AEGIS + and WEPP) of interest to CIAT's agro-ecosystem researchers.

Identification of areas for intensive agro-ecosystem research

In the Strategic Plan, CIAT had decided that areas for intensive research would be located representing a wide range of diversity within each of the savannas, hillsides and forest margins agro-ecosystems. Land management tools, particularly GIS were instrumential in the process. That major effort is now completed, and is described in the Results section for each agro-ecosystem. Carrying the approach further, a number of specific types of land use analyses have been requested for particular agro-ecosystems, and are underway as described below and in the Results section.

Resource degradation evaluation and regional characterization of catchment areas in the hillsides of Central America and the Andes

An assessment of the state of degradation in the hillsides of tropical America was carried out to help in prioritization in CIAT's new hillsides effort. The levels and causes of degradation were estimated from the 'World Map on the Status of Human-Induced Soil Degradation', UNEP/ISRIC 1990. Rainy months and soil depth were calculated. This initiative is continuing as we are currently overlaying the limits of hillsides catchments with the FAO Soils Map of the World and the GLASOD map of soil degradation, for Colombia and parts of Ecuador and Panama.

Andean hillsides characterization and simulation modelling

This study provides essential input into area-based hillsides research in the Río Ovejas watershed, Colombia, and is being undertaken in cooperation with several NGOs, the CVC (Regional Planning Authority, Cauca Valley, Colombia) and the Universities of Georgia and Leicester. Initially, we are producing a detailed digital elevation model of the area from 1:25,000 maps. This will be completed early in 1995 and the data will be used to calculate slopes. Three dimensional digital orthophomaps are being prepared with land use, rivers and roads draped over them. Three-dimensional visualization greatly helps in understanding the uses of the landscape.

An agricultural and socio-economic census has been undertaken for the Rio Cabuyal site within the Ovejas watershed, and this will be mapped along with other data such as soils, rivers, climate, roads and slope. Land use and land use changes are being extracted from aerial photographs from 1950, 1970 and 1990 for the Rio Cabuyal. These data are also being used to help characterize land use over a 100 by 50 km area covered by SPOT satellite imagery, and land use change over a 185 by 185 km area covered by LANDSAT TM and MSS imagery dating back to the 1970's.

These data will be used with other more comprehensive data as inputs to AEGIS + farm simulation modelling and the TOPOG watershed modelling programs, to explore the possible impacts of different cropping systems on erosion and water yield.

A comparison of Andean hillsides land managment in Colombia and Bolivia

Hillsides sites are very diverse, as conditioned by their geographic isolation due to topography and often distinctive ethnic origins. The objective of this project, starting in collaboration with the University of Kassel and CIP and funded by BMZ, is to develop an accurate GIS spatial database describing this diversity, detailing topography, drainage, soils, climate, land use, access and infrastructure at two distinct Andean hillside sites, to be overlaid with cropping systems, social structures, marketing and other data. This database will provide a clear picture of the linkage of social, economic and physical factors within these areas, and an identification of potential or actual environmental hazards within or outside them due to agricultural land management.

Watershed modelling

Besides agro-ecosystems, there is value in viewing land use at different levels of scale, as explained in the Paradigms and Perspectives section. Watershed-scale studies are most advanced for the hillsides, in collaboration with scientists from the University of Florida. The main objective is to develop a predictive simulation model based on an understanding of biophysical processes at the level of a prototype watershed. An additional objective is to asses some of the externalities (eg., effects on downstream communities) associated with different types of land use in the watershed. A similar approach is currently being discussed for the savannas in collaboration with the Federal University of Uberlândia, Brazil.

Latin America's protected areas

Protection of environmentally-sensitive lands is critical for the preservation of biodiversity and natural ecosystems. When we started the Strategic Planning process, however there was no single compilation available of the land reserves set aside from development in Latin America, so we developed one.

World trade in plant nutrients

Imbalances in nutrient flows on a national or regional scale alter an important part of the resource base, the supply of critical nutrients. A large proportion of the exports of the developing countries are agricultural or forestry products. To analyze these flows, nutrient movements were analyzed using the years 1967 and 1985 as points of comparison. The year 1967 gives a view of the newly post-colonialist, pre-green revolution situation, while 1985 reflects massive changes due to those events, as well as influences of the cold war which affected trade patterns. It would be interesting to compare this pattern with subsequent changes triggered by the new dynamics of the post-cold war world. We therefore propose to follow up the study with a third reference year, possibly 1995 or 1996 as data become available.

Land quality indicators

A metholodogical problem plaguing RMR research has always been how one could actually measure sustainability. It is an *ex-post* concept, which can only be measured with certainty after a long time period has elapsed. One solution to this problem is believed to be in the identification of sustainability indicators, which anticipate longer-term changes occurring in systems. The identification of these indicators is a high priority activity because it is a fundamental tool needed for policy advice, and to enable research to proceed in a practical, limited time frame. An interinstitutional initiative is being launched to jointly identify such indicators.

Mapping the environments of ecotypes and wild relatives of crop plants

In the interest of conserving the world's precious and dwindling resources of biodiversity, it is critical that the locations of diverse ecotypes and species of key plant genera be identified so they can be visited and seeds collected, and/or the sites can be protected by governments as strategic biodiversity reserves *(in situ* conservation). One clue in identifying these locations is to search GIS databases for the climatic and soil combinations known to be compatible with the adaptation of particular species. The LM SRG has developed a powerful technique of climate comparison based on the 12 point Fourier transform. The technique has been used in the past to guide the teams searching for predators of cassava mealybug and green mites which were sent as biological control agents to Africa. That work is now having enormous impact in controlling the mealybug pest.

Working with a Visiting Researcher of the University of Cambridge, the Group has developed a method of using these transformed climate data to produce a probability density mapping of climates similar to the collection sites of wild relatives of common bean (*Phaseolus vulgaris*) held in the germplasm collection (Fig. 11). Location data for wild cassava (*Manihot*) species are at present being processed in collaboration with the World Conservation Monitoring Centre (WCMC) in Cambridge and further environmental similarity research will shed light on the diversity of genetic material in this genus. Mapping the wild species of the genus *Arachis*, which contains promising forage legume genetic resources, and other crop plants are planned for the near future.

Development of a core sample of the world genetic resources of common bean

CIAT, in accordance with its responsibility for collecting and safeguarding the world's genetic resources of common bean *(P. vulgaris)*, holds over 27,000 accessions of this species. However, many users, particularly in developing countries find the costs involved in screening the full collection for important economic traits to be beyond their means. We are therefore in the process of identifying a representative subset, chosen carefully to represent the maximum diversity of sites of origin, which involves a stratified sampling based on environmental data from the points of collection.

SAVANNAS

Strategies and priorities for the savannas were set out in CIAT's Strategic and Medium-Term Plans, although they will evolve as the understanding of this agro-ecosystem progresses. Much of the detail of the surveys, consultations and other exercises in the intitial priority-setting process were described in the section on Consultations.

CIAT's priority objectives in the savannas are to:
i) identify key agricultural sustainability problems and opportunities;
ii) strategic research on the biophysical bases of degradation and sustainability;
iii) develop more sustainable prototype systems; and
iv) strengthen national capacities for designing more sustainable production systems.

Feedback on priorities is received from national programs in Bolivia, Brazil, Colombia and Venezuela through the annual IDB-supported savanna workshops. At the Brazil (1993) workshop, national scientists requested that CIAT undertake:

- a coordinating role for collating and disseminating information on agropastoral research;
- training new researchers and organizing specific courses;
- long-term research of a strategic nature on the key processes, mechanisms and themes involved in the sustainability of agropastoral systems;
- support to NARS in identifying and obtaining funds for research;
- the development and testing of prototypes suitable for agropastoral systems; and
- improvements in methodology for on-farm research in the savannas.

More recently, the development paths and respective research priorities of the Bolivia, Brazil, Colombia and Venezuelan savannas were reviewed in detail by multi-institutional groups in each of the respective countries as part of the development of the SSALLSSA Project Proposal (described under land management in New Project Initiatives section).

Based on these priorities and feedback, our current activities include:

- strategic analyses of the dynamics of change as the usage of savanna lands intensifies;
- strategic analyses of current farming systems to determine their degradative and/or regenerative principles, and user motivations for engaging in them;
- development of prototype sustainable agro-pastoral and agro-silvo-pastoral systems; and
- forming consortia, networks and specialized linkages for joint research collaboration and training, including the writing of projects for external funding.

It is reassuring to note that to a large extent, CIAT's research agenda for the savannas coincides with that identified by a number of independent groups related to development and ecologically-oriented academic institutions.

CIAT has located its area-based savanna experimentation in the Meta region of the Colombian savanna, and the Uberlândia region of the Brazilian savanna (Figs. 3, 7). We have established large, long-term experiments in each area to investigate the strategic principles involved in more sustainable crop rotations and ley-farming systems, and the changes they induce relative to non-disturbed native savanna. These efforts are complemented with on-farm trials in nearby farmers' fields and the testing of prototype improved systems, including farmers' reactions to them. The externalities which savanna land uses generate for other regions and even globally (such as atmospheric gases) are also receiving study.

The specific priority activities we are engaged in for the savannas are as follows:

Savanna agricultural systems characterization, and dynamics of change

The tropical savannas are a relatively new agricultural area to most of their farmers, who are recent immigrants. They are widely experimenting with a range of crop and livestock systems. Highly contrasting management practices among farms in the savannas provide an opportunity to study the dynamics of change, and to indicate probable future changes. Cross-sectional studies have begun in the Colombian and Brazilian savannas, in our area-based research locations. We have selected fields in contrasting systems of land use, and are monitoring soil chemical, physical and biological parameters, biomass productivity and, where applicable, animal productivity. These studies are supported by socio-economic characterization based on regular surveys and monitoring of whole farm inputs and outputs.

The nature and extent of trade-offs among conflicting uses of resources in three sites at contrasting stages of development in Brazil is proposed for study using multiple objective programming. Analysis of secondary information identifies the factors, socioeconomic as well as biophysical, with major influence on resource degradation and regeneration. Data from the farm level will be linked to related information from the watershed and regional levels, for extrapolation to the whole savanna area of Brazil.

Biodiversity of the savannas

The savannas are an important repository of biological diversity for future generations. Native vegetation still covers about 90% of the savannas of Colombia, 78 % of the savannas of Venezuela and 50-60 % of the savannas of Brazil. It is likely that as land use in the savannas intensifies, the native savanna will come under increasing pressure. We are studying the dynamics of native vegetation in response to system intensification in Colombia, in collaboration with a number of institutions. In Brazil, other institutions such as CPAC are leading this thrust. The studies in Colombia are conducted at several complementary scales, in both flat and undulating lands. Not just plant diversity, but also soil fauna diversity in Colombia and mycorhizzae diversity in Brazil are receiving attention.

An inventory and classification of vegetation using satellite images of differing spectral frequencies has been undertaken in collaboration with IGAC, Bogotá, and the Ecole Nationale Agronomique of Paris-Grignon. The classifications are verified (ground truthed) in field studies at Carimagua, and the extent to which trends in plant dynamics and soil cover can be detected by satellite images is being assessed. The results will ultimately provide a tool to monitor changes in vegetation as development in the savanna proceeds. Dutch and French students are assisting with preliminary studies of the vegetation in the undulating 'Serranía' savannas to relate the species composition to management practices and soil type.

The timing of burning exerts a powerful influence on the productivity and the dynamics of botanical composition of the savannas. If native pastures are mismanaged by overgrazing or injudicious burning, their species composition changes and they are said to degrade. To understand how burning-induced degradation and biodiversity are associated, a long-term experiment on time and frequency of burning and grazing intensity on native savanna is being carried out at Carimagua, Colombia.

Latin America is the center of origin of many forage legumes. Since the mid-1970's, CIAT has been actively collecting diverse *Rhizobium* genotypes which co-evolved with these legumes. The CIAT collection now numbers over 4,000 accessions. Inoculants and ampoules are routinely prepared and sent out to research institutes throughout the region, with over 100 requests being serviced per annum. Collections are continuing, such as strains for the promising new forage legume *Arachis pintoi*.

Strategic agricultural production systems research

The Brazilian experience has shown that repeated annual cropping with high inputs cannot be sustained due to the deterioration of soil physical properties and increases in erosion, weeds and pests. Alternative systems that lessen or reverse the deleterious effects of continuous cropping are required to sustain the productive potential of the savannas.

The RMR initiative is attempting to quantify and identify impacts of different savanna production systems on soil sustainability parameters such as nutrient flows, organic matter, and microbial and soil fauna populations. Special, long-term experiments for this purpose have been established in Colombia (where the trials are called 'Culti-Core') and Brazil (called 'CPAC', after the Brazilian Center where they are located). The data will allow us to adapt, develop and validate integrated computer models that simulate the effects of changes in system components on system sustainability.

In terms of prototype improved systems, we are studying the sustainability of improved pasture technologies developed in the past at CIAT. This has led to an important new discovery: the capacity of introduced pasture grasses to store additional atmospheric carbon, a pollutant implicated in global warming (see box in Results and Achievements section).

To address bottlenecks in farmer adoption of improved pastures, the agropastoral prototype is being researched collaboratively by CIAT and EMBRAPA, and appears highly promising (Fig. 4), as explained under Results and Achievements. Introducing legumes into the pasture component, and helping national institutions increase the menu of crop options beyond upland rice now forms a focus of agropastoral systems investigations. Maize, sorghum, soybean, grain legumes, green manures, inter-crops, and more types of forage grasses and legumes are being examined. Brazilian institutions are already promoting the crop-pasture technology to farmers. CIAT is concentrating more on strategic research, and extending these concepts to Colombia, Venezuela and Bolivia.

Modeling organic matter turnover and microbial biomass

The weathered, acidic Oxisols and Ultisols that dominate the savannas are critically constrained for agricultural uses by low inherent soil fertility. The most effective and sustainable approach to increasing their fertility is believed to be through increasing soil organic matter quantity and quality, and increasing soil biological activity, along with some key supplemental fertilizer inputs. Furthermore, soil microbial biomass responds rapidly to changes in soil management compared to total soil organic matter, so it may have added significance as a "sustainability indicator" presaging longer-term changes in quality and quantity of soil organic matter. However, much of this is speculative because tropical soil organic matter dynamics have not received much research attention and are little understood. Current research is addressing this knowledge gap.

The complexity of interactions between different forms of soil organic matter require a modeling approach. The CENTURY model was originally developed for simulating organic matter dynamics and nutrient cycling in natural grasslands of the North American Great Plains. Over the years, its use has been gradually extended to other eco-systems and other climate zones, and the model now has been adopted for the tropics by the Tropical Soil Biological and Fertility Network and the Global Slash and Burn project. There is a need to validate and modify it to fit tropical savanna conditions, which is the purpose of this work.

Cation balances and nutrient cycling

In general, the typical Oxisols and Ultisols of the savannas are deficient for multiple nutrients, and yet are not conducive to the efficient use of applied chemical nutrients. Strategic studies are needed to reveal principles involved in maximizing the efficiency of nutrient capture and re-cycling within different management systems, and ways to lower chemical inputs through practices which increase their efficiency of recovery and use by cultivated species. The low ability of savanna soils to retain nutrient cations (Ca, Mg and K) together with high acidity and soluble aluminum implies that fertilizer applications need to be carefully balanced to avoid nutrient deficiencies, inefficient use of inputs and losses through leaching. In the Culti-Core long term plots (Colombia), as well as at a number of satellite sites, long-term experiments are underway to assess more accurately the nutrient requirements of component crops, and to estimate nutrient losses and use efficiency under alternative management strategies. Experiments are underway to determine the optimal balances of Ca, Mg and K for several crops, Si for rice, and to study the dynamics of applied cations and soil acidity, and the interaction of amendments on nutrient fluxes, fate and residual values. The results will be used to adapt and/or modify currently-available nutrient cycling models.

Phosphorus dynamics

P deficiency is probably the single most important nutrient limitation in savanna soils. It is associated with a high P-fixation capacity. Fixed P often becomes slowly available, so it may have substantial residual value. Furthermore, systems that direct P inputs into pools that are protected from fixation would help improve use efficiency of P fertilizer. But development of such systems requires knowledge of the processes that affect both the residual value of previous P fertilizer applications and its rate of movement between P pools in the soil.
Experiments have been established in Colombia to:

- Determine the optimal levels of soluble phosphate fertilizer for major crops (this work is in close collaboration with germplasm development efforts outside the RMR initiative to increase the P recovery and use efficiency of beans, forages, rice and cassava);
- Characterize the fate of P applications (uptake by crop, removal in products, immobilization in organic matter, reversion to less soluble inorganic phases); and
- Determine the residual value of phosphate applications. These four-year experiments are designed to allow comparisons between P of different ages in the soil and enable the parameterization of a time-dependent model of residual P.

Measurements include the estimation of microbial P and determination of various inorganic and organic P pools using methods developed at the University of Saskatchewan (Canada). Sequential P fractionation data such as these form the basis of the P sub-model in the CENTURY soil organic matter model developed to simulate the dynamics of C, N, P and S in temperate grassland soils. Modification and application of CENTURY (and other simulation models) will be attempted, to assess the net effects of different interacting processes on resource sustainability.

Strategic studies on carbon budgets

The Latin American tropics play a key role in the generation (through burning) and storage (through vegetation) of global carbon, a pollutant that is believed to contribute to global warming. Cropping systems in the savannas are dynamically changing, and changes in dry matter accumulation or destruction over large areas could have major effects on global carbon budgets. It is important to gain a quantitative understanding of these massive carbon turnovers and dynamics, and their causes. Investigations are underway to quantify carbon budgets in the long-term savanna trials established in Colombia and Brazil. A recent finding (1994) that improved pasture grasses sequester large amounts of carbon in their roots is receiving worldwide notice (see section on Results and Achievements, and Fig. 12). Collaborators at Cornell University, USA and others are investigating the dynamics of related gases.

HILLSIDES

The 1991 hillsides land classification study, described in the Results and Achievements section, had identified the major environmental problems of the well-watered hillsides. Consultations, characterizations and literature reviews indicate that the rapid rate of environmental degradation in the hillsides (Fig. 5) is driven by the unfavorable structure of incentives for hillside farmers to invest in conservation. These incentives are shaped by the specific agroecological conditions faced, the technologies available, the prices of inputs used and outputs produced, the opportunities for off-farm employment and migration, as well as cultural and organizational norms of natural resource management. Social mechanisms linking income-generating activities to conservation farming techniques must be found, if degradative processes are to be ameliorated.
In that context, top priority objectives in the hillsides are to:
i) understand the mechanisms of degradation;
ii) generate appropriate, practical prototype systems to increase sustainability, through a participatory process;
iii) develop methodologies for stimulating community-based action to resolve resource management problems; and
iv) strengthen the capacities of national systems to generate and transfer resource-enhancing technology.

Accordingly, we are engaged in the following types of activities:

- Diagnostic research on the effects of soil degradation, to better identify problems and set priorities among them. This diagnostic research is developing indicators and data which are important inputs to models.
- Design of prototype production systems that are more sustainable yet meet farmers' needs. Possible components of the system will be narrowed to a few using *ex-ante* simulation modelling.
- Decision-support systems incorporating different types of models, including the biophysical models mentioned above as well as others drawing on indigenous technical knowledge. These will be introduced into participatory organizational frameworks to facilitate conflict resolution and joint action at the community and watershed level.
- Community-based, participatory research and development methodologies are being used to evaluate these models, technology components and prototype systems. This ensures the relevance and adoptability of innovations.
- Training of national scientists in all of the above methods.

For the two area-based research projects (Andean and Central American), the specific priorities of local and national institutions were consulted in order to tailor the research work to those differing environments, and are described under the respective headings later.

These efforts are being executed through the following strategic research projects:

Soil degradation, conservation and regeneration

The purpose of this project is to define and quantify the effects of soil degradation and regeneration in the hillsides, estimating their true costs and benefits. These data will serve as inputs into decision-support and other types of models (see later).

Various practices for soil conservation and regeneration in the hillsides are being energetically promoted, largely by NGO's with relatively weak research capabilities. A widespread process of trial and error is underway. There is a need for well-researched principles to aid the selection of suitable practices to be incorporated into hillside production systems.

A major problem is the scarcity of systematic data on the actual extent of soil degradation and its effects on productivity in the hillsides. The application of decision-support systems will require more accurate input data on key environmental parameters, such as soil quality and degradation, as well as of the stakeholders using these resources. Processes determining soil regeneration in tropical hillside soils are poorly understood. There is a lack of satisfactory indicators to measure the tangible benefits of existing or new practices, which hampers their adoption by farmers, and the design of appropriate incentives to promote their use.

Studies are being carried out across contrasting land uses and stratified by environment to improve soil quality inventory mapping. Indicators of soil quality status are being defined, and studies being conducted to quantify levels of resilience of the soil resource base by measuring potential crop yields and species diversity of soil macrofauna. Databases on soil chemical properties will be linked to GIS analysis to improve regional capability to extrapolate results.

In the Andean study area (Río Ovejas watershed), experiments across six benchmark land use types are supplying data for nutrient, water balance, crop and hydrology models, directed at understanding sources of variability. Soil profile information compatible with the requirements of the IBSNAT suite of crop models has been keyed to mapping units, to analyze sources of variability at the watershed scale.

The relationship between soil erosion and productivity remains poorly researched and little understood for tropical soils. CIAT and the University of Hohenheim are collaborating in a project funded by the German Government to understand the mechanisms of soil erosion at two Andean hillside sites in Colombia, seeking principles with wider application. Management practices which improve soil conservation are also being investigated, principally live barriers and cover crops.

A survey of soil macrofauna as potential indicators of degradation, patterned after the CIAT work in the Colombian savannas, is being carried out in collaboration with the Université de Paris, ORSTOM and the Universidad Complutense Madrid. It is comparing biodiversity across ten contrasting land use types during the wet and dry seasons in the Río Ovejas watershed. Other "early warning" indicators being examined include soil acidification, and in the near future, ratios of total carbon to macro- and microbiological carbon.

Decision support systems for land use planning and technology design

Purpose: To process information from strategic research in the form of decision-support systems that can be continuously updated to assist in obtaining objective information about tradeoffs resulting from changing practices, which in turn will aid in the formulation of plans for more sustainable agricultural land usage and protection of ecologically fragile areas.

As explained in the Paradigms and Perspectives section, decision-support systems will become an increasingly important technology for negotiating alternative land-use scenarios. A prototype decision-support system for land use planning in the hillsides must help both plot-level stakeholders (farmers) and communities to reach an accord on preferred options among a number of alternatives. However, available models (eg. expert systems; GIS-linked simulation models) do not yet transfer effects across different scales, nor are their suitable bioeconomic models calibrated for hillside farming conditions. A decision support system is needed which can inform about how technology choices at the farm level (ie. farmer decision-making) affect resource degradation at the watershed scale.

An innovative bioeconomic model is being tested in collaboration with the University of Florida linking household economic circumstances and farmer decision-making with process-level crop models. The objective is to predict the effect of management decisions on degradative processes at the watershed level, such as water run-off and nitrate leaching, as well as farm family wealth resulting from simulated cropping alternatives. This research will provide analytical tools for at least two end-user groups. One is the stakeholder-based community planning organization, such as CIPASLA (described in a box in the Consultations section). A second group may be credit delivery institutions wishing to assess the payback potential of innovative cropping enterprises.

Prototype systems for ecologically sound production in the hillsides

This project aims to develop agro-silvo-pastoral systems which improve soil quality, water management, and the efficiency and productivity of labor. Priority needs are for systems which improve crop productivity and forage availability, enhance erosion control and soil physical rooting conditions, and increase water infiltration, water-holding capacity, and nutrient retention by the soil.

This project will examine existing systems as well as innovative ones proposed by farmers, national institutions and/or CIAT's scientists. Research will look at opportunities for combining diverse yet complementary species in sustainable prototype systems, including short-cycle, shallow-rooted monocrops, deep rooted perennials, and agro-silvo-pastoral systems. Some of the options currently being considered include perennial and annual forages for their potential as feed for dairy cattle, cereals such as millet to be used as poultry feed for egg production, perennial barriers such as citronella with potential for industrial use, and vetiver grass, which has no direct crop value but performs excellently as an erosion barrier.

These system trials were established at two sites with varying conditions and with three replications in each site in fall 1994. Participatory technology evaluation by farmers, and the establishment of participatory system trials designed by farmers will complement the agronomic research, to provide information on farmers' objectives in system design, and criteria for acceptability.

Closely integrated with this research is economic analysis of market opportunities related to technology design. Field data collection has already been initiated. The economics research will help biophysical scientists narrow down options for inclusion in prototype systems.

Area-based research

The strategic research projects above are being implemented and validated through two area-based, special-funded initiatives, one in Colombia for the Andean hillsides and the other in Central America (Honduras and Nicaragua), described below.

Improving agricultural sustainability and livelihoods in the Central American hillsides

Deforestation in Central America is continuing-particularly in the poorest countries of the region, Guatemala, Honduras and Nicaragua. By the mid-1960's, the forests covered just 60% of their original area, and now this has fallen to 30%; in the 1970's alone, 15% of the forested area disappeared. Our inter-institutional hillside project is addressing this crisis.

Funding has now been approved from the Swiss Development Cooperation for the first two-year phase of the inter-institutional CAHP (Central American Hillsides Project), based in Honduras and Nicaragua. This project will help develop more productive and sustainable land use systems through research on system components and their interactions, development of policy guidelines, and dissemination of research results. The first official meeting of the steering committee was held in May, 1994 with representatives from CIAT, CIMMYT, IPGRI, and regional and national partner institutions. Research priorities were set, namely:

1. to understand the effects of hillside conservation practices and rotational systems of land use on soil degradation and regeneration (via long-term experimentation);
2. the analysis of factors related to successful or unsuccessful adoption of conservation practices; and
3. economic valuation of individual and social costs and benefits of conservation practices for steep-slope farming.

Additional outputs of the steering committee meeting included approval of a six-month workplan, and guidelines for cooperation with national and local institutions.

Improving agricultural sustainability and livelihoods in the Andean hillsides

This is the second of the two area-based hillsides collaborative projects with national and local institutions, in this case supported by IDRC (Canada), the Colombian Government and the W. K. Kellogg Foundation (the latter for the participatory research aspect). It builds on historical CIAT-Colombian collaboration inthe Río Ovejas watershed of the Cauca Valley.

In recognition of the need to catalyze a community-based, participatory research agenda, the interinstitutional consortium CIPASLA was formed (see box in Results and Achievements section). Planning workshops of CIPASLA identified the following top priorities:

1. studies of alternative production systems, including conservation practices, both indigenous and "exotic";
2. ways to increase the role of livestock in existing production systems; and
3. the monetary value of soil conservation and reforestation, and the distribution of benefits among different groups.

Low priority was given to research on component technology development, on studies of farmers' attitudes and on regional analysis of existing land use patterns.

The consortium has begun inter-institutional testing of participatory approaches to soil conservation. Farmer-participatory evaluation of forage legume nurseries has also been initiated.

FOREST MARGINS

Following the budget crisis, plans for the forest margins (Fig. 6) had to be radically scaled back beginning 1994. Most of the remaining work falls under the Global Slash-and-Burn project, funded by the GEF. The IDB is helping strengthen this work through supplemental funding of the characterization effort.

Global Slash and Burn Project

The main objective of the slash and burn project is to develop alternative sustainable systems which can stabilize farmers on existing cleared lands, thereby relieving pressure for further deforestation.

Activities planned to meet this objective include:

- analyses of land use patterns over time and space;
- developing an understanding of the causal factors in deforestation through policy analyses and studies of farm decision-making processes;
- biophysical research to identify and evaluate alternatives to slash and burn;
- research on social and economic potentials for adoption of such alternatives; and
- collaboration with partners and farmer-participatory research to ensure technology adaptation and adoption.

Diagnosis of agricultural land use in the Brazilian forest margins

This IDB-sponsored effort, begun in 1994, follows on initial characterizations carried out during the Strategic Planning process, and reinforces the characterization work of the Slash and Burn project. Activities include: (a) collection and synthesis of secondary data, (b) interviews of colonist-farmers and cattle ranchers, (c) GIS analysis of land use patterns over time, (d) field sampling and analysis of changing plant communities relative to different land uses and intensities of land uses, and (e) analysis and synthesis of results.

VI. Results and Achievements

In general terms, the outputs expected from CIAT through mult-institutional collaboration in RMR are described in Table 1, according to the levels of scale under analysis.

Table 1. Hierarchical levels of analysis undertaken in Resource Management Research, and expected outputs.

Hierarchical level		Types of outputs
Cropping system	*	Resource-friendly prototype technologies
	*	Mechanistic models
	*	Research methods
Farming system	*	Characterized & classified systems
	*	Productive, viable, resource friendly prototypes
	*	Empirical bioeconomic models
Watershed	*	Georeferenced models of land use
	*	Estimates of externalities for alternative land use scenarios
	*	Databases linked to decision-support systems
	*	Institutional models for community-based R&D
Regional land use	*	Models of causal relationships
	*	Land use planning tools
	*	Policy effects on technology adoption
	*	Policy implications of new technologies

During the start-up phase of the RMR initiative, considerable investment of time and resources had to go into priority-setting processes, particularly the identification of areas, and sites within areas for research focus (Figs. 3, 7), building of technical capacity, and establishing links with other institutions (the latter is discussed in the Consultations section). Once these areas and consortia were established, work proceeded within each to identify hypotheses about land degradation, and more sustainable systems. The results of those efforts, emphasizing outputs generated, are presented here.

LAND MANAGEMENT

Strengthening GIS capability at CIAT

A GIS Specialist was recruited in the second half of 1992 to build up the GIS area, and new software and hardware purchased and installed. During 1993 support staff were trained in basic GIS techniques including high quality data entry using conventional digitizing tablets and modern map scanning techniques, data base management, and the programming of the new GIS software using its macro language. The new facility is based upon the latest server and workstation technology with excellent networking facilities. This ARC/INFO system, run under UNIX on a SUN-based workstation, is far more powerful than the previous system (IDRISI software on AS400 hardware). Databases are being compiled using ORACLE software.

Stochastic rainfall models

Over the last 16 years CIAT has built what is perhaps the world's best climate database for the tropics. It is widely used by CIAT and distributed to other CGIAR centres and to other institutions throughout the world. Data from some 18,000 stations are now held in the files.

In order to utilize these data for risk analysis a robust system of stochastic simulation of daily rainfall is necessary. Markov rainfall models were chosen. The first publication from this research (Jones and Thornton,1993) describes the testing of the third order Markov model with resampling of parameters. It shows that for tropical situations the third order model outperforms other more simple applications and that the resampling of parameters accurately simulates the year to year variance which other models fail to account for. This model has recently been employed in Burkina Faso by IFDC in a project associated with the Famine Early Warning System of FAO (FEWS).

Work has proceeded with the generalization of the model with an aim to provide interpolated mapping of the model parameters to interface with GIS linked models of cropping risk. It was conclusively proved that the order of the model required is closely associated with the climate system. This resolves a controversy of many years standing between researchers in temperate countries and the tropics. It is postulated that the frontal weather systems of the temperate regions decouple the longer lag periods of the model necessary for tropical simulation. Additional data received will allow the development of an interpolation routine which can be generalized for the broadscale use of the model.

Locating an area in Brazil for intensive savannas research

A classification study of the tropical savannas of Brazil to determine appropriate study areas for joint research with EMBRAPA and local agencies was completed in 1992. It is described in detail in the CIAT document *"Area Classification and Mapping for the Cerrados Region of Brazil"*. Data from the climate database and the land system study were used to provide images of climate, soils and terrain for the region. One indication of the quality of the study is that the digital elevation model has been requested by the National Geophysical Data Centre (NGCD), Boulder, Colorado, because it is now the most advanced dataset available for this region. These biophysical maps were complimented by data from the Brazilian agricultural censuses from 1970, 1975 and

1980. Some 38 total images, that is, maps of key climatic, soils, topographical, farming systems, and socioeconomic data, were integrated using principal-component analysis to produce 18 distinct factor images. A two-stage cluster analysis was used to reduce this to 11 distinctive agro-ecological classes demarcated by biophysical and land use patterns. These were used to characterize 12 potential study areas of 60 km radius each (about the size of one LANDSAT image) which represent key diversity clusters across the Brazilian tropical savanna. The resulting GIS map is reproduced in Fig. 7.

The study was a critical resource used in a major Workshop held in Brasilia in 1992 to select candidates for the final study area. This Workshop was described earlier, in the Consultations section of this document. The final outcome was the selection of the area around Uberlândia for area-based research, because it has access to most of the savanna diversity clusters within a 60-kilometer radius.

Characterizing an area in Colombia for intensive savannas research

The savanna area of Altillanura between Puerto Lopez and Puerto Gaitan in the Department of Meta in eastern Colombia had earlier been selected for in-depth study by CIAT, based on long-standing collaboration there with Colombian institutions. To assist this work we are developing a detailed GIS coverage of the region. Soil maps at a scale of 1:100,000 have been digitized and a simple user interface has been developed.

Work is proceeding to produce a digital elevation model of the area with sufficient precision to be useful for running erosion models. Correct elevation models now exist for a representative sample of map sheets from the region. A complete DEM (Digital Elevation Model) is expected in the near future. These can now be overlaid with the access, rivers, soils and land use data. Satellite images of land use will shortly be available for combining with the digital images.

Negotiations have been initiated with the Colombian Ministry of Agriculture and now with DANE, the national agency for census and statistics, to collaborate in an ongoing monitoring of the actual land use of the region. CIAT will use data to prepare a sampling framework for the monitoring of the area using remote sensing and sampled ground truthing.

Locating an area in Central America for intensive hillsides research

As part of the Strategic Planning and priority-setting processes, GIS techniques were applied to assist in the identification of specific, representative areas for agro-ecosystems research. The first to be identified was a hillsides area in Central America, based on a study of biophysical and socioeconomic data collected during 1989-90. This landmark study became a model for similar studies in other agroecosystems. The report is included in the proceedings of the 1991 Costa Rica Workshop (*Agricultura Sostenible en las Laderas Centroamericanas. Oportunidades de Colaboracion Interinstitucional, 1991*). Variables belonging to the physical environment, the use of the land, and socio-economic aspects were used. The information was digitized and processed through a Geographical Information System (GIS), using a grid of spatial cells. Multivariable analysis revealed rural impoverishment, demographic concentration, urbanization and urban impoverishment, and migration as the major factors explaining a large portion of the variance in the original 21 variables. Forty-two relatively homogeneous groups of cells were defined through cluster analysis. On the basis of correlation between descriptive variables at the regional scale, a number of dynamic processes such as concentration of resources and small farms, demographic concentration (eg., urbanization), migration, conversion of forests to pastures, isolation and colonization, and the intensification and expansion of plantations were inferred, all in their spatial context.

The study was presented to a major Workshop of the hillsides Consortium (described in the Consultations section of this document) held at CATIE headquarters in Costa Rica in August 1991, to launch an inter-institutional hillsides project. The Workshop recommended that a focal group follow up and identify potential areas for a research base. Seven watersheds were identified and visited based on the land use study described here. Complemented by information collected at the sites, the focal group proposed three different locations. After a two-month field study period, a site was finally selected in the Atlantic littoral portion of Honduras. The site, situated in the department of Atlantida, close to the town of La Ceiba, is a frontier hillside zone which has been absorbing large numbers of immigrants from the drier western highlands in recent decades. This has resulted in severe deforestation and degradation from overgrazing. If continued at the current rate, these practices will lead to the disappearance of one of the few significant areas of tropical forest remaining in Central America.

Later, based on consultations through the CAHP consortium, La Ceiba was complemented by three additional sites in accordance with the area-based research concept, located in Honduras and Nicaragua. The set of four sites now covers a wider range of variability in precipitation, a major factor in Central America.

Resource degradation evaluation and regional characterization of catchment areas in the hillsides of Central America and the Andes

Across the approximately 92,000,000 hectares classified as hillsides and mapped in this study, water erosion was by far the most important degradative symptom observed. Very small areas of wind erosion and chemical deterioration were also noted. Altogether, some 26 percent of the total area was subject to serious water erosion, to a degree classified as "moderate" in 14,000,000 hectares, and "severe" for 11,600,000 hectares. The main causes were deforestation, overgrazing and agricultural activity, contributing in roughly equal proportions.

Locating areas in Brazil for intensive forest margins research

Large-scale characterization of parts of the Brazilian Amazon including Acre, Rondonia, Maranhao and Para were carried out in 1991-92, as summarized in *Characterization of forest margin areas in Latin America for CIAT, D. M. Robison, January 1992*. Additionally, CIAT contracted a land use study based on secondary data sources from a respected Brazilian NGO, the Instituto Sociedade, População e Natureza (ISPN), also published (Mueller et. al. 1992). These studies tentatively identified four areas for further investigation, representing four main dynamics for colonization in the Brazilian Amazon: spontaneous, government-sponsored, private, and large company concessions.

As mentioned in the Consultations section, a major inter-institutional Mission was carried out in February of 1992 to choose among these four areas for an inter-institutional forest margins research effort. In preparation for this meeting, CIAT had applied GIS techniques to develop a digitized mapping of Acre-Rondonia including soil, geology and vegetation characteristics. As a result of the Mission and depending heavily on the CIAT-led analyses, the Acre/Rondonia (government-sponsored colonization) and Para (private) areas were chosen.

Acre/Rondonia, or AcRon is so named because it is located in the strip linking the states of Acre and Rondonia (and being claimed by both states). Further characterization work ensued, as described in CIAT manuscripts entitled *Research Site Selection in Acre and Rondonia States of the Amazon Region in Brazil, Conducted from 31 August-15 September 1992;* and *Biophysical and Agroecological Characteristics of Two Areas in Acre and Rondonia, Land Use Program, August 1992.* One of the main advantages of the AcRon area is the variability in forms of land use, facilitating comparisons of land use decisions and their causes, such as the differing interests of colonists, extractors, ranchers, and others. Taking advantage of the CIAT-led characterization work, the Global Slash and Burn Consortium (which includes CIAT) later selected Acre-Rondonia for research focus.

In the case of Para the choice was among areas in Maraba, Paragominas and Santarem. The characterization of these areas is reported in a CIAT manuscript entitled *Site selection in Pará. Comparison of Marabá, Paragominas and Santarem, 1993.* Given the unforseen budget crisis of CIAT, however a decision was made in late 1993 to suspend plans for work there.

Visualizing deforestation and land use by settlers in Brazil's forest margins

A satellite image from 1991including Pedro Peixoto covering 357,000 hectares indicates that 19% of the total area is deforested, including 20-29% of private lands (292,000 hectares) and 10% of the remaining 64,000 hectares. Additional analysis is attempting to analyze deforestation as a functions of time and distance from roads.

A digitalization of cadastral data for sites in Acre and Rondonia has been overlaid onto sattelite images (Fig. 8 and 9), outlining the parcellation of land to different owners. This is a powerful tool for large-scale analyses of land use. Data for soils, rivers, topography and vegetation has also been compiled. In the Theobroma area, results indicate that about 1400 parcels (114,000 hectares) are on more favorable Ultisol soils, 2200 (124,000 hectares) are on medium-quality Oxisols and Alfisols, and 250 parcels (14,000 hectares) are on poor quality Distropepts. The distribution is similar in Pedro Peixoto. This information enables a follow-up study to see if differences in soil quality engender different forms and sustainabilities of land use.

Latin America's protected areas

We compiled a GIS database of these areas, and published it in the CIAT working document *'Legally protected areas of Latin America'* (Robison et. al. 1993). It includes an environmental classification of the protected areas. This inventory is a valuable resource for identifying conservation efforts and needs on a continental scale. The database highlights the startling fact that the tropical Amazonian rainforest is by no means the only ecosystem at risk. Montane rainforests, dry tropical forests and highlands are much smaller to begin with, and these as well as the tropical savannas have proportionately smaller areas still left undisturbed. These areas also appear to be disappearing more rapidly than the Amazon forest. Very little of these areas are legally protected, perhaps because their value is less widely recognized. They are in urgent in need of conservation.

Maintenance and updating of this database will continue in the future. The recent digitization by CIAT of the vegetation map of South America will allow further characterization of protected areas by vegetation type.

World trade in plant nutrients

World trade figures for all agricultural and forestry products were taken from FAO publications and data tapes. Tonnages of product were converted into elemental equivalents of N, P, and K and mapped. Fertilizer trade figures were obtained from IFDC and were mapped for comparison. Preliminary observations show that the major sink for elements being exported is the developed world, particularly Europe. India clearly shows the benefit of the Green Revolution: in 1967 it was a net importer of plant nutrients in the form of food products, but by 1985 it had become a strong exporter. Many African nations are also strong exporters but that outward flow is not balanced by fertilizer imports. After further analysis of the maps, a publication will be forthcoming.

Land quality indicators

An international workshop on Land Quality Indicators (LQI) for the savannas and hillsides of tropical America was implemented jointly with the World Bank in June

1994, involving an interdisciplinary and interinstitutional team of CIAT, CIMMYT and GASE (an environmental NGO). LQI were discussed and proposed for the two agroecosystems. A summary document on Measurements and Indicators of Sustainability was produced. The need for defining agroecosystem-specific indicators was highlighted. The World Bank will publish a document integrating earlier proposals and the outputs of the Workshop. As a follow-up to the Workshop, proposals for activities supported by the Bank have been prepared, and are being discussed with the Bank.

SAVANNAS

Dynamics of savanna farming systems

Rapid rural appraisals led to the identification of a small number of farms in the Uberlândia area with sharply contrasting management, particularly in the use of inputs. These farms appear to represent the spectrum of change over time as the savanna has been settled and its usage intensified. There are large differences in agricultural productivity, soil quality and economic performance among the sampled farms. One of these farms, on very fragile, sandy soils, has records of inputs and outputs going back 10 years. During this time the farm was transformed from a traditional, extensive cattle ranch to a management-intensive agro-pastoral system with regular, planned rotation of crops with pastures. Preliminary analyses show that soybean yields increased when planted after pastures and that the older the pasture, the higher the soybean yield. Likewise, crops had a beneficial effect on pastures. About half the farm is now sown to crops each year, but the remaining half carries more cattle than the whole farm did before, because pastures planted after 3-4 years of crops are more productive. Soil parameters are being monitored at fixed sites. The data show that the size of soil aggregates declines under crops, but that they recover during the pasture phase of the rotation, as does soil organic matter content.

That this well-managed farm has steadily improved its productivity suggests that savanna farming need not be an inevitable downward spiral of degradation.

Biodiversity of the savannas

Benchmark studies characterizing the biodiversity of vegetation in the savannas will allow us to monitor future changes in plant community structure in response to changes in land use management practices. In a census of native savanna vegetation conducted in collaboration with the National University of Colombia, Palmira, 150 plant species (108 genera of 45 families) were identified. These were classified into the main vegetation groups in the well-drained, flat savannas using statistical clustering techniques, and were related to physiographic features of the land. Two keys were prepared for the identification of the main savanna grasses, one based on vegetative characters and another on floral characters.

RMR brings powerful tools to biodiversity conservation and utilization

The preservation and equitable use of biological diversity emerged as top global priorities from the UN's 1992 Earth Summit in Rio de Janeiro. The coexistence of expertise in GIS and in germplasm research at CIAT put it in a position to contribute importantly to this task. The melding of the longstanding crop commodity expertise of CIAT with the new tools of GIS is also helping to redirect our germplasm efforts down the path of RMR.

Mapping the environments of wild relatives of crop plants

We have transformed climate data to produce a probability density mapping of climates similar to past recorded collection sites of wild relatives of crops. Its first application was on the common bean, *Phaseolus vulgaris*, based on collection data from the 27,000 accessions held in CIAT's germplasm bank (Fig. 11). The maps show a number of areas not previously collected and therefore predict, *a priori* that these new areas have a high probability of yielding important new genetic diversity for collection and conservation, and/or for *in situ* preservation by national governments. This will be verified by ground surveys in the future. A similar analysis is underway for cassava.

Creating a "core collection" of common bean

A representative sampling within common bean's genetic diversity was needed to reduce the costs and increase the efficiency of screening for valuable new traits. Using the CIAT climate database and the digital version of the FAO 1:5,000,000 soils map, an environmental classification was developed based key parameters spanning the known range adaptation in this species. Using this database, and the known sites of collection of 27,000 accessions in the world collection, stratified samples of individuals originating from the whole range of climate-soils combinations were identified. These now constitute the core collection, a resource freely available to all bean researchers.

Latin America rice distribution

The distribution of the rice crop was mapped using data from national agricultural censuses, and checked by national research collaborators. It quantifies the areas grown to different management systems (upland, rainfed lowland, irrigated) in Latin America, to help guide priority-setting for research in the crop. This was overlaid with the environmental classification in CIAT databases, and a breakdown of the rice growing environments of the continent was assembled.

Asian cassava distribution

The spatial distribution of cassava cultivation across Asia has now been produced, completing the global set. When climatic and soils data are added, the distribution map will be used to compile an inventory of cassava growing environments. A subset of the FAO soils map and the NOAA digital elevation model will be made for the area, and the climate data interpolated using algorithms developed by CIAT.

In a comparison of flat vs. the undulating 'Serranía' lands of the Colombian savannas, studies of species composition as affected by degradation and burning have shown that there are important botanical, compositional and production differences in the native savanna related to different burning regimes in these different topographies.

Studies of soil fauna indicate that a 10-fold increase in worm biomass found under grass-legume pastures did not come at the expense of biodiversity - the same number of earthworm species were present as in native savanna. Ten to fifteen different species (exact number pending final taxonomic identification) were present under both conditions. Compared with the gallery forests, the grasslands of the savannas had lower diversity and numbers of earthworms.

Strategic agricultural production system research

Studies are confirming earlier indications that continuous annual cropping in the savannas is not sustainable. At Matazul Farm from 1989 to 1992 there was a linear decline in rice yield of nearly 400 kg/ha/yr (r^2=0.96), from 3.8 to 2.6 t/ha, despite fertilizer inputs being adjusted yearly to maintain appropriate nutrient levels and balances. There has also been a significant decrease in soil aggregate stability despite minimum tillage practices. Since nutrient deficiencies are being corrected by the application of fertilizer, we suspect that yield losses may be more related to the buildup of weeds and perhaps to deteriorating soil physical properties. In 1993, the experiment was modified to test whether better management of these factors could counteract the declining yields. There was an improvement of about 800 kg/ha, but not to the original levels. Starting in 1994, herbicides have been added to the management regime to try to increase yields further, while still maintaining the soil nutrient balance. This work will continue for several more years.

In contrast, work on more diverse systems is producing some important findings with large potential impact, especially in three areas:

1. The sustainability dimensions of improved tropical pastures
Results continue to indicate strongly that improvements in the predominant agricultural use of the savannas, namely as pastures for livestock, can simultaneously increase both production and sustainability of the resource base.
Research predating the RMR initiative, aimed at finding means of regenerating degraded pastures (which cover an estimated 50% of the area sown to introduced pasture grasses, or 17-39 million hectares in Brazil alone), had shown that animal productivity could be doubled by a regeneration process including tillage, modest fertilization, reseeding with introduced grasses (such as *Brachiaria*, *Andropogon* or other adapted genera), proper stocking rates, and the provision of supplemental minerals to animals. Another doubling could be obtained by the inclusion of legumes in pastures during the regeneration process. Persistence (survival) of legumes in grass-legume mixtures continues to be a problem, however.

Through CIAT's crop research, a more persistent legume has recently been identified, *Arachis pintoi*. The RMR initiative has shown that *A. pintoi* can provide an additional

40 to 80 kg nitrogen per hectare per year in the Colombian savanna, replacing the need for nitrogen fertilizer. An interesting feature of this legume is that it was discovered in the Brazilian savanna, providing an eloquent testimony to the value of preserving native species in this ecosystem for uses yet to be discovered.

Soil invertebrate fauna (ants, termites, earthworms, beetles, spiders etc.) play an important role in improving soil structure, in moving organic matter down the soil profile, and in recycling organic matter. Earthworms are the highest-biomass component of soil fauna. A student from the University of Paris conducted a preliminary survey of earthworm populations under native savanna vegetation (including gallery forest), improved pasture and several crops in Colombia. A highly significant finding was that the grass-legume pasture treatment increased earthworm biomass tenfold relative to the native savanna, to 51.1 grams fresh weight per square meter surface area (50 cm deep). In contrast, row cropping (rice and cassava were observed) almost eliminated macro-fauna. Extrapolated to a per-hectare basis, the earthworm biomass found in grass-legume pastures is roughly the same biomass as that of the cattle grazing above the ground, at the recommended stocking rate of two head per hectare. The "below-ground grazers" may have even more significant effects on system sustainability than cattle. The grass-legume pasture contained 20 times more turricules than native savanna. Turricles are the soil-loosening, tower-like casts deposited over the soil surface by earthworms of the genus *Martiodrilus*. Measurements of soil ingestion rates estimated that this genus could be processing around 800 tons of soil per year on a dry weight basis.

2. Enhanced sequestration of atmospheric carbon by tropical pastures
A major new finding emerging from strategic studies of improved pasture systems is that they could be acting as an important sink for global carbon dioxide, a pollutant which contributes to global warming (see box).

Tropical Pastures May Help Counter Global Warming

A major discovery receiving worldwide attention (Fig. 12) arose during 1994 through the analysis of soil organic matter data from collaborative CIAT/CORPOICA trials in the savannas of Colombia. It was recently published in the journal Nature (Fisher et. al., 1994). The roots of introduced pasture grasses, which now replace native savanna vegetation on at least 35 million hectares, were observed to significantly increase soil organic matter and hence, carbon storage relative to the native cover. In other words, these improved pastures appear to be acting as a previously unrecognized net sink for carbon, which can help counter the buildup of atmospheric carbon dioxide, which is a major contributor to global warming via the greenhouse effect.

At a farm near Matazul in the Colombian savanna, a three-year-old grass-legume *(Andropogon gayanus/Stylosanthes capitata)* pasture, sown with a rice nurse crop in 1989 and grazed for three years at 2 animals per hectare, contained 237 tons of carbon per hectare in the top 100 centimeters of soil, as compared to 186 tons in native savanna. The difference of 50 tons of carbon per hectare appears to be a net gain in storage due to the adoption of this improved pasture system. While we do not yet know if the rate of accumulation is increasing, stable or decreasing, a simple average annual value (dividing by 3.5) of 14 tons of extra carbon is indicated.

In the same set of trials at Matazul, a grass-only pasture of *Brachiaria dictyoneura* had 20 more tons of carbon per hectare after three years than native savanna, and when a legume was included, this rose to 28 tons, for annualized values of 7 and 9 tons per hectare, per year more than native savanna.

Confirmation of these findings was sought at another location 200 kilometers away, in nine-year old pastures at Carimagua, Colombia. A grass-only pasture of *Brachiaria humidicola* sown in 1984 and grazed at 3 animals per hectare for five years had 26 tons of carbon per hectare more than native savanna in the top 80 cm of soil. In neighboring plots where the same grass pasture was oversown with the legume *Arachis pintoi* in 1987 and then grazed at the same stocking rate, 70 more tons of carbon per hectare than native savanna were measured. Again, a simple division by 9 would indicate additions of 3 and 8 extra tons of carbon per year, relative to native savanna.

Extrapolating these figures to a global scale provides stunning results. If these data are at all indicative of what is happening in the 35 to 78 million hectares of introduced pasture (mostly *Brachiaria decumbens*) in the savannas of Brazil, then the 3 to 14 extra tons of carbon per hectare extrapolate to 100 to 500 million tons of extra carbon total over the whole area (using the conservative estimate of 35 million hectares), being fixed annually over what was previously thought for the tropical savanna. This could account for a significant part of the so-called missing global sink for carbon.

As a point of reference, a large automobile produces one ton of carbon in about 8,500 miles of motoring, so these improved pastures could be sequestering each year the carbon produced in that year by more than 215 million large cars, assuming an annual usage of 20,000 miles. As another comparison, a mature tropical forest contains about 130 tons of carbon per hectare, so the amount sequestered each year by improved pastures could be equivalent to the carbon lost when 3.9 million hectares of rainforest are cut down.

In monetary terms, Pedro Sanchez of ICRAF has estimated the value of removing a ton of carbon from the atmosphere as ranging from US$20 to $220 per ton. Using a rough figure of $100, the 100 to 500 million ton storage estimated above leads to a possible benefits range worth $10 to $50 billion each year. This is 3-15 times more than the total value of beef harvested from the savannas every year.

It may be hard to imagine that 50% more carbon is stored beneath a tropical grass pasture (roughly 200 tons/hectare) than in the above-ground vegetation of a typical rain forest (about 130 tons/hectare). The explanation, apparently lies the slow rate of oxidation of below-ground carbon. It accumulates over long periods of time, whereas above-ground vegetation is quickly oxidized. Results from temperate climates indicate mean ages of below-ground carbon in the neighborhood of 5,000 years. Under warmer, tropical conditions breakdown could be expected to be much more rapid, but we have no data to confirm this. Collaborators at the Australian National University, Canberra are currently dating carbon from our soil samples to answer this question. Since most of the sequestration was below the plough layer (top 15 cm), it is likely to be long-lasting since it is not exposed to the extra weathering and microbial oxidation processes that occur when tilled. Cropping these soils between pasture cycles would therefore not be expected to greatly reduce their carbon sequestration characteristics.

Why are introduced grasses fixing so much more carbon than native savanna vegetation? Apparently, the very low inherent soil fertility of the savannas made it unnecessary for native vegetation to evolve a capacity to respond to richer nutrient supplies. Introduced grasses carry the responsiveness trait; this was probably a major reason agriculturalists selected them in the first place. We are now attempting to measure these productivity differences more precisely, but related observations suggest that the "net primary productivity" of the introduced grasses may be some 40-60 fold greater than that of savanna vegetation. Above ground, it may be difficult to observe this rate difference by eye because gains in production are balanced by increased rates of senescence, but below ground the breakdown processes are apparently much slower, resulting in net accumulation of carbon.

This discovery shows that improved agricultural technologies not only have the potential to increase agricultural productivity and sustainability, but to contribute positive effects to the global environment as well. We are currently seeking additional funding to be able to explore the ramifications of this major discovery in more depth (see New Project Initiatives section).

2. Improved agro-pastoral systems

In improved agro-pastoral systems, upland rice or other grain crops are seeded at the same time as the improved pasture seed, within the same rows. The grain crop is harvested after about four months, bringing the farmer quick cash income to pay for the costs of the improved pasture seed, and acting as a "nurse crop" to enhance and speed up the establishment of the pastures. Part of this beneficial effect is due to the use by pasture grasses of the residual fertilizer left by the crop. The end result is that cattle can be put onto the pasture shortly after the rice is harvested, starting the livestock cash flow after just a few months instead of after a year. By overcoming farmers' economic bottlenecks, we expect agro-pastoral systems to greatly stimulate the regeneration of degraded pastures. In Colombia, different variations of this crop-pasture paradigm have been under investigation by CIAT and national institutions for a number of years, with encouraging results which have received worldwide notice (Figs. 4 and 13).

There is evidence of rapidly increasing adoption. In Brazil, CNPAF/EMBRAPA estimates that there were more than 50,000 hectares grown under improved rice-pasture in 1993. They expect 100,000 hectares in 1994, and more than one half million hectares within five years. In Meta, Colombia, a representative set of savanna farms is being tracked to observe farmer responses. At present only 17% of the area of the sample farms is planted to improved pasture species, and only 18% of that area includes legumes. Despite the novelty of the concept of pasture regeneration, and security difficulties constraining agricultural development there, about 4,500 hectares are now planted to the upland rice-pasture version of the agro-pastoral prototype, a remarkable degree of adoption considering that the system was just introduced in 1991. At present there are fewer farmers in the savannas of the other countries, but Venezuela is expecting to have 25,000 hectares under the system within five years.

We are studying the adoption process in Colombia to learn farmer reactions to the system and how it might be enhanced further. As expected, farmers are experimenting with different variants, and the survey noted some major differences between farmers' practices and those recommended by the extension service. The area being sown to improved pasture is positively associated with highly capitalized farms, with secure tenure and proximity to markets, but absentee ownership did not impede adoption.

CIAT's emphasis is on understanding principles which could lead to the successful introduction of legumes into the pasture sown under the crop, including studies of the competitive interactions among all three plant components: grass, legume and crop.

Agropastoral systems have the advantage that they encourage frequent (about every five years) regeneration, obviating the former requirement for persistence over a 10-20 year period, which ruled out many otherwise-promising legume candidates. *Stylosanthes*, for example has been found to be sufficiently persistent to last 5 years.

A second problem is that the fertilizer and management provided for the crop greatly increases the vigor and competitiveness of the grass at the expense of the legume.

However, trials in Brazil have identified certain legumes, particularly *Stylosanthes guianensis* cv. Mineirao and *Arachis*, which establish well with *Paspalum spp.* and *Brachiaria brizantha* under rice and maize.

Another factor to be considered is competition by crops against pastures, and vice-versa. Brazilian results show that vigorous regrowth of pasture grasses in a low input system severely reduces yields of intersown upland rice. In high input systems using maize, the fast-growing, tall grass *Panicum maximum* showed good compatibility; both maize yields (7 t/ha) and grass establishment were excellent, but here the legumes suffered badly from competition.

Microbial biomass

A study was carried out in Colombia to determine how the soil microbial biomass responds when native savanna was brought under continuous annual upland rice, versus rice-pasture systems. A greater proportion of soil microbes was active in pastures, especially with a legume component, than under continuous rice. This may be due to a greater and steadier input of organic matter to the soil from leaf litter under pasture. Although the amount of microbial biomass carbon per gram of soil did not vary much among treatments, the nitrogen content of the microbes and the contribution of microbial nitrogen to total soil organic nitrogen was much higher under pastures than in continuous rice. Estimating microbial turnover time at 0.5 to 1.5 years, nitrogen cycling through the microbial biomass is 44 to 166 kg ha^{-1} yr^{-1}. Values after five years of continuous rice were about half the value for pastures. This is undoubtedly one dimension contributing to the greater sustainability of rice-pasture as opposed to rice alone, and the principle likely applies to other annual crops as well.

Native populations of mycorhizzal fungi of the genera *Gigaspora, Scutellospora, Acaulospora* and *Glomus*, is low (12 spores/50 g) under native savanna vegetation in Brazil. After two years in the CPAC experiments, the improved pasture and cropping management systems have increased mycorrhizal population and activity. During pasture establishment in the first year spore numbers in the 0-20 cm soil depth of the pastures increased 25-fold compared to the native savanna, although it declined in the second year. Root colonization followed similar trends. Cropping with soybeans increased populations three-fold during the first year, and increased to levels similar to those found in improved pastures by the second year. The differences are probably associated with differences in root morphology and dynamics of mycorrhizal dependency.

Soil physical structure

In the CPAC experiments in Brazil, the effect of land preparation on soil physical properties and root growth was assessed by opening several root profiles in the maize, pasture and native savanna treatments. After three consecutive cropping seasons , results are showing that soil fertility management, rather than land preparation, is the major factor influencing root penetration to depth. Sub-soil acidity, relieved by application of gypsum, impeded root development of crops more than soil compaction.

Comparisons of surface compaction showed that mechanical resistance was higher in the top soil of pastures compared to crops or native savanna. However, absolute values are still not limiting root growth according to previous work conducted at CPAC. There were more *A. gayanus* pasture grass roots in the 0-65 cm layer than in either the savanna or the continuous cropping system treatments.

Water-holding capacity of the soil was measured in two long-term pasture experiments with different grass and legume species and different stocking rates. The soils under improved grass-alone pasture generally had a lower hydraulic conductivity (*K*) compared with native savanna at a specified value of volumetric water content or, stated differently, were wetter at a given value of the hydraulic conductivity. This implies that after a given amount of rain, soils under improved grass-alone pasture drain less well and hence are more susceptible to damage by animal trampling or tillage, than the native savanna. However, adding a legume to the pasture increased *K*, which should improve drainage. These differences appear to be due to differences in root systems among the different systems, and to differences in biomass and/or composition of soil fauna, especially earthworms.

Dynamics of phosphorus pools

In contrast to most temperate ecosystems, phosphorous (P) is one of the most limiting nutrients in plant production in the tropics, because the soils are low in P and have a strong P fixing capacity. Our work in the Colombian savannas showed that C/P ratios in plants are very much higher than the ranges presently assumed in the CENTURY model. Although the option exists in the model to modify these ranges, using it for conditions of such extremely low P availability stretches the model's use beyond the limits of reliability. Recent work in our group on P-fractionation in savanna soils indicated that the soil-P chemistry section of the model may need to be modified for the conditions of low-P soils. Given the wide adoption of the CENTURY soil organic matter model, developed to simulate the dynamics of C, N, P and S in temperate grassland soils, for use in tropical ecosystems, this calls for caution. Using data from above- and below-ground litter decomposition experiments in the savanna and from soil-P fractionation, the phosphorus chemistry section of the model is presently being analyzed and will be adapted where necessary.

Investigations are underway by a Swiss-financed postdoctoral fellow using long-term pasture experiments to compare P dynamics in improved pastures versus native savanna soils at Carimagua, and comparing improved pastures sown under rice versus continuous annual rice at Matazul, both in the Colombian savanna. Results show the importance of the microbial P pool in P cycling and availability, especially in grass-legume pastures, which appear more efficient than grass-only pastures, native savanna or rice monocultures at cycling P through labile P pools. Sequential P fractionation data such as these form the basis of the P sub-model in the CENTURY model. Preliminary evidence from these studies indicates that critical C:P ratios which determine the partitioning and rates of P fluxes to different soil P pools may require modification for tropical soils. This research is leading to the identification of much more sensitive indicators of soil quality than are currently available.

Nitrogen fixation and recycling

Field experiments indicate that fixation of atmospheric N consistently accounts for more than 80% of all legume nitrogen, even on varying soil types and with different rates of fertilizer applied at pasture establishment. Such findings, if widespread, suggest that an analysis of legume dry matter may be sufficient for estimating amounts of N fixed in pasture systems. This would greatly simplify efforts to quantify N fixation inputs into the N cycle.

The recycling of N via animal excreta is also being studied. Preliminary experiments with ^{15}N-labeled urine suggest a recovery of about 10% by herbage 9 weeks after application. Losses from the soil-plant system over the same period amount to some 30%.

An examination of the nitrogen (N) cycle in tropical pastures revealed that under relatively lax grazing the majority of N recycling occurs via plant litter rather than animal excreta. Therefore we are beginning to characterize and quantify litter production and decomposition in pastures, followed by decomposition of crop residues in crop-pasture systems. Large differences in rates of decomposition and nutrient release patterns were observed between six forage legumes and four grass species with some legumes decomposing at rates up to twice as fast as grasses. Others decomposed at similar rates to grasses but the release of nutrients was greater owing to a greater initial concentration of nutrients in legume litter compared with the grasses. The lignin:N ratio was the best compositional indicator of decomposition rate. Neither litter particle size nor ease of access of macrofauna had major effects on the rate of litter decomposition. There were no synergistic or inhibitory effects of mixing litters of different qualities, such as grass and legume. Decomposition data were successfully fitted to the CENTURY model. Currently the data are being tested in more recent versions of the model.

In the long-term "Culti-core" trial at Carimagua, litter production has been monitored in stocking rate, establishment fertility and soil type treatments. In general there was little effect of stocking rate on litter production on either soil type. Higher establishment fertility, however, increased litter production with increasing plant biomass. Litter production over the 3 years ranged from 1.1 to 5.2 kg of dry matter per hectare per year. Nutrient contents in the litter were low, especially after the disappearance of the legume component during the first two years of the experiment.

HILLSIDES

The major achievements to date are the successful establishment of two research consortia, one each for the Andean and Central American hillsides, and the initiation of their participative RMR agendas. The effective initial application of *ex-ante* impact and simulation models to evaluate resource management trade-offs facing hillside farmers and communities, is also noteworthy.

Within a five year horizon, this collaboration should generate strategies and a methodological tool kit containing the principles to successfully execute major bilateral-funded projects to improve hillside resource management across Latin America and the Caribbean.

This strategy and toolkit will consist of:

- regional land classifications using collaboratively-developed spatial data bases, to identify and select strategic watersheds for focus attention;
- improved methodologies for soil quality assessment, and indicators of sustainability to facilitate prioritization of endangered watersheds, extrapolation of results and targeting of soil conservation practices;
- bioeconomic models and methods for economic valuation of conservation technologies and *ex ante* impact assessment, to assist local and national agencies in prioritizing interventions to control natural resource degradation;
- a suite of analytical and heuristic models calibrated for tropical hillside conditions which can be used in interactive decision-support systems, tailored to users' requirements;
- methodologies and organizational principles for effective use of decision support and *ex ante* impact assessment models, widely disseminated among diverse client groups though training materials; and
- guidelines for combining component technologies (such as improved crop germplasm) into systems which lead in a progression to more sustainable ones.

Soil degradation and regeneration

A fundamental question is whether human pressure on the land has irreversibly changed, for better or for worse, the productive potential of the soil. Maximum yield trials using bean, maize and cassava as indicator crops, were seeded across six hillside land use types, ranging from 40 year-old secondary forest to intensively cropped cassava land. Early results indicate that different land uses have not resulted in irreversible soil degradation which cannot be overcome by fertilizers.

The study of soil chemical properties for soil quality inventory mapping showed spatial autocorrelation for many properties, notably carbon, acidity and micronutrients, across contrasting land use types. The results of this study are being used to define representative, diagnostic properties for different land use mapping units, and land-soil evaluation.

The survey of soil macro-fauna is finding the lowest biodiversity in the intensively cultivated bean-maize-cassava land use type. Results will be related to the maximum yield potential trials to validate macrofauna biodiversity as an indicator of soil degradation. Research on indigenous indicators used by farmers to assess soil degeneration showed that soil macrofauna, especially earthworms were widely used.

Decision support systems

The results for this project are highighted in the box article which follows.

Policy: Handling Complexity through Modelling

Government (and commercial sector) policies have a great deal of influence on how natural resources are managed. In its Strategic Plan, CIAT explicitly recognized the importance of policy, and committed itself to conduct analyses that increase the options available to decision-makers.

Technically, policy analyses pose special constraints. One cannot change a policy in order to observe its effect, as is done, say in fertilizer trials. Modeling appears to be a promising approach for dealing with this methodological difficulty. By developing an understanding of basic factors affecting the variables of interest, such as productivity, deforestation, soil loss, water runoff, biodiversity, etc. and the effects that different policy decisions would be expected to have on those factors, models can be constructed which are driven by hypothetical policy changes.

In the hillsides, decision-support models are also seen to have great potential in helping communities see the value of different management and policy trade-offs in negotiating win-win solutions with downstream parties affected by soil erosion, water supplies and other hillside resource degradation problems. As a first step in this process, three examples of *ex ante* impact analysis were carried out.

In the first example, a 35-year, regional simulation run estimated US$378 million in benefits from erosion control in the hillsides and US$282 million from improved fallow. Off-site beneficiaries obtained a significant portion of benefits from erosion control. The regional simulation showed that the greatest impact from improved fallow technology (legume/pasture and crop rotations) is in improved livestock productivity. The study has been accepted for publication (Pachico et. al., 1995).

The second study examines land use changes in a small catchment involving tradeoffs among options of forest, pasture, or annual crop systems, particularly the effect these tradeoffs might have on water supplies to downstream users. A simulation was carried out using actual climate and soils data from the Río Ovejas, Colombia site. Results show that values can be estimated for water yield in a transition from monocrop beans to sown pasture or forest. Results also show an overall reduction in water yield downstream when reforestation is simulated. This result is contrary to downstream stakeholder beliefs that obligatory reforestation of hillside watersheds will yield more water downstream. This finding illustrates the potential utility of simulation modelling to better inform decision-makers.

The third hillsides example evaluated a proposed small-scale irrigation project in the Colombian watershed from the perspective of conflicting uses for the water resource. The *ex-ante* impact analysis demonstrated that even small irrigation projects can invoke important trade-offs. For every 100 hectares of irrigation of a short-season crop during the dry season, the Río Cabuyal would lose 10% of its flow. The degree to which such trade-offs are acceptable would have to be judged through negotiations among the stakeholders, including those downstream who utilize the outflow.

Central American hillsides

In the La Ceiba, Honduras study area of our CAHP initiative, the dynamics driving hillside degradation have been analyzed and bear a remarkable similarity to the forest margins situation. Since the best, level farmland is already occupied, poor and landless immigrants, seeking relief from the oppressive poverty of their communities of origin, move into the hillside forests and clear them for agriculture, dominated by maize-bean culture. With slopes exceeding 30%, however the clean cutivation required for beans in the first rainy season is causing heavy soil erosion. Over time, the land increases in value as population centers expand, and financial need eventually compels smallholders to sell their land to cattle ranchers looking for more grazing land. The smallholders then move further upwards into the watershed, clearing new areas in a cycle that may only end when there is no forest left, as in Haiti.

Agroforestry and forestry culture would be the ideal types of sustainable systems for farmers on these slopes, and several NGO's are promoting these alternatives. However, adoption has been limited due to the considerable up-front investment and the long establishment cycle required for tree crops, and the uncertainty of predicting, years in advance the market prospects for their harvested products. As a result, most farmers continue to annual-crop maize and beans. The lesson for researchers is that it will be necessary to devise a transitional process of increasing sustainability that will ultimately result in agroforestry, a process that would need to generate income and food along the way. If technologies were available to elevate yields and reduce the risk of annual cropping, farmers would feel more secure about reducing the area planted to these crops, and investing labor and land in agroforestry systems.

In devising such a process, we are learning from indigenous knowlege through participatory approaches. Our surveys have observed that farmers have developed innovations to help reduce erosion and increase soil fertility, most notably the use of a leguminous, viny green manure crop (*Mucuna deeringianum*) in "second-season" maize production. The second season is warmer and drier, but farmers make the effort to utilize it because market prices are higher at that time than in the first rainy season. Farmers are also using mulch under beans in that season, to conserve soil moisture.

Most beans, however are sown in the first rainy season and on the highest, steepest slopes because this time and place tend to be cooler, minimizing both diseases (particularly web blight, *Thanatephorus cucumeris*) and heat injury. Given the higher market prices, farmers would be willing to increase the more sustainable second-season bean system if disease and heat tolerant varieties were available, while reducing the erosive first-season bean crop. Farmer-participatory and inter-institutional efforts involving CIAT are now underway to identify such varieties.

Andean hillsides

A major achievement has been the formation and launching of the interinstitutional consortium CIPASLA (see box in Consultations section). The research agenda is just beginning. CIPASLA has started testing participatory approaches to soil conservation, and results so far are promising. A five-fold increase in the adoption of soil conservation barriers was observed in the pilot micro-catchment area in Río Ovejas due to farmer participation in the adaptive research process.

FOREST MARGINS

Characterization work prior to 1994 was part of the Strategic Planning process and the onset of the Global Slash and Burn project, mainly to identify areas for intensive research focus, which resulted in the choice of Acre-Rondonia, Brazil. Those results, and the continuing analyses of satellite imagery were outlined earlier in this section, under Land Management. Much of the characterization work is also outlined in the Focus Agro-Ecosystems section. Current socio-economic characterization results are described below.

In its institutional capacity as the Latin American coordinator of Slash and Burn, CIAT was instrumental in acquiring the additional active participation of IFPRI, even though the initial stage of the Slash and Burn Project had not contemplated its participation. IFPRI will contribute to socioeconomic work in Acron, greatly strengthen the policy research capabilities of the consortium.

Diagnosis of agricultural land use in the Brazilian forest margins

·In 1994, the forest margins effort was considerably strengthened with the addition of an anthropologist and agronomist, and substantial additional funding from IDB. The team embarked upon more detailed characterizations of the two AcRon sites, Pedro Peixoto and Theobroma, to help form hypotheses about principles driving current land use practices, and the identification of more sustainable ones. The socio-economic factors largely driving deforestation were described in the Focus Agro-Ecosystems section, and the main elements are schematically presented in Fig. 16.

In August/September 1994, a major field characterization survey was conducted, together with IFPRI, ICRAF, EMBRAPA-Acre, EMBRAPA-Rondonia and PESACRE, involving about 80 farmer interviews. Some main results are as follows.

Settlers come from either the north of Brazil and have little experience of agriculture, or from the south and are better educated and have more experience. Most have moved at least once since they arrived in the region. Farmers organizations exist but are poorly supported.

Mean sizes of settlers' parcels were 88 hectares in Pedro Peixoto and 76 hectares in Theobroma. For Pedro Peixoto, 69% of their holdings was still forested, as compared to 54% in Theobroma. Settlers cleared an additional average of one hectare of primary forest per year at both sites. Pasture accounted for 20 and 26% of parcel area, respectively for the two sites, with the rest in crops and fallows.

Most settlers reported the purpose of burning the slashed vegetation as to make room for crops. Only a few reported ash improved soil fertility, or decreased the incidence of weeds and other pests. This result highlights a difference between these comparatively recent settlers, and traditional slash and burn agriculturalists in other parts of the world who universally perceive burning in terms of nutrient management and pest control. Farming continued for an average of two years after clearing, then discontinuing cultivation due to lower productivity and a buildup of weeds, insects and diseases.

Rice is the most important crop in these areas both for home consumption and sales of surpluses; sales average 2.6 tons per farm per year. Upland rice is the most common crop to be planted after clearing primary forest (92% of farmers in Pedro Peixoto and 70% in Theobroma). Yields are low, around 1.5 tons/hectare. Maize, cassava (in Pedro Peixoto) and pasture are common in the second year. There is little or no mechanization or use of chemical fertilizers and lime.

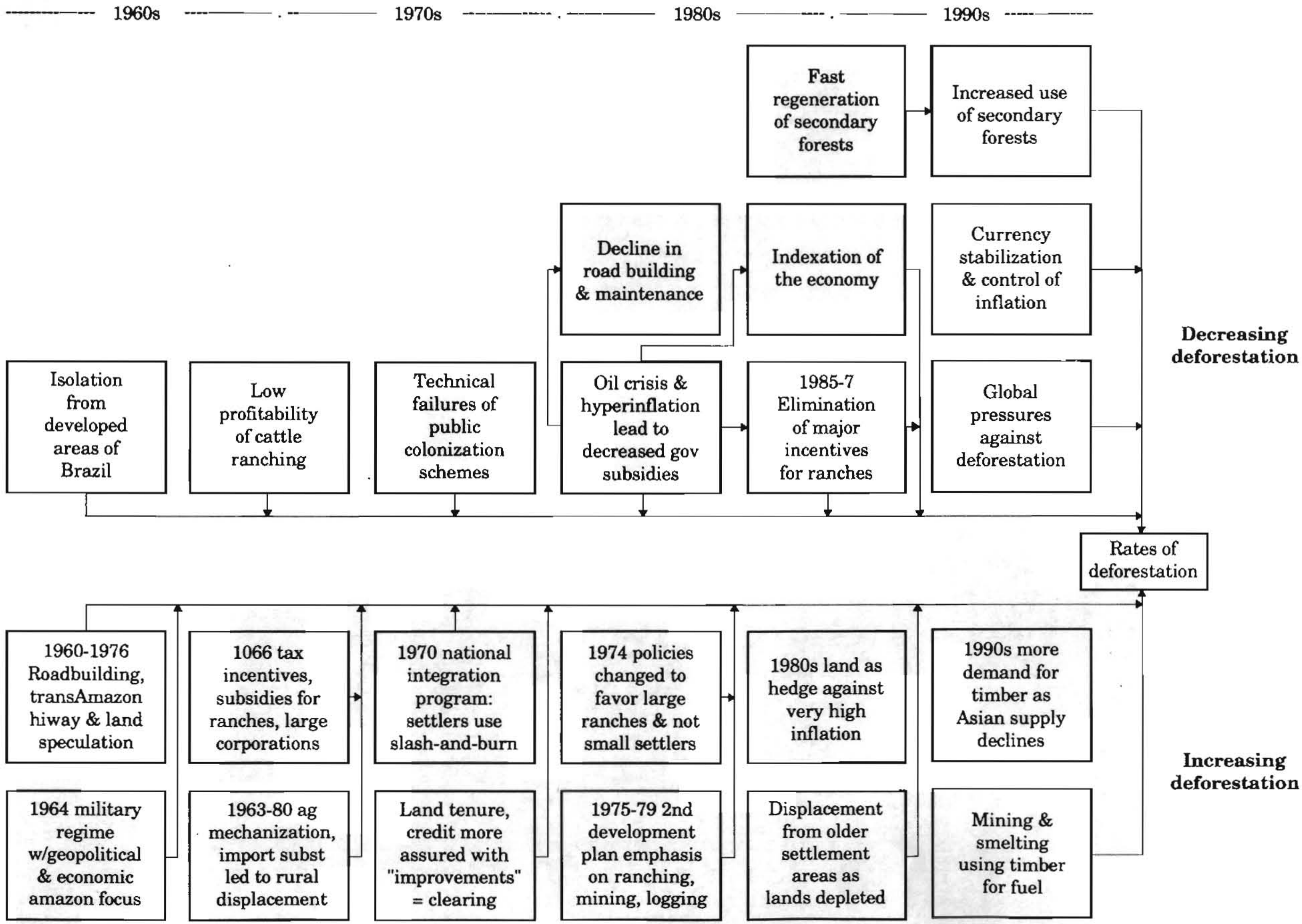
Some agro-forestry exists in home gardens using fruit trees such as mango, banana, jackfruit, pineapple and oranges. Forest products harvested include Brazil nut, palm hearts, wood, animals and fish. Extractive activity in the forest, including timber and rubber, is declining as an economic enterprise. Some annual cropping is followed by conversion into perennial plantations of rubber, coffee and cocoa. Coffee and cocoa are more common in Theobroma but in general settlers agree they are not economically attractive any longer.

In Pedro Peixoto there are more cattle than in Theobroma, and some surplus milk is produced. Predominant pasture species include *Brachiaria brizantha*, *B. decumbens* and *B. humidicola*. Some Pedro Peixoto farmers are also using the legume *Pueraria phaseoloides*, either sole or in mixtures with *Brachiaria* grass. Pastures tend to be overgrazed resulting in compaction, soil erosion and weed infestation. Technology is urgently needed to recuperate these pastures; but technologies such as agro-pastoral systems are constrained by lack of capital, machinery and inputs.

Improved cropping systems for the forest margins

A CIAT agronomist was outposted to EMBRAPA-CPAF in 1994 to participate in the project, collaborating with EMBRAPA in evaluating germplasm of annual food crops and forages tolerant to acid soils. It is still too early to report substantive results from this work. ICRAF and CIAT are jointly beginning to evaluate potential agroforestry-based permanent cropping systems and improved fallows.

Figure 16. Policies and other factors leading to greater and/or lesser deforestation over time in the Amazon.



VII. Organization of Resource Management Research at CIAT

The Strategic Plan (1991) gave the responsibility for research on preservation of the natural resource base to a new Resource Management Division, while the ongoing crop improvement efforts became housed in a Germplasm Development Division. However, a fundamental tenet of the new CIAT was that these two elements, administratively separate, should nonetheless be vigorously integrated through the research agenda. This was to take place through the CIAT-wide adoption of a "systems perspective" in research. Germplasm improvement was no longer to be viewed solely from the objective of increasing the quantity of crop commodity produced, but now through the wider lens of its contribution to sustainable agricultural development. An increased emphasis on collection and conservation of genetic resources (biodiversity) was one such contribution, building on CIAT's experience and in-house skills.

Within the Resource Management Division, four Programs were created, corresponding to the thrusts identified as top priorities during the planning process: Land Use, Savannas, Hillsides and Forest Margins.

The Strategic Plan was operationalized through a second major planning process, the Medium Term Plan (MTP) for 1993-1998. The MTP laid out the details of <u>how</u> CIAT would proceed towards its new goals, including the financial committment to areas related to resource management. Each Program was to consist of a Leader with a team of 4-6 core-funded senior scientific staff, in specific disciplines. RMR (including germplasm conservation) was planned to absorb about 38% of CIAT's core funds for the period. Crop commodity research, which had previously absorbed about three-quarters of CIAT's research budget, would now be allocated just 45%. The remaining 17% was intended to be spent on training, information and communications.

The core funding needed for CIAT to carry out the MTP was estimated at US$31 million, in 1992 dollar value terms. Given the intense global interest in preserving the environment, particularly those areas related to the tropical rainforests of Latin America, this target seemed entirely reasonable, being similar to previous years' budgets. However, due to the unforseen changes in priorities of donors mentioned in the first section of this document, CIAT's core budget fell precipitously, to 26.9 million in 1992, 23.5 million in 1993, and 23.9 million in 1994 (all expressed in 1992 dollar value terms).

The program funding cuts and increasing costs obviously impeded CIAT's ability to achieve the targets set for its ambitious new agenda. CIAT's management was faced with very difficult choices in scaling back the activities of the Institute. The Medium-Term Plan had been rendered obsolete by these unforseen cuts, so a revision was constructed in 1994, called the Action Plan. After much soul-searching, it was decided to deliver the most severe cuts to the crop research and institution-building areas. The fledgling resource management effort was also affected, but was given more protection in view of its priority and critical start-up stage, and the special support of several key donors such as Germany, Denmark, the Netherlands and Switzerland, among others enabled us to initiate the process.

How did CIAT adapt its planned RMR activities to accomodate these cuts? A number of scientific positions simply could not be recruited as planned. The Medium Term Plan had aspired to a total of 18.5 core-funded senior scientist positions in the RMR Division by 1994. As of 1 Jan. 1995, however the crisis enabled only 14 positions to be filled or under recruitment. Furthermore, the recruitment process for several positions was frozen throughout 1992 and 1993 due to the grave budget situation, postponing key aspects of the RMR research agenda. The current staffing patterns, in relation to the intentions of the Medium-Term Plan, are shown in Table 2.

The biggest casualty of the cuts was the planned separate Forest Margins Program, which was merged with the Savannas Program, through the formation of a new Tropical Lowlands Program late in 1993.

Complementary-funded special projects have partially helped counter some of the losses of several core positions, as shown in Table 2. For example, the secondment by IFDC of a nutrient cycling specialist to the Savannas Program in 1992 compensated for one core position, and the provision of several scientists to area-based research studies in the Central American hillsides, the Colombian savannas and the Brazilian forest margins have enabled those projects to go ahead as planned.

Despite the budget crisis, the RMR agenda at CIAT has been vigorously launched and continues to gain momentum. We believe that continuation of its outstanding record of accomplishments, some receiving global acclaim, will strengthen the confidence of donors and encourage them to increase their investments in this new frontier.

Table 2. Senior scientific staffing plans envisaged for the RMR Division in 1993, and the actual situation on 1 January 1995.

Position in Medium-Term Plan for 1993-98:	Present status, and year scientist joined the CIAT RMR Initiative:
Land Use Program (became **Land Management** in 1994)	
Leader	Gilberto Gallopin, '93
Agricultural Land Use Specialist	Peter Jones, '83
Environmental impact economist	Changed to Tropical Ecologist, recruitment opened '94
Geographical Information Systems Specialist	William Bell, '92
Resource Economist	Recruitment opened '94
Sociologist	Samuel Fujisaka, '94
Complemetary-funded:	none
Savannas Program (became **Tropical Lowlands Program** in 1994)	
Leader	Raul Vera, '91
Crop/past. Systems Agronomist, Brazil	Miguel Ayarza, '93
Nitrogen Cycling Specialist	Richard Thomas, '91
Nutrient Cycling Specialist	Changed to Cropping Systems Agronomist, Jose Sanz, '93
Ecophysiologist	Myles Fisher, '91
Farming systems economist	Joyotee Smith '94
Complementary-funded:	
Botanist (CIRAD-CA)	Georges Rippstein, '91
Nutrient Cycling Specialist (IFDC)	Dennis Friesen, '92
Hillsides Program	
Leader	Jacqueline Ashby, '92
Soils Management Specialist	Edwin Knapp, '92
Socio-anthropologist	position closed
Production Systems Specialist	Raul Moreno, '92
Complementary-funded:	
Soil Scientist (SDC)	Hector Barreto, '94
Agricultural Economist (SDC)	Karen Dvorak, '94
Forest Margins Program (closed, merged into Tropical Lowlands Program in 1994)	
Leader	Jan Salick left '93, closed '94
Soil Organic Matter Specialist	position closed
Production Systems Specialist	position closed
Anthropologist	position closed
Complementary-funded:	
Agronomist (for Forest Margins) (GEF)	Michael Thung, '94

VIII. Appendices:

A1. CIAT Publications in Resource Management Research, 1991-1994

A2. Major Meetings and Consultations: A Chronology

A3. Acronyms

A1. CIAT Publications in Resource Management Research, 1991-1994

I. Refereed Journals

Fisher, M. J., I. M. Rao, M. A. Ayarza, C. E. Lascano, J. I. Sanz, R. J. Thomas and R. R. Vera. 1994. Carbon storage by introduced deep-rooted grasses in the South American savannas. Nature 371:236-238.

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Decaëns, T. 1993. Impact des pratiques agricoles sur la macrofaune des sols dans quelques pâturages et cultures des Llanos Orientaux de Colombie. D.E.S.S. Université de Paris XII, 55 p. + Annexes.

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4. Manejo y utilizacion de pasturas en suelos acidos de Colombia.

A2. Major Meetings and Consultations: A Chronology

April 14-18, 1986, Rome:
FAO Workshop on Agro-ecological Characterization, Classification and Mapping. This workshop and subsequent intercenter working groups helped guide CIAT's initiative to develop comprehensive environmental databases and mapping techniques. They laid the basis for fruitful intercenter exchange of data and methodologies.

October 3-7, 1988, CIAT, Cali, Colombia:
"Think Tank" consultation with NARS on possible directions for CIAT in RMR. The think tank involved NARS Directors from several Central and South American countries, plus a number of distinguished consultants, the most notable of whom was Prof. Edward Schuh, Dean, Humphrey Institute of Public Affairs, University of Minnesota. Helped form CIAT's thinking and awareness of national needs and priorities in RMR.

February 2, 1990, Brasilia:
Collaborative savanna meeting, CPAC-CNPAF-CIAT to discuss potential research sites. Agree on need to include socioeconomic and technological research. Identified need for rapid rural appraisals.

July 15, 1990, Villavicencio, Colombia:
Delphi survey of farmers and farm organizations' impressions about the potential of rice-pasture associations (agropastoral systems) in the Colombian Llanos.

September 3-4, 1990, CIAT, Cali, Colombia:
CIAT Workshop/Expert consultation titled "The Future Agricultural Development Context in Tropical America: Implications for CIAT's Strategy". A consultation with national research leaders (Argentina, Brazil, Colombia, Costa Rica, Chile), regional organization representatives (CATIE) and expert consultants (FAO, United Kingdom, USA, Uruguay) to review and advise on CIAT's strategic planning process.

September 10-15, 1990, CIAT, Cali, Colombia:
Workshop on nutrient cycling in pastures. Eight international consultants invited to prepare critique of the proposed "core" experiment at Carimagua.

August 13-16, 1991, Coronado, San José, Costa Rica:
Workshop "Agricultura Sostenible en las Laderas Centro Americanas. Oportunidades de Colaboración Interinstitucional". Participants (approx. 90) were regional, national, NGO and IAR's active in agricultural research and rural development in Central America. This was the major formative meeting for CIAT's collaborative hillsides research effort in Central America.

August 18-22, 1992, Villavicencio, Colombia
First annual IDB-funded Workshop on Agropastoral Systems for the Savannas. This workshop linked the savanna countries (Bolivia, Brazil, Colombia, Venezuela) interested in the development of sustainable agropastoral systems.

August 24-26, 1992, Brasilia, Brazil
Workshop in Brasilia hosted by EMBRAPA: "Pesquisa em Sistemas Mistos Sustentaveis nos Cerrados". Formally launched CIAT's collaboration with Brazilian savanna institutions. Reviewed extensive data including GIS maps to determine where research should locate, and to set broad priorities for research.

September 21-25, 1992, Oslo-Arendal, Norway:
CGIAR/UNEP/GRID Workshop on GIS data for CGIAR centers. Organized by UNEP & IUFRO in cooperation with FAO. The meetings strengthened cooperative links among UNEP/GRID, FAO and CIAT and facilitated database exchanges.

November, 1992, CIAT, Cali, Colombia:
Workshop: "Taller Interinstitucional sobre Agricultura Sostenible en Laderas". Participants (50) from NGO's, NARs, natural resources agencies and community organisations with active programs in Río Ovejas watershed, Cauca, Colombia. This formally launched collaboration among CIAT and Colombian institutions on research in the Andean hillsides.

March 15-20, 1993, Brasilia and Goiânia, Brazil:
Second annual IDB-funded Workshop on Agropastoral Systems for the Savannas. Organized by CPNAF and CPAC, and attended by Bolivia, Brazil, Colombia and Venezuela. Exchanged methodologies and results, established collaborative trials and formally launched the collaboration as a network.

July 14-16, 1993, Nairobi:
Workshop on Developing Large Environmental Data Bases for Sustainable Development. Organized by UNEP & IUFRO in cooperation with FAO. A followup of the earlier meeting in Norway, this led to a wider network of data exchange with other agencies, and placed CIAT as one of the lead centers in environmental databases and GIS.

August 16-20, 1993, CIAT, Cali, Colombia:
The inauguration of the MAS (Management of Acid Soils) Consortium, a global group including CIAT, several national research programs, and universities in Germany and the USA. Priorities and organizational issues were discussed, and plans laid for project proposal development.

August 27-28, 1993, Managua, Nicaragua:
Workshop "Taller de Consulta para Investigación en las Laderas de América Central". Following on the basic collaboration developed in the earlier Costa Rica Workshop, this meeting made more detailed plans for the CIAT-convened consortium involved in hillsides research in Central America. Participants (approx. 22) were from NARs, NGO's, regional and IARCs, with emphasis on Honduras and Nicaragua.

October 1993, Puerto Velho, Brazil:
Planning meeting of the Global Slash and Burn Project, with ICRAF, EMBRAPA, CIAT, WRI and TSBF in attendance. Responsibilities and time frames were agreed upon.

December 6-10, 1993, CIAT, Cali, Colombia:
Workshop to plan a project on transfer of technologies for improved agropastoral production systems to farmers. FAO/CIAT/NARS, for submission to UNDP.

March 23, 1994, Yaounde, Cameroon:
Slash and Burn Global Steering Committee meeting. Progress on the joint agenda was reviewed.

March 28-April 1, 1994, CATIE, Turrialba, Costa Rica:
First MAS Steering Committee meeting. Established agro-ecosystem working groups, prioritized projects for development and timetables.

April 2-6, 1994, Quito, Ecuador:
Planning workshop for CIAT-CONDESAN special project in Ecuador. Participants (20) prepared a special project document for joint project in a highland-mid-altitude hillsides watershed.

May 18-20, 1994, La Lima, Cortés, Honduras:
Meeting of the steering committee of the Central American Hillsides Project (CAHP) to review progress to date.

June 6-10, 1994, CIAT, Cali, Colombia:

Workshop on Land Quality Indicators, jointly organized by CIAT (LM) and the World Bank. Experts attended from the World Bank, CIMMYT, IBSRAM, IICA/GTZ, FAO, AGRI-CANADA, IFPRI and USDA-Soil Conservation Service. Consolidated multi-institutional interest in research on indicators of sustainability. CIAT and CIMMYT contributed a joint paper; led to the preparation of three project proposals to the World Bank.

June 19, 1994, Ottawa:

Participation in the International Workshop on Agroecosystem Health. Developed cooperation between CIAT and the University of Guelph to open a new line of research on tropical agroecosystem health at CIAT.

June 21-22, 1994, Goiania, Brazil:

PROCITROPICOS meeting to finalize project on "Regeneration and sustainable management of degraded soils in savannas".

July 5-6, 1994, CIAT, Cali, Colombia:

Meeting of the Scientific Council of PROCITROPICOS. Decided to merge their agropastoral project with the FAO/CIAT initiative.

July 25-29, 1994, at CIAT, Cali, Colombia:

International Workshop on the Neotropical Savannas of South America - Organized by CIAT, with the participation of representatives of NARDS, governmental and non governmental organizations dealing with agriculture or the environment from Bolivia, Brazil, Colombia and Venezuela, and from two research institutes at Wageningen (Holland). It led to the joint development of the SSALLSSA proposal to be submitted to DGIS, the Netherlands.

August 11-12, 1994, San José, Costa Rica:

Meeting with IDB, CATIE, IICA and CORPOICA to review CIAT's draft proposal for its new CGIAR ecoregional convenor responsibility for Latin America and the Caribbean. The proposal had previously been reviewed by CIMMYT, IFPRI and CIP.

August 29- September 4, 1994, Villavicencio, Colombia:

CIAT's first training course on agropastoral systems, in collaboration with CORPOICA. Targeted to extension specialists, there were 15 participants, from Bolivia (3), Nicaragua (1) and Colombia (11). Sponsored by a number of public, private and farmer institutions. Four training manuals produced.

September 19-23, 1994, Barinas, Venezuela:

Third annual IDB-funded Workshop on Agropastoral Systems for the Savannas, attended Bolivia, Brazil, Colombia and Venezuela. The network of savanna research institutions continued to develop a cohesive plan of work, by reviewing collaborative trials and seeking to harmonize methodologies.

September 26-30, 1994, Zschortau, Germany:

Planning meeting for the Soil, Water and Nutrient Management system-wide initiative of the CGIAR. A planning document was produced, and the Managing Acid Soils savanna project of CIAT was submitted.

December 7-9, 1994, Caracas, Venezuela:

Meeting of Directors' Committee of PROCITROPICOS. Created a Savannas Consortium including Bolivia, Brazil, Colombia and Venezuela as national partners, and CIAT, FAO and CIRAD-CA as international partners.

December 17-18, 1994, Rome:

Meeting to prepare an implementation plan across CGIAR Centers for the new system-wide Soil, Water and Nutrient Management initiative.

A3. Acronyms

AcRon	A strip of land linking the states of Acre and Rondonia, Brazil (claimed by both states)
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development), Germany
Ca	Calcium
CAHP	Central America Hillsides Project (CIAT-coordinated)
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Tropical Agronomic Center for Research and Training), Costa Rica
CD-ROM	Compact Disk-Read Only Memory
CETEC	Corporación para Estudios Interdisciplinarios y Asesoría Téchnica (Corporation for Interdisciplinary Studies and Technical Assessment), Colombia
CGIAR	Consultative Group on International Agricultural Research
CIAL's	Comites de Investigación Agropecuaria Local (Local Agricultural Research Committees), Colombia
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture), Colombia
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (International Center for Maize and Wheat Improvement), Mexico
CIP	Centro Internacional de la Papa (International Potato Center), Peru
CIPASLA	Consorcio Interinstitucional para una Agricultura Sostenible en Laderas (Interinstitutional Consortium for Sustainable Agriculture in Hillsides), Río Ovejas, Colombia
CIRAD-CA	Centre de Coopération Internationale en Recherche Agronomique pour le Développement-Département des Cultures Annuelles (International Center for Agronomic Research for Development-Annual Crops Department), France
CNPAB	Centro Nacional de Pesquisa de Agrobiologia (National Center for Agrobiology Research), EMBRAPA
CNPAF	Centro Nacional de Pesquisa em Arroz e Feijao (National Center for Rice and Bean Research), EMBRAPA
CNPGC	Centro Nacional de Pesquisa de Gado de Corte (National Center for Beef Cattle Research), EMBRAPA
CNPGL	Centro Nacional de Pesquisa de Gado de Lete (National Center for Milk Cattle Research), EMBRAPA
CNPMS	Centro Nacional de Pesquisa de Milhot e Sorgo (National Center for Maize and Sorghum Research), EMBRAPA

CNPS	Centro Nacional de Pesquisa de Seringueira (National Center for Soybean Research), EMBRAPA
CONDESAN	Consorcio para el Desarollo Sostenible de la Ecorregión Andina (Consortium for the Sustainable Development of the Andean Ecoregion), coordinated by CIP
CORPOICA	Corporación Colombiana de Investigación Agropecuaria (Colombian Corporation for Crops and Livestock Research)
CPAC	Centro de Pesquisa Agropecuária dos Cerrados (Center for Agricultural Research for the Savanna), EMBRAPA
CRC	Corporacion para la Reconstruccion y Desarollo del Cauca (Corporation for the Reconstruction and Development of Cauca), Colombia
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
CVC	Corporación Autónoma Regional del Valle del Cauca (Autonomous Regional Corporation of the Cauca Valley), Colombia
DANE	Departamento Administrativo Nacional de Estadisticas (National Administrative Department of Statistics), Colombia
DGIS	Directorate General for Development Cooperation, The Netherlands
DRI	Programa de Desarrollo Rural Integrado (Program for Integrated Rural Development), Colombia
DTM	Digital Terrain Model
ECONORCA	Empresa Cooperativa del Norte del Cauca (Cooperative Enterprise for North Cauca), Colombia
EMATER	Empresas Estaduais de Asistância Téchnica y Extenção Rural (State Enterprises for Technical Assistance and Rural Extension), Brazil
EMBRAPA	Empresa Brasiliera de Pesquisa Agropecuária (Brazilian Enterprise for Agricultural Research)
ERS1	Earth Resources Satellite
FAO	Food and Agriculture Organization (United Nations)
FEDEARROZ	Federación Nacional de Arroceros de Colombia (Colombian National Rice Growers Federation)
FEDECAFE	Federación Nacional de Cafeteros de Colombia (Colombian National Coffee Growers Federation)
FEWS	Famine Early Warning System of FAO
FIDAR	Fundación para la Investigación y el Desarollo Agricola (Foundation for Agricultural Research and Development), Colombia
FONAIAP	Fondo Nacional de Investigaciónes Agropecuarias (National Foundation for Agricultural Research), Venezuela

FSR	Farming Systems Research
GASE	Grupo de Analisis de Sistemas Ecologicos (Group for Analysis of Ecological Systems), Argentina
GEF	Global Environment Facility, UNEP
GIS	Geographical Information Systems
GLASOD	Global Assessment of Soil Degradation project, UNEP-ISRIC, Wageningen, The Netherlands
GPS	Global Positioning Satellite
GRID	Global Resources Information Database, UNEP, Nairobi
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation)
HDP	Human Dimensions of Global Environmental Change Programme
HIMAT	Instituto Colombiano de Meteorologia y Adecuación de Tierras (Colombian Institute of Meteorology and Land Remediation)
IARC	International Agricultural Research Center
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
IBSRAM	International Board for Soil Research and Management
ICA	Instituto Colombiano Agropecuario (Colombian Institute for Crops and Livestock)
ICRAF	International Centre for Research in Agroforestry, Kenya
IDB	Inter-American Development Bank, Washington
IDRC	International Development Research Centre, Canada
IGBP	International Geosphere-Biosphere Programme, Australia
IFDC	International Fertilizer Development Center, USA
IFPRI	International Food Policy Research Institute, USA
IGAC	Instituto Geográfico Augustín Codazzi, Bogotá
IICA	Instituto Interamericano de Cooperación para la Agricultura (Inter-American Institute for Cooperation in Agriculture), Costa Rica
INDERENA	Instituto Nacional de Recursos Naturales Renovables (National Institute for Renewable Natural Resources), Colombia
INTA	Instituto Nacional de Technologia Agropecuaria (National Institute for Crops and Livestock Technology), Nicaragua

IPHAE	Instituto para o Homen, Agricultura e Ecologia (Institute for Man, Agriculture and Ecology), Porto Velho, Brazil
ISPN	Instituto Sociedade, População e Natureza (Institute for Society, Population and Nature), Brazil
ISRIC	International Soil Reference and Information Centre, Wageningen, The Netherlands
K	Potassium
LQI	Land Quality Indicators
LUCC	Land Use/Cover Change, an international initiative of the IGBP and HDP
MAS	Management of Acid Soils Consortium (CIAT-coordinated)
Mg	Magnesium
MSS	Multi-Spectral Scanner of LANDSAT
MTP	Medium Term Plan for 1993-1998, CIAT
N	Nitrogen
NARDS	National Agricultural Research and Development System
NARS	National Agricultural Research System
NCSU	North Carolina State University
NGCD	National Geophysical Data Centre, Boulder, Colorado
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration, USA
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-Mer (Office for Overseas Scientific and Technical Research), France
P	Phosphorous
PESACRE	Pesquisa e Extensão en Sistemas Agroflorestais do Acre (Research and Extension on Agroforestry Systems for Acre), Brazil
PROCITROPICOS	Programa Cooperativo de Investigación in los Trópicos (Cooperative Program for Research in the Tropics), IICA
R&D	Research and Development
RMR	Resource Management Research
RRA	Rapid Rural Appraisal
S	Sulfur

SENA	Servicio Nacional de Aprendizaje (National Learning Service), Colombia
SSALLSSA	Strategies for Sustainable Agricultural Land Use in the Lowland Savannas of South America, a CIAT-coordinated project
TM	Thematic Mapper of LANDSAT
TSBF	Tropical Soils Biology and Fertility Programme, Kenya
UMATA	Unidad Municipal de Asistencia, Colombia
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNELLEZ	Universidad Nacional Experimental de los Llanos Occidentales Ezequel Zamora (Ezequel Zamora National University for Experimentation in the Western Savannas), Venezuela
UNEP	United Nations Environment Programme
USA	United States of America
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WCMC	World Conservation Monitoring Centre, Geneva
WRI	World Resources Institute, Washington

Correct Citation:
CIAT, 1995. Charting a New Course: CIAT's Initiative in Resource Management Research for Latin America and the Caribbean. CIAT Working Document No. 144. CIAT, Cali, Colombia. 94 p.

Printed at CIAT, Cali, Colombia, on 30 June 1995.

The International Center for Tropical Agriculture (CIAT, its Spanish acronym) is dedicated to the alleviation of hunger and poverty in developing countries of the tropics. CIAT applies science to agriculture to increase food production while sustaining the natural resource base.

CIAT is one of 16 international agricultural research centers sponsored by the Consultative Group on International Agricultural Research (CGIAR). The Center's core budget is financed by 21 donor countries, international and regional development organizations, and private foundations. In 1994, the donor countries include Australia, Belgium, Brazil, Canada, China, France, Germany, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America. Donor organizations include the European Economic Community (EEC), the Ford Foundation, the Inter-American Development Bank (IDB), the Rockefeller Foundation, the United Nations Development Programme (UNDP), and the World Bank.

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Cover photo:

Air, water, land, vegetation and agriculture -precious natural and human resources form the focus of CIAT's resource management initiative, as illustrated here by the tropical savanna landscape stretching eastwards from the Andean mountain range near Villavicencio, Colombia.

Credit: Luis Fernando Pino