# CIAT's research on natural resource management in the tropical lowlands of Latin America

Raúl R. Vera[1]
July 1996

## Introduction

CIAT's Tropical Lowland Program resulted from the merging in late 1993 of the former Savannas and Forest Margins programs originally proposed in CIAT's Strategic Plan and implemented in mid 1992.

The Savannas initiative had its origin in the long presence of CIAT in the area through research carried out by the Rice Program, the former Tropical Pastures Program and to a lesser extent the Cassava Program. Savanna land resources, as well as those of the rest of the South American tropical lowlands had been extensively characterized from a biophysical point of view by work carried out by the former Agroecological Studies Unit (AES) in the late 70's and early 80's.

The stock of knowledge on the Forest Margins area was less, and was primarily based on research undertaken by the former Tropical Pastures Program in the Peruvian Amazon (Ucayali department), and to a lesser extent, the Napo department in Ecuador and Caqueta department in Colombia, all of which used intensively the studies developed by the AES mentioned above.

Merging research in those two agroecosystems was a pragmatic decision associated with financial constraints but it made sense strategically in that both agroecosystems share a number of geographic and biophysical characteristics, most notably acid soils of low fertility. Also there is spatial continuity between them. In effect, all of the savanna countries, namely Bolivia, Brazil, Colombia, Guyana and Venezuela, are also Amazonian countries. This has implied that throughout much of the present century, both agroecosystems have interacted closely as consequence of the movement of large segments of population along the savanna-humid forest transition zone. In countries such as Bolivia, Brazil and Guyana this transitional area is currently subjected to rapid rural and urban

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[1] Leader, Tropical Lowlands Program, CIAT, A. A. 6713, Cali, Colombia

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development.[2]

Rationale

In the view of some like Norman Borlaugh[3], the **neotropical savannas** constitute the last significant agricultural frontier in the world, whereas for others it is a fragile and precious natural resource, rich in flora and fauna, and located in the basin of major American rivers. The savannas of tropical South America extend over 250 million hectares, and include the Cerrado (180-205 million ha), the llanos of Colombia (17 million ha), and of Venezuela (28 million ha) and large areas of Bolivia (14 million ha). Biodiversity in the savannas has been less well studied than that of the Amazonian rainforest, and has certainly attracted much less attention in the world press and scientific literature. Nevertheless, and as an example, the Brazilian savannas or Cerrados include well over 160,000 plant species (approximately 5% of the known plant species worldwide). Similarly, recent studies in the gallery forests of the savannas have shown that the richness and diversity of the small fauna in them is a large or larger on a per hectare basis, than that of the Amazon rainforest.

Over the last 40 years of so, the neotropical savannas have been settled and therefore, have been heavily intervened by human action[4]. This has led the Cerrados for example, to supply about a third of Brazil's rice and soybeans total production, and 10-15% of its maize, while at the same time housing approximately 30-40% of its national cattle herd. Current estimates of sown grass pastures in the neotropical savannas amount to 40-50 million hectares, while annual cropping varies between 10 and 12 million hectares per year. In some countries, sugar cane, tree plantations, and various other annual crops constitute major land uses. Overall, 26% Brazil's national agricultural production of six major crops was produced in the Cerrados in 1990.

Despite the large, and continually increasing contribution of the neotropical savannas to agricultural production, food security and income, it should be

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2 The differences and similarities between savanna and non-savanna countries, and implications for research, are discussed at length by Smith et al. (1994) *"The forest margins and savannas of Latin America: a unique opportunity for contributing to natural resource management"*, paper presented at the 2020 Ecoregional Workshop, Airlie House, Virginia, USA, Nov. 7-10.

3 Borlaugh, N. E. and C. R. Dowswell (1994) Keynote lecture, 15th World Congress of Soil Science, Acapulco, Mexico.

4 See also Vera et al. (1992) An. Acad. Bras. Sci. **64**(1):105-125, and Tropical Lowlands Program, Annual Report 1994, p. 3-13.

remembered that the Latin American population is highly urbanized in contrast to that of Africa and Asia. This is particularly true in the case of the savanna countries; 70% of the population is urban, and there are areas in the savannas where cropping and cattle operations are particularly successful, where urbanization exceeds 85%. In these regions, the issue of the linkages between agriculture, agroindustry and the rest of the economy in terms of employment generation and overall economic activity has not been investigated, although there is every reason to believe that these linkages are strong and have major multiplicative effects (see Trigo, 1990 [5] for the issue of urbanization and agricultural intensification, and Schetjman (1994)[6] for linkages).

Land distribution in the neotropical savannas is highly skewed as elsewhere in Latin America. Nevertheless, more than 50% of the farms in the Cerrados are less than 50 hectares in size. Similarly, in Bolivia, parts of Colombia and of Venezuela, relatively large areas are home to a variety of indigenous peoples.

Although the situation is rapidly changing, inappropriate technology has been used in much of the above areas. Erosion, soil chemical and physical degradation, build up of pests in monocropped areas, and others are common problems. The impact of land use on flora and fauna have been scarcely assessed, but constitute a major problem area as shown by recent studies conducted by the National University of Colombia under the auspices of CIAT (Mejia, 1995 unpublished).

An aspect that has received very little attention is the fact that the Cerrados of Bolivia and Brazil are the origin of all of the major rivers draining south to the River Plate (for example, the Paraná river can be traced back to an area near Brasilia). Similarly, the Bolivian and Brazilian Cerrados also give rise to major affluents of the Amazon river. Other savanna areas, such as those of Colombia, portion of the Guianas and Venezuela constitute the watershed of the Orinoco river. It is then obvious that land use changes in the neotropical savannas are bound to have very major effects downstream. In fact, there is abundant anecdotal evidence, and also some quantitative estimates, of significant contamination and siltation of major rivers (e.g., the Paraná, San Francisco and Orinoco rivers), as well as point estimates of unacceptable high levels of organo-chlorides and organo-phosphates in fish of some of these rivers.

The savannas of Bolivia, Colombia and Venezuela are a major source of oil

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5 Trigo, E. J. (1995) *Agriculture, Technological Change and the Environment in Latin America: a 2020 perspective.* Food, Agriculture and the Environment Discussion Paper 9, IFPRI, Washington D.C. 19p.

6 Schetjman, A. (1994) Revista de la CEPAL 53: 1467-157.

for these countries, with subsequent road and other infrastructure development closely associated with further and rapid settlement and agricultural intensification. The effects of road and infrastructure development on land use change can be seen today most dramatically in the Bolivian portion of the Cerrados, about to be transversed by an interoceanic road that will link Sao Paulo in Brazil, with Iquique in Chile.

Rapid frontier expansion occurred also in the **Forest Margins** areas beginning in the 60s. Between 1970 and 1985 the rate of deforestation in the Brazilian Amazon was estimated at 1.5-2.0 million ha per year. However, there is still considerable opportunity for influencing future land use patterns, since only 6% of that area has been cleared. In the FM land concentration is lower than in the savannas, but still high, with a Gini coefficient of 0.79 in 1985, with small farms coexisting with large landlords. Shifting cultivation by small holders was estimated to account for 32% of deforestation in 1980. There are large differences in land use patterns in cleared areas between countries and between regions within countries. As an example, 29% of the cleared areas was dedicated to agriculture and 57% to pasture in the states of Acre and Rondonia, Brazil, in 1985. The consequences of this type of intervention in the tropical humid forests have been amply discussed in the literature and do not need further elaboration here, but is important to reiterate that many of these settlement areas are geographically and politically contiguous with savanna lands, and share many of the same soils and biophysical constraints.

Research strategy in the neotropical savannas

The overall goal of the program is ***to develop and test a diverse set of sustainable land use forms for the acid-soil savannas***. Ideally, these alternative land uses will combine increased productivity with preservation and even enhancement of the resource base, and with improved equity.

It is of outmost importance that diversification of land use in terms of native vegetation, annual crops, perennial crops and plantations, and livestock be considered as a major research thrust, among other reasons because of the increasing need of the region to become competitive in world markets and create for itself and for its products, unique market niches. CIAT and the CGIAR system, have promoted a series of consultation meetings with policy makers of the region. These meetings, the last of which was held in Colombia in 1995, have consistently and repeatedly concluded with the plea that the research system should focus its efforts on how to increase agricultural competitiveness. This should not be understood as synonymous with the ability to compete in traditional crops such as corn or soybeans, though these are essential components of today's' savanna

farming systems, but rather, with the need to develop and adapt also nontraditional tropical commodities.

It is realized of course that this ideal combination of diversified and productive commodities with resource preservation and equity may not be attainable, or only partially so. If that is indeed the case, tradeoffs have to be identified and quantified, and alternative development paths or scenarios must be constructed, so that policy makers, and society, will be able to take decisions on an informed and scientific basis.

The strategies to achieve that goal revolve around three major inter-related project areas:

- The study of the dynamics and trends of land use patterns, leading to: (a) biophysical and socioeconomic characterization of both agroecosystems; (b) identification of representative sites and extrapolation domains; (c) identification of causes and consequences of land use change, and (d) modeling alternative development scenarios;

- Understanding of the biophysical and socioeconomic processes that affect resource management, following a holistic approach at several spatial scales (Figure 1), depending upon the specific processes under study;

- Development and testing of alternative prototypes of agropastoral and agro-silvo-pastoral systems, based on the understanding developed above.

It was recognized from the outset that these objectives are too ambitious for a single Program and even for CIAT as a whole. Therefore, implementation of research projects in each of the above areas has implied close collaboration with a wide range of government and non-government institutions, listed in various CIAT's documents.[7]

Figure 1 shows how our main three projects, presented below, target a relatively narrow range of scales, and how by overlapping they attempt to cover a range that allows analysis and extrapolation across the spectrum of scales.

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[7] See *External Program and Management Review*, October 2-9, 1994, and *Funding Request for 1995*.

*Dynamics of Land Use*

The overall purpose is to provide the basis for developing technologies and policies that contribute to sustainable agriculture by studying the dynamic processes underlying patterns of land use. The project characterizes the determinants and consequences of land use change in representative sites of savannas and forest margins via the study of secondary data, participatory field studies, analyses supported by geographical information systems and modeling at the farm and landscape levels. In the final analysis, it aims to assess the consequences of past and present policies and derive technological recommendations and policy options.

The program has on going studies of land use across a range of sites in the tropical lowlands which are examining trends and consequences that may affect technology generation and adoption, potential policy interventions and their interactions as well as possible tradeoffs incurred in terms of productivity, equity and resource conservation. The range of sites includes:

a. extensive and semi-intensive pastoral lands in the savannas of Colombia;
b. intensive cropland and mixed farming in the Brazilian Cerrados, a transition area between the Brazilian Cerrados and the Amazon basin and
c. the benchmark site of the Alternatives to Slash and Burn Global Program located between the states of Acre and Rondonia in Brazil.

Important **highlights** to date include:

a. The detailed characterization of approximately 60% of the Cerrados areas for which there is sufficient and consistent secondary information, based on over 30 biophysical and socioeconomic variables[8], complemented by a further socioeconomic analysis carried out by a contracted NGO. These

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8 See *An analysis of Forest Margins and Savanna Agroecosystems in Brazil*, by C. Mueller, H. Torres and G. Martine, Institute for the Study of Society, Population and Nature (ISPN), Brasilia, Brazil, 1992, and *Area Classification and Mapping for the Cerrados Region of Brasil*, by P. G. Jones, M. Rincón and L. A. Clavijo, CIAT, second draft, July 1992.

studies were led by CIAT's Land Management Unit, and it involved a CIAT interprogram working group and Brazilian researchers from several different institutions.
It led to identification of high priority representative sites in the Cerrados. Among these CIAT and EMBRAPA-CPAC choose Uberlandia to begin initiation of field work, pending further, and ongoing, detailed analyses based on Rapid Rural Appraisals, field Surveys and interviews with qualified informants, and collection and analyses of additional secondary data.

b. Detailed Rapid Rural Appraisals carried out in several candidate areas for research on the Brazilian forest margins area, namely, areas in the States of Para, Maranhao, Acre and Rondonia, and in savannas areas of the Cerrados and Colombia's llanos. These studies were carried out by interdisciplinary and interinstitutional teams, and were supported by analyses of secondary data, satellite images, and remote sensing.[9].

For example, it led to the selection of the stretch of land extending between Rio Branco, Acre, and Theobroma, Rondonia, as the initial site for research on the Forest Margins by both the TLP and the Alternatives to slash-and-burn global project, and to the selection of Uberlandia in the Brazilian Cerrados, as our main benchmark site [10].

c. Highly advanced studies on the dynamics of deforestation and its underlying causes, and more generally on the dynamics of land use in the Acre-Rondonia site and more recently, a comparable site in the area of influence of Pucallpa, Perú. A comparable study in areas of the Bolivian Cerrados, still relatively untouched, would be highly desirable.

d. Adoption studies initially conducted in the savannas of Colombia, have identified both opportunities and constraints to the adoption of grass-legume leys in relation to a number of variables of the socioeconomic context, thus contributing to better focusing research efforts in this area [10] (Table 1 and Figure 2).

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9 Most of this information has been published only as working documents, the exception being the *Report of a research-site selection in Acre and Rondonia states of Amazon region, Brazil*, M. Avila, compiler, ICRAF, Nairobi, Kenya, 1994.

10 Smith, Cadavid, Rincón and Vera (submitted)

*Mechanistic understanding of soil-plant-animal processes*

The project investigates the biophysical processes that effect resource management, develops and uses land quality indicators and analyses the tradeoffs incurred within existing and alternative systems. The latter is achieved within the context of the findings from the land use dynamics and prototype systems projects.

The aim of this project is to improve the biophysical efficiency of agricultural production such that the efficiency of use of both internal and external inputs is maximized, and environmental effects are minimized. Ensuring maximum efficiency requires quantitative knowledge of underlying processes such as nutrient cycling, and changes in physical and biological soil properties. The project therefore seeks to quantify soil and soil/plant processes associated with changes in primary biomass productivity in contrasting land use systems that extend from no external input native savanna, to intensive crop systems supported by medium levels of external inputs. This project interacts most closely with the *Prototype sustainable cropping systems* project described below.

Currently, the project is implemented via two major long term experiments established in the Cerrados of Brazil and savannas of Colombia respectively. They involve a variety of land use systems, ranging from grazed native vegetation to input-intensive cropping systems, and constitute an excellent platform for researchers and institutions interested in assessing specific variables. For example, the Cerrados experiment, and shortly also our Colombian trial, is being used by Cornell U. researchers to measure gas fluxes as related to land use system. Similarly, French researchers are monitoring the dynamics of soil meso fauna in an attempt to learn how to manage it and enhance soil biological activity.

Important **highlights** of this project to date include:

a. The finding that some deep-rooted introduced forage grasses can contribute substantial amounts of organic

matter to the soil, particularly when associated with productive, well adapted legumes[11]. Although many questions about this phenomenon remain unanswered, it does support the hypothesis that agropastoral systems that involve planned rotations of annual crops and perennial forage species contribute to soil enhancement and may have positive effects in terms of global warming.

b. A forage phase in the crop sequence has been shown to lead to increase soil biological activity, increased soil fauna biomass and maintenance of its species diversity, increased VMA infection potential, and beneficial effects on nutrient partitioning in soil organic matter (Figure 3).

c. Much improved and sensitive methods for soil organic matter and P partitioning have been tested and adjusted for acid soils. These methods, though more time consuming and expensive than traditional ones, provide a much better understanding of P dynamics and appear to have more predictive power.

d. A clearer and more quantitative understanding of N cycling in acid tropical soils, generally low in organic matter, has begun to emerge. The relative roles of N cycling via feces, urine and litter has been quantified and a simple N cycling model with considerable predictive power has been developed.

As implied above, these research activities are long-term and are therefore expected to provide more and significant outputs in the near future such as models of nutrient cycling and of physical and biological soil degradation and rehabilitation. These models, and the improved understanding that they represent, will constitute the basis for the design of sound prototype land use systems.

*Prototype sustainable cropping systems*

In the present context, cropping systems include both pastoral and perennial plantations components as well as annual crops. Numerous alternative cropping systems are practiced by farmers throughout the

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11 Fisher, M. et al. (1994) *Nature* 371 (September 15):236-238.

lowland tropics; these systems are under rapid evolution in response to changing economic and environmental conditions, and rapidly changing technologies. As consequence of this diversity, only a carefully selected small number of very contrasting *prototypes* can be examined in any detail.

The project seeks to build on existing farm-based systems, in order to generate technologies, land management strategies and policy options for the sustainable agricultural development of the target regions. Research activities and selected farming systems are based on the identification of the major problems, opportunities and niches identified in the land use dynamics projects, and is supported by the understanding of soil-plant-animal processes developed in the respective project.

The project includes biophysical and socioeconomic monitoring of extant land use systems, and on farm participatory evaluation of alternative systems. These types of activities have been implemented with various degrees of intensity in three sites: the Uberlandia region in the Brazilian Cerrados representing input- and management-intense agropastoral systems, the area of influence of Puerto López in the Colombian Llanos representing more extensive, cattle-based land use systems, the colonization projects of Pedro Peixoto (Acre) in the Brazilian Amazon, and the area near Pucallpa in the Peruvian Amazon representing different situations of small settlers practicing shifting agriculture.

Some of the **highlights** are as follows:

a. A reliable method that combines use of SPOT images and ground measurements has been developed and tested in the Colombian Llanos to assess the extent and intensity of degradation of native savanna plant communities in response to various management practices. Long-term monitoring of fixed points is providing quantitative evidence on the relative resilience of different plant communities, and may lead to identify "keystone" species as well.

b. The yield and economic advantages of the (low external input) rice-pasture prototype system has been amply demonstrated. Soil enhancement under this system has also been shown (Table 3).

Nevertheless, the precise niche(s) for this type of system still needs to be defined. Derived prototypes using new acid soil tolerant varieties of maize and soybeans are being tested. The inclusion of systems based on tropical fruit plantations is being planned in cooperation with the Colombian national research organization, CORPOICA.

c. The positive effects in terms of land use and food production of integrating crops and cattle production have been documented for a small number of on-farm case studies. Nevertheless, it is clear that these systems are management-intensive.

Institutional relations

The Program's strategies and research activities are only a small part of the set of actions required to achieve sustainable development of the tropical lowlands. The Program is therefore actively developing collaborative studies with a diverse suite of national, international, regional R&D institutions. Formal projects and networks (i.e., the Agropastoral Research Network, MAS, etc.) as well as numerous informal linkages have been, and continue to be established[12]. Only few major partners can be listed here, including CIAT-Sta. Cruz, CORPOICA, EMBRAPA and FONAIAP as *national research institutions* in Bolivia, Colombia, Brazil and Venezuela respectively; *universities* such as National University, U. Javeriana and Technological University of the Llanos in Colombia, UNELLEZ and U. San Bolivar in Venezuela, the Federal University of Uberlandia in Brazil, Hohenheim and Gottingen universities in Germany, Colorado SU, Cornell and Ohio SU in the US and U.Complutense in Spain; various *NGOs* such as several cooperatives in the Cerrados, farmers and cattlemen associations in Colombia and Venezuela, ISPN in Brazil; *international institutions* like IFDC, TSBF and CIRAD; *regional consortia* like PROCITROPICOS and *international consortia* like ASB.

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12 See *External Program and Management Review,* October 2-9, 1994, and Tropical Lowlands Program, Annual Report, 1994 for a complete listing.

Table 1. Adoption of improved pastures in the Colombian llanos

| | 1979 | 1995 |
|---|---|---|
| Improved grass pasture, % of the area | 2 | 20 |
| Animal units/ha | 0.09 | 0.28 |
| Beef production, kg/ha | 16 | 50 |
| Potential herd size (000 heads) on well drained savannas | 959 | 1726 |

Source: Tropical Lowlands Program Annual Report 1995.

Table 2. Beneficial effects of grass/legume pastures in agropastoral systems (based on Thomas et al., 1995)

| Parameter | Benefit | Reference |
|---|---|---|
| **Animal production** | | |
| Animal live weight gain | + + | Vera et al., 1992; Vera et al., 1994 |
| Reduction of age at first calving | + | Vera, 1991; Vera et al., 1993 |
| Reduction in calving interval | + | Vera et al., 1993 |
| Milk yields | + | Lascano & Avila, 1991;<br>Ullrich, Vera and Weniger, 1994 |
| **Crop yield** | | |
| Rice after pasture | + + | Thomas et al., 1995 |
| **Soil improvement** | | |
| Total soil carbon | + | Fisher et al., 1994 |
| Soil Carbon in sand fractions | + + | Guggenberger et al., 1995 |
| Potential N mineralization | + | Rao et al., 1994 |
| Wet aggregate stability | + | Gijsman & Thomas, 1995a |
| Water infiltration rate | + | Gijsman & Thomas, 1995b |
| Microbial-P | + | CIAT, 1995a |
| Nutrient cycling via litter | + | Thomas & Asakawa, 1993<br>Guggenberger et al., 1995 |
| Earthworm populations | + + | Decaens et al., 1994 |

+ = an increase of <100% compared with grass-only or native savanna pastures.
+ + = an increase of >100% compared with grass-only or native savanna pastures