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TROPICAL LOWLANDS PROGRAM

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EXECUTIVE SUMMARY

The Tropical Lowlands 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.

Despite its brief institutional history, the program has already been reviewed in depth a number of times by external reviewers. Between mid 1994 and early 1995, and together with the rest of CIAT, the Program was subjected to an External Program and Management Review (EPMR). In mid 1995 the whole area of Resource Management was examined by an Internally Commissioned External Review (ICER). Lastly, in August-September 1995, research activities carried out in the savannas and partially financed by an Interamerican Development Bank (IDB) grant were reviewed by an external consultant. Since detailed research summaries were prepared for each of these events, the present brief report represents an update of those earlier documents.

All of the above external reviews were extremely supportive of the suite of ongoing research activities in the savannas while mixed comments were made on the new biophysical research projects underway in the forest margins. As a consequence of these suggestions, greater emphasis has since been placed on detailed characterization of contrasting land resources, an evolutionary change that is reflected in the present report.

The Program's goal is to develop and test a diverse set of sustainable land use forms for the tropical lowlands of Latin America. Thus far, research activities have concentrated on the acid-soil savannas and forest margins of tropical America, while incipient collaboration with a number of National Institutions is beginning to pay attention to the problems and opportunities of younger and more fertile savanna soils.

The strategies to achieve the Program's goal revolve around three major inter-related Projects, each of which addresses different geographic scales of resolution (for an example, see Figure 1 under TP01). The projects are:

- ❑ the study of the dynamics and trends of land use patterns, leading to biophysical and socioeconomic characterization of both major agroecosystems, followed by the identification of representative and contrasting sites and extrapolation domains, and later, to modeling of alternative scenarios;
- ❑ development and testing of alternative prototypes of agropastoral and agrosilvopastoral systems based on the identification of the major problems, opportunities and niches identified in the land dynamics project (e.g. Figures 2 and 3 under TP01), and supported by an understanding of the soil-plant-animal processes developed in the third project;
- ❑ understanding the biophysical processes that affect resource management and the tradeoffs incurred therein, following a holistic approach at various degrees of resolution depending upon the specific process under study.

On going studies of land use across a range of sites in the tropical lowlands are examining trends and consequences that may affect technology generation, potential policy interventions and their interaction, as well as possible tradeoffs incurred in terms of productivity, equity and resource conservation. The range of sites encompassed thus far includes extensive and semi-intensive pastoral lands in the savannas of Colombia, intensive cropland and mixed farming systems in the core area of the Brazilian savannas (Cerrados), a transition area between the Brazilian Cerrados and the Amazon basin, and the benchmark site of the Alternatives to Slash and Burn Global Program located between the States of Acre and Rondonia, Brazil.

The studies conducted in the Colombian savannas indicate clearly the complex interactions that exist between land prices and their respective rates of increase, the development of infrastructure, technology adoption and technological demands and opportunities in a region that is experiencing rapid changes as consequence of an evolving socioeconomic context. The consequences for the Program's strategy in terms of technology generation are still under discussion.

Studies conducted in the core Cerrados increasingly point out to the social importance of the small to medium sized, family operated farm sector. Although its economic importance in terms of overall agricultural output still needs to be quantified, it appears to have an important role in terms of at least, milk production. It may also have implications in terms of resource degradation associated with lack of policy and credit incentives, and of appropriate technology. These studies are continuing.

In the Cerrados frontier, and transition to the Amazon rainforest area, the Program's initial studies are documenting the past impact of policy and favorable credit conditions in terms of settlement of the region, its marked urbanization and the creation of urban employment related to rapid agricultural development. Given a equally rapidly changing policy scenario, hypothesis regarding the future path of development of these regions are being assessed and their consequence in terms of agricultural and ecological tradeoffs will have to be quantified via modelling of alternative scenarios. This type of study will be undertaken in the coming year. Similarly, niches for alternative technological interventions within this varied region are beginning to emerge. Some are already clear and have been identified by farmers much in anticipation of research findings. Constraints such as soil compaction and the buildup of pests and diseases in intensively monocropped areas have led to rapid adoption of no till techniques, at the cost of the increased use of herbicides mixtures. These studies, supported by personal observation and close interaction with a variety of farmers have led the Program to adjust its research agenda to include issues such as minimum and no till techniques and their consequences in terms of soil physical, chemical and biological properties as well as plant productivity. A clearly deficient research area related to the above issue is that of integrated pest management, though modest advancements are being made in terms of weed management.

Long term studies with alternative prototypes for the savannas have continued; the longest running experiment is now seven years old, having been initiated by the Rice and former Tropical Pastures Program in the savannas of Colombia. Similar experiments are ongoing also in the Brazilian Cerrados. It is now clear that the temporal integration of annual crops and grass-legume pastures is highly desirable from a biophysical point of view, but it is not an unqualified panacea. There is no doubt that a planned and carefully managed temporal sequence of the above components is perfectly feasible and leads to enhancement of the soil resource and leads to sustained high yields of crops and animals. It is also equally clear that these prototypes are very management- and information- intensive, and as such, are bound to be more constrained by socioeconomic constraints than less intensive alternatives also under study. Also, depending upon the components chosen, some tradeoffs between crop and pasture yields may be incurred, as shown by studies carried out in Brazil, but these are probably less influential in terms of system output than the policy dimensions referred to above.

Human intervention and land use intensification throughout the tropical lowlands can be linked to loss of plant, and other, genetic resources, and as a minimum, with significant shifts in terms of plant populations. These trends are under study in the Colombian savanna lands and in the rainforest area of Acre and Rondonia. Marked changes in savanna plant communities can be induced by fire and grazing management. These studies are very long term and no definitive conclusions can still be drawn out either from field studies or based on remote sensing, particularly as the latter have been delayed by lack of access to recent images. Nevertheless, field studies are suggesting an expected degree of resilience in the herbaceous cover of the savannas subjected to extreme management practices. An important consequence of these surveys is the identification of large differences in plant richness and possibly genetic diversity, across contrasting savanna landscapes. These results are being georeferenced, and eventually, will be overlaid against a soil, slope, etc., database under development. Equivalent analyses of vegetation dynamics are ongoing in the Acre-Rondonia site. As expected, species diversity was highest in the rainforest, but it was also high in 3-5 years old fallows, whereas the least number of plants were encountered in pastures.

Changes in land cover have been associated with changes in a number of soil parameters. Significant progress has been made in identifying key soil processes in agropastoral and sequential crop production systems in the Colombian savannas, and in the Brazilian cerrados. Equivalently, modest studies on some of these soil processes were initiated or are planned for the forest margins. Common problems identified between the main savanna sites in Colombia and Brazil include weed infestations in crop sequences, lack of persistence of forage legumes, soil compaction, disruption of soil macro aggregates by cultivation and a reduction in macro porosity under cropping compared with native savanna vegetation or sown pastures.

Nutrient cycling studies have revealed inefficiencies in fertilizer and green manure use which, when combined with previous reports of poor recoveries of nutrients via litter and animal excreta suggest that there are numerous points of intervention where research can result in improvements.

The important role of soil biota, particularly earthworms is becoming clearer both in terms of improving soil structure and nutrient cycling especially during a phase of improved grass/legume pasture. The contrasting population dynamics of earthworms, termites and other soil macrofauna in alternative land use systems are being studied as well.

Emissions of the greenhouse gases, methane and nitrous oxides, appear to be low in the crop-pasture experiments in Brazil, with no indication that methane oxidation is reduced by agricultural activities. Some of these ecological services, such as the C sequestration process reported earlier, may have an economic value, an issue which will be subject to future studies.

Institutional issues such as

cooperation, institutional strengthening and training have been dealt with at length in previous reports and are therefore not addressed in the present document.

Research strategy and projects

Raúl R. Vera

Background

The TLP 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 program had its origin in the long presence of CIAT in that ecosystem through research carried out by the Rice Program, the former Tropical Pastures Program and to a lesser extent the Cassava Program. Savannas 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 those two programs was a pragmatic decision based on CIAT's financial difficulties experienced in the 1992-1993 period. It made sense strategically in that both agroecosystems share a number of geographic and biophysical characteristics, most notably acid soils of low fertility, and that 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 development.

Despite its brief institutional history, the Program has already been reviewed in depth a number of times by external reviewers. Between mid 1994 and early 1995, and together with the rest of CIAT, we were subjected to an External Program and Management Review, and in mid 1995 by an Internally Commissioned External Review. Lastly, in August-September 1995, research activities related to the savannas and partially financed by an IDB grant, were reviewed by an external, IDB-appointed, consultant.

Rationale

In the view of some like Norman Borlaugh[1], 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),

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

the llanos of Colombia (17 million ha), and of Venezuela (28 million ha) and large areas of Bolivia (14 million ha). Over the last 40 years of so, the neotropical savannas have been settled and therefore, have been heavily intervened by human action. 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. 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. 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 given that *the savannas are rich in both* (for example, the flora of the Cerrados may amount to 10,000 species). Furthermore, 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. Similarly, the savannas are a major source of oil for some countries, with subsequent road and other infrastructure development and further and rapid settlement and agricultural intensification.

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.

Program's goal and strategy

The overall goal of the program is to develop and test a diverse set of sustainable land use forms for the acid-soil savannas and forest margins of tropical America. Ideally, these alternative land uses will combine increased productivity with preservation and even enhancement of the resource base, and with improved equity. It is realized of course that this *ideal combination* may be unattainable, or only partially so, and that if that is indeed the case, tradeoffs have to be identified and quantified so that policy makers, and society, will be able to take decisions on a more informed 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 initially to biophysical and socioeconomic characterization of both agroecosystems, identification of representative sites and extra-polation domains, and later to modeling alternative scenarios;

- Understanding of the biophysical and socioeconomic processes that affect resource management, following a holistic approach at various degrees of resolution 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.

Program's projects

Up until the beginning of 1995, the Program had several projects in each of the above subject matters grouped for each of the main agroecologies, namely Cerrados, Llanos and Forest Margins. These were consolidated at the beginning of the year, such that there is a single *Dynamics of Land Use* project across the tropical lowlands, a single *Mechanistic Understanding of Soil Processes in Agropastoral and Sequential Crop Production Systems*, with subprojects for the Llanos and Cerrados respectively, and a single *Prototype Sustainable Cropping Systems*, with subprojects for the Llanos, Forest Margins and Cerrados respectively. This reorganization has led to improved coordination and standardization across sites.

It will be noted that each of the Program's projects addresses research issues at different geographic scales of analysis. Thus, the *Dynamics of Land Use* project refers to scales above the individual farm level, and reaches a whole agroecosystem regionally defined, whereas the *Prototype Sustainable Cropping Systems* project spans the scales between single paddocks or plots within farms and watershed at the upper limit of the range. Lastly, the project entitled *Mechanistic Understanding of Soil Processes in Agropastoral and Sequential Crop* comprises process studies carried out in the laboratory, greenhouse and on small plots in the field.

Dynamics of Land Use

This is a truly inter-program project, developed and implemented in collaboration with the Land Management SRG, and should be considered in conjunction with their project entitled *Diagnostic surveys and research planning for the Brazilian Amazon and lowlands savannas of South America* (UT04). 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. On a more short-term basis, this project has been developing databases on the spatial and temporal dynamics of land use which allow a detailed biophysical and socioeconomic characterization of the target agroecosystems, identification of experimental sites and a gradually improving definition of extrapolation domains.

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[2], complemented by a further socioeconomic analysis carried out by a contracted NGO. These studies were led by the Land Management SRG, and 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. These studies were carried out by interdisciplinary and interinstitutional teams, and were supported by analyses of secondary data, satellite images, etc.[3]. 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.

c. Ongoing, but highly advanced studies on the dynamics of deforestation and its underlying causes, and more generally on the dynamics of land use, conducted by CIAT's Land Management SRG and TLP in the Acre-Rondonia site.

Other ongoing studies, in various stages of implementation, are being conducted for selected areas within the Cerrados and Colombian Llanos. As indicated above, most of the initial characterization is led by the Land Management SRG, but involves continued consultation and collaboration with TLP staff.

Mechanistic understanding of soil processes

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.

Due to resources constraints, it has only been implemented in two savannas sites so far. The set of experiments that form part of this project have been designed and implemented with EMBRAPA-CPAC in

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[2] 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 Brazil*, by P.G. Jones, M. Rincón and L.A. Clavijo, CIAT, second draft, July 1992.

[3] 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.

Brazil, and with CORPOICA, IFDC and CIRAD in Colombia. Scientists from various other institutions are also involved in assessing other specific parameters.
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[4]. 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 even 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 partioning in soil organic matter.

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 land use systems.

Various meetings, workshops and seminars with scientific counterparts of Bolivia, Brazil, Colombia and Venezuela have insisted on the need that CIAT not only engages in this type of experimentation, but that it also play a leading role, as recognized by PROCITROPICOS[5].

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 lowland tropics; these systems are under rapid evolution in response to changing economic and environmental conditions, and rapidly changing technologies.

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 are supported by knowledge generated in both of the previously cited projects, which provide the socioeconomic and geographic context, and the required understanding of

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

[5] Minutes of PROCITROPICOS Council of Directors, December 1994.

biophysical processes respectively.

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, the area of influence of Puerto López in the Colombian Llanos, and the colonization *projects of Pedro Peixoto* (Acre) and Theobroma (Rondonia) in the Brazilian Amazon. In all cases, numerous other institutions are involved.

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. 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.

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.

d. New and varied crop and forage germplasm has been introduced to the Acre-Rondonia site with the aim of diversifying and stabilizing agriculture in the deforested areas, under the hypothesis that if successful, the process should lead to decrease incentives for continued deforestation.

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. Only a 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.

Future chalilenges

The most immediate challenge is the implementation of the Program's role in

CIAT's Ecoregional initiative, which implies a more extensive coverage of the tropical lowlands than was possible in the past. A similar consideration applies to the relation of the Program with newly created regional and national consortia and other institutional bodies. Notable among them is the evolving *Forest* consortium under creation by PROCITROPICOS, equivalent, but more diverse than the *Savannas* consortium.

Among existing commitments, CIAT's involvement in the *Alternatives to Slash and Burn* Program deserves special mention to the extent that during the final months of 1995 preparations were undertaken to include other benchmarks sites in Latin America, beginning with the Ucayali Department of Peru. Characterization of the latter site in 1996 will require the Program's involvement, together with staff of the Land Management Program.

Lastly, there is a strong and reiterated demand by various National Institutions for the Program's involvement in training activities. How this will be done is still under discussion.

Interprogram Project TD01: Land Use Dynamics:
Tropical Lowlands and Land Management

Project Officer: ***Joyotee Smith***

Rationale

This project contributes to the strategy for technology generation, policy and institutional change, by studying the human processes underlying land use change, ie the interaction between people and the resource base. This is expected to provide a demand - driven orientation to CIAT's research agenda.

Planned Outputs

1. Analysis of the past and future trajectory of development paths in the Savanna and Forest Margin, to generate internationally relevant principles about the driving forces behind land use change.

2. Analysis of the consequences of development paths for

   - economic sustainability and equity
   - ecological sustainability (on - and off -site), with the results feeding into the Project on Mechanistic Understanding of Soil Processes (Project TM).

3. Ex - ante validation of response to potential technological and policy interventions. The results provide best - bet technological options for the Project on Prototype Systems (Project TP), as well as policy recommendations.

Planned Activities

The strategy of the project is to start by obtaining a broad overview of land use dynamics in the mandate area based on secondary data, and a preliminary regional land use model, which provides a vision for the future development of the area. This is followed by field data collection, GIS analysis, farm and watershed level models in selected sites to identify the driving forces behind land use change, their socioeconomic and ecological consequences, and responses to changes in policies and technologies. Sites are selected to represent different hypothesized development paths, or different stages in the same development path. Thus synthesis of results from these sites is expected to lead to the derivation of internationally relevant principles about the determinants and consequences of land use change. These results feed back into, and improve the regional land use model.

Past Achievements

1. A preliminary vision of the future evolution of the Savanna and Forest Margin has been developed, based on the analysis of secondary data, and a regional land use model for Brazil. In the savanna, it was decided to focus on the Colombian Savanna, hypothesized to be representative of extensive systems, and the Brazilian Savanna, hypothesized to be representative of intensive systems. Analysis of census data from the Brazilian savanna has revealed different patterns of land use change within Brazil. Cluster analysis of

census data has identified sites representative of these different patterns. In the Forest Margin two areas of focus have been selected in collaboration with the 'Alternatives to Slash and Burn' project: Acre and Rondonia in Brazil, as an example of government sponsored settlement, and Pucallpa in Peru, as an example of spontaneous settlement. Socioeconomic characterization of two sites in Acre and Rondonia in the Forest Margin of Brazil has been carried out based on farm surveys and GIS analysis. Land use change in the Colombian Savanna, from extensive ranching on native savanna to improved pastures, has been documented. These achievements are summarized in the Savanna Programs Biennial Report for 1992-1993, and the Tropical Lowlands Annual Report for 1994.

Achievements in 1995

Driving Forces Behind Land Use Change in the Colombian Savanna: *Joyotee Smith and J. V. Cadavid, with the collaboration of R. Vera, C. Lascano, J.I. Sanz, P. Hoyos, T. Romero, A. Rodriguez (CIAT), and A. Rincon, M. Alvarez, G. Bueno (CORPOICA).*

Major changes in land use in the Colombian savanna have taken place in the last 15 years. It is commonly recognized that these changes can have major implications in terms of agricultural production, because the Latin American savannas are recognized to be the last remaining frontier in the world. It is less well known that land use change in the savanna can have major ecological implications both within and outside the savanna because the savanna is part of the watershed of four major rivers.

The most important change in land use in the Colombian savanna has been the shift from extensive cattle ranching based on native savanna grasses, to semi - extensive ranching in which native grasses are complemented by increasing amounts of *planted pasture* (about 20% of pasture area on average in 1995). This has been accompanied by an active land market, and a decrease in average farm size, with about half the farms having changed hands after 1982.Simultaneously, 49% of adopters report degradation of improved pastures, particularly loss of soil cover, and 60% report degradation of gallery forests, particularly selective removal of species for fencing paddocks of improved pasture (Table 1). Degradation of pastures and gallery forests could have serious ecological implications on- and off- site, particularly via soil erosion and siltation of rivers.

Results from a whole farm livestock production model show that the major driving force behind land use change has been the high rate of increase in land prices. (Land prices increased at an annual rate of around 14 to 16% p.a. in real terms during the last 15 years). This increase was a result of improvements in infrastructure, and acquisition of land for money laundering. The conversion of native savanna to improved pasture also pushed up land prices because planted pasture sells for at least 2.5 times more than native savanna, giving an annual rate of increase of 20.5% per annum for land converted to improved pasture.

Assuming a 1500 ha. farm, a time horizon of 15 years, and land value appreciation of 14% p.a.,the livestock model shows (Figure 1) that the Internal Rate of Return (IRR) for animal production on native savanna is less than the current high rate of interest (15% p.a. in real terms). This accounts for the high premium commanded by land planted to improved pasture. If the improved pasture technology did not exist, farmers would have tried to increase production from native savanna, most probably by increasing the frequency of burning, which research shows leads to floristic and soil degradation. The availability and adoption of improved pasture has therefore enabled cattle ranching to remain viable, relieved pressure on the native savanna and contributed to the maintenance of its biodiversity.

The model shows that the faster the rate of conversion to improved pasture, the higher is the IRR (Figure 1). Conversion of 80% of the farm to improved pasture in 15 years gives an IRR of 21%, vs an IRR of 15% for the actual average rate of conversion of 20%. Table 1 shows that conversion rates are highest on the smallest farms. However, the absolute area converted is very similar across all farm sizes: around 200 to 300 ha., implying that cash constraints prevent farmers from converting more than 300 ha in 15 years. Thus the cost of conversion to improved pastures ($530/ha.) impedes the speed of adoption.

Table 1. Characteristics of farms in the Colombian savanna by infrastructure and topography: survey data, 1995.

Infrastructure / Topography	Moderate/ Plateau	Poor / Plateau	Moderate/ Undulating	Poor / Undulating	All farms
Number of farmers	11	29	26	32	98
% farm in improved pasture [1]	50[a]	19[c]	35[b]	10[c]	20
Average farm size (ha) [1]	418[c]	1998[a,b]	915[b,c]	2989[a]	1857
Animals/ha [1]	0.6[a]	0.3[b]	0.3[b]	0.2[b]	0.28
Area converted to improved pasture (ha)	209	380	320	299	371
Farm aquired after 1982 (% farmers)	64	48	62	52	54
Changes in gallery forest (% farmers)	89	52	50	63	60
Resident on or near farm (% farmers)	55	55	42	59	47
Farm provides > 50% of income (% farmers)	18	31	19	28	31
Land Price ($/ha)	~384	~96	~384	~96	~292
Transport cost to major market ($/head of cattle)	~22	~46	~22	~46	~38

[1] Differences in letters indicate significant differences (5% level), Duncan's Multiple Range Test.

The high rate of land price appreciation has allowed farmers to overcome this impediment to adoption. If land appreciates at 14% p.a., conversion of 20% of the farm in 15 years gives an IRR equal to the real rate of interest. If land price appreciation had been 5% p.a., a conversion rate of 80% in 15 years would have been required to give the same IRR. In the absence of land appreciation, even 100% conversion would not be profitable (Figure 1). Therefore the rapid increase in land prices has enabled farmers to adopt improved pastures in spite of cash constraints. If the rate of increase in land prices falls in future, and capital remains expensive, farmers are likely to recuperate profitability by adopting more intensive management practices. While the ongoing improvement in transport links to Bogota, and the discovery of oil deposits implies that land prices should continue to increase in the medium term, a countervailing effect may be the Colombian government's efforts to stamp out the drug trade.

Improvement of infrastructure has lowered transport costs for inputs and output. However, results show that even when unit transport costs are halved, this has a negligible impact on profitability (Table 2), due to the relatively low levels of inputs and the high value of output relative to transport cost. Therefore reduction in transport costs, due to improved infrastructure, do not appear to be responsible for changes in land use. The implication is that land price increases have included a large component which is *unrelated to land productivity.*

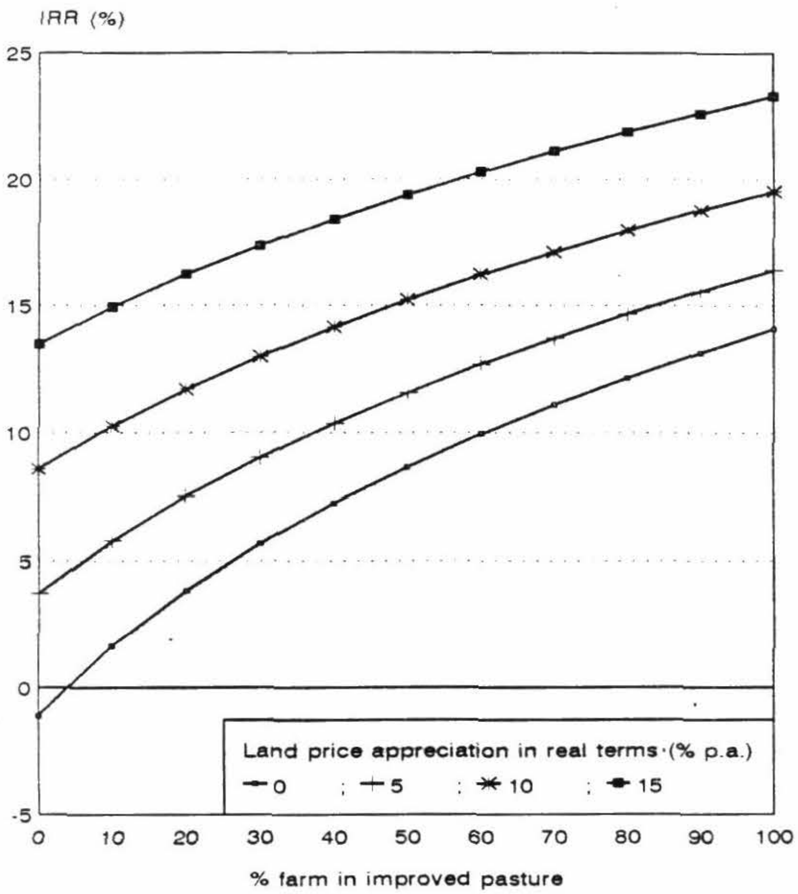

Figure 1. Internal Rate of Return (IRR) of improved grass pastures:
Simulated values from whole farm livestock production model, 1995.

Farm size: 1500 ha; time horizon: 15 years.
Price data from area of moderate infrastructure/plateau
Data source: Lascano,C. (1995). Location: Carimagua; Topography: well drained;
Plateau: B. decumbens, P. phaseoloides.

Table 2. Sensitivity analysis: simulated results from whole farm livestock production model, 1995[1].

IRR[2] with 20% grass pasture	% grass pasture required for IRR[2] of 15%	Land Price ($/ha)	Transport cost ($/head of cattle)	Land price premium for grass pasture vs native savanna
15	20	384	22	2.5
14	35	96	22	2.5
15	20	384	46	2.5
17	10	384	22	5

1 Farm size: 1500 ha. Time horizon: 15 years. Rate of land price appreciation: 14% p.a. (real terms). Price data from area of moderate infrastructure/plateau.

2 IRR: Internal Rate of Return.

Data Source: Lascano (1995). Location: Carimagua; Topography: well drained plateau: *B. decumbens, P. phaseoloides.*

The IRR is only marginally higher in areas of where land prices are 4 times higher (Table 2), the higher IRR being due to the higher base price from which increases in land price can be captured. The implication is that the higher rate of conversion in areas of higher land prices (Table 1), is due not to high land prices per se, but because an active land market in areas of high land prices has led to a reduction in farm size, permitting a faster rate of conversion to improved pasture.

Survey results show that improved pastures are subjected to high grazing pressures. About a third of the farmers graze improved pastures continuously. The rest graze pastures for 76% of the time, with stocking rates of upto 1.7 AU/ha. Nutrient deficiency may also contribute to pasture degradation, as P is the only macro nutrient commonly applied. Grass- legume pastures have been proposed as a means of providing N, and therefore preventing pasture degradation. They have also been shown to improve nutrient cycling, quality of organic matter, soil biological activity and carbon sequestration. However, only 2% of the area contains legumes, and 88% of farmers who planted legumes report that legumes failed to persist.The reported lack of persistence of currently available legumes when planted with C4 grasses, is well supported by data from trials, the exception being the recently released legume, *Arachis pintoi*.

Application of the livestock model to data from available on - farm trials shows that on a farm with fragile soils and undulating topography, the IRR for grass - legume pastures is marginally lower than for pure grass pastures. On a farm with highly sandy soils, the IRR to grass-legume pastures is 4% higher than for pure grass pastures, with 20% conversion to improved pastures. When 50% of the farm is planted to improved pastures, the profitability advantage of grass-legume pastures over pure grass pastures increases to 7% (Table 3). In the first trial (farm Guayabal) LWG was lower on the grass-legume pasture. In the second (farm Amparo) it was about 30% higher. In both trials legumes effectively disappeared after 3 years, and had to be resown, while the grass persisted. Thus the performance of legumes is highly variable on-farm, and the advantage over pure grass is relatively small at low rates of pasture adoption. More data on the performance of legumes on-farm, and under farmers' management are required. In a controlled trial, with best practices, on an experiment station

(Carimagua), it was possible to maintain the legume content for 16 years without renovation. Simulation analysis with data from this trial shows that farm profitability is 6% higher for grass-legume pastures than pure grass pastures, if 20% of the farm is converted to improved pasture. The advantage of grass-legumes increases to 11% under 50% conversion to improved pastures. Without legume persistence, the IRR for legume pastures is about 5% lower. In addition, a persistent legume with consistent on-farm performance may result in legume pastures commanding a higher price than pure grass pastures. With high rates of land appreciation, this could contribute substantially to the profitability of legumes. Legume persistence, however, is favored by a flexible grazing regime, which requires intensive management and a large number of paddocks, both of which are difficult to implement in conditions of absentee ownership and cash constraints. Recent data indicate that *Arachis pintoi* persists under heavy grazing pressure. Economic analysis of Arachis is underway. The analysis also shows that the advantage of legumes over grass pastures increases at lower rates of land appreciation. If land prices increase at 5% p.a. the IRR of legumes is almost 30% greater than that of grass pastures (Table 3). The implication is that legumes should be targeted to areas of relatively high land prices, where the increase in land price has begun to taper off. In the Colombian savanna, where land prices are increasing rapidly, one option may be to consider N applications as a means of improving the ground cover of grass pastures. Trials to quantify the response to N are scheduled to start next season.

Table 3. Internal Rate of Return, pure grass vs grass - legume pastures: simulated results from whole farm livestock production model, 1995 [1].

	20% conversion to improved pasture		50% conversion to improved pasture	
	Grass	Grass-Legume	Grass	Grass-Legume
B. dictyoneura, C. acutifolium, and *S. capitata* [2]	14.8	14.4	17.7	16.9
B. dictyoneura, C. acutifolium [3]	13.4	13.9	14.7	15.7
B. decumbens, P. phaseoloides [4, 5]	15.7	16.7	18.9	20.9
B. decumbens,P. phaseoloides [4, 6] (without legume persistence)		16.1		19.7
B. decumbens, P. phaseoloides [4, 5] (land price appreciation 5% p.a.)	7.2	8.6	10.3	13.1

1 Farm size: 1500 ha; Time horizon: 15 years; Rate of land price appreciation: 14% p.a. (real terms); Price data: from area of moderate infrastructure/plateau.

2 Data source: Sanz and Vera (1994). Farm Guayabal, Ondulating topography; fragile soil; Renovation every 4 years.

3 Data source: Sanz and Vera (1994). Farm El Amparo, sandy soil; Renovation every 4 years.

4 Data source: Lascano (1995). Carimagua, well drained plateau.

5 No renovation.

6 Renovation every 3 years.

In conclusion, the rapid increase in land prices has been the key driving force behind recent land use change in the Colombian savanna. If land prices continue to rise rapidly, the adoption of grass pastures should continue to increase with relatively low levels of management. The pressure on native savanna should ease, and the main focus on technology development should be on preventing the degradation of grass pastures and gallery forests. Technologies which are intensive in management or capital requirements are unlikely to be adopted. If the increase in land price slows down substantially, there may be a greater incentive for the adoption of more intensive practices, including grass-legume pastures, particularly in areas of higher land prices. We plan to present our results to farmers in the savanna for their feedback.

Driving forces behind land use change in Mato Grosso state in the Brazilian savanna: *Joyotee Smith, Miguel Ayarza (CIAT), and Paulo R. F. Franz (EMBRAPA), with the collaboration of Edsen Oliveira (CIAT).*

Analysis of census data from the Brazilian savanna has revealed several patterns of land use change within the Brazilian savanna. Key informant interviews and secondary data collection are being carried out in strategically selected sites in the Brazilian savanna to develop hypotheses about the driving forces behind land use change. These hypotheses will be tested in a project in collaboration with the University of Hohenheim, which is due to start next April.

Mato Grosso was selected because, as a frontier region far from markets, it provides a strategic contrast to Uberlandia, where the Tropical Lowlands Program has been active for a number of years. Comparison of the two areas should provide insights about the determinants of land use change. Mato Grosso is also a transitional area between the savanna and the Forest Margin. As such it provides opportunities for studying interactions between the two ecosystems.

Production systems in Mato Grosso can be classified into four broad categories. The most spectacular is capital intensive annual crop production dominated by soybean. This is mainly carried out on the flat plateaus (chapadas) occupying 40.6% of the state. The northern part of the state is the transitional area between the savanna and the Forest Margin, where logging is the dominant industry. The southern part of the state borders on the Pantanal, the largest wetland area in the world. Transitional areas between the Pantanal and the chapada consist of rolling landscapes, characterized by cattle ranching and sugarcane production. The riverine areas in this region have commercialized small scale milk production. Selected characteristics of these four production systems are given, for typical municipalities, in Table 4.

Capital-intensive soybean production in the chapada (typified by Lucas do Rio Verde) appears to be an anomaly, because the area is a frontier region settled as late as the mid 1970s, and characterized by land abundance. Also the area is about 2000 km away from ports in Parana from where the soybean is exported. Under these conditions one would expect semi-extensive cattle ranching, as in the Colombian savanna. Yet the production system is very similar to soybean systems in Parana, an area of high land prices, close to export markets. Mato Grosso is now the second largest producer of soybean in Brazil. In 1992 it produced 19% of Brazil's production, and yields (approximately 2.7 t/ha.) are the highest in Brazil. Discussions with key informants revealed that this capital intensive system in a remote frontier area is the result of past subsidies, particularly incentives for private investment, such as subsidized credit at negative real interest rates of up to -35%

p.a., uniform minimum support prices for crops and fuel (irrespective of distance), support for processing industries, and access to public land for private colonization projects. In addition, the construction of the Cuiaba-Santerem road enabled settlers to take advantage of the subsidies. Settlement in the area was driven by private enterprises which began by subdividing and selling public land, to relatively well- off settlers from southern Brazil, who were attracted by the low cost of land in Mato Grosso, and the agroecological conditions in the plateau which favor mechanized soybean. Since then, these private enterprises have been a major economic force in the area, constructing and maintaining infrastructure for soybean production, such as farm to market roads, storage facilities, generating electricity, and even carrying out some agricultural research. Key informants were unanimous that these developments would have been impossible without subsidies, particularly negative real interest rates. This is borne out by the fact that key informants were also unanimous that the profitability of soybean production is now seriously threatened. This appears to be due to macro stabilization policies which have resulted in real interest rates as high as 40% p.a. in real terms. This is a serious burden for farmers who have borrowed heavily for acquiring machinery, and who, in addition, have to pay recurring costs of about $300/ha. for soybean production. Other factors are competition from MERCOSUR, currency appreciation and deterioration in transport infrastructure linking the area to its markets. As a result transport costs to the south are now $80 to $90/t, which is expected to push prices for soybean down to a level where recurring costs can barely be covered.

Table 4. Characteristics of production systems in Mato Grosso State, Brazil, 1993/94.

	Lucas do Rio Verde	Sinop	Barra do Bugres	Sao Jose Dos Cuatro Marcos
Topography	Plateau	Savanna/Forest Transition	Undulating	Riverine
Dominant entenprise	Soybean	Logging	Cattle/Sugar Cane	Milk
Crop area (%)	32	4	2	9
% crop area:				
Rice	15	58	4	5
Beans	0.2	0	0.3	5
Maize	13	8	3	24
Soybean	72	31	0	0
Sugar cane	0	0	88	1
Cattle/km^2	4.9	15.4	18.7	49
Population density	3.51 (1993)	23.63 (1991)	29.2 (1989)	35.5 (1988)
Farm size distribution				
Farms > 200 ha (%)	86	35 [a]	n/a	12
Farms < 50 ha (%)	8	30 [b]	n/a	44

[a] Farms > 120 ha (%)

[b] Farms < 60 ha (%)

Private enterprises in the area are trying to maintain the viability of crop production by exporting produce from Atlantic and Pacific ports. This will require major improvements in infrastructure through northern Mato Grosso, Para and Rondonia, which will almost certainly lead to massive deforestation. Given the current balance of power in Brazil, economic interests are likely to prevail over protection of the environment. The major impediment to the export corridors will be funding, given the high cost of capital.

Agricultural development in the frontier regions has generated substantial quantities of employment in small towns which have sprouted up in these areas, dedicated to servicing crops such as soybean and sugarcane. Population growth has been 17% in the decade of the 1970s, and 12 % in the following decade. While population density is still very low ($2.3/km^2$ in 4 municipalities in the vicinity of Lucas do Rio Verde), due to settlement having started in the 1970s, it is substantially higher than in the Colombian savanna, where settlement began in the 1930s, and population density is now about $1.4/km^2$ in the municipalities of Puerto Lopez and Puerto Gaitan. In Mato Grosso urban growth appears to be more rapid in dynamic agricultural areas, thus supporting the hypothesis that agriculture has been the engine of growth.

Mechanized monocropped soybean production has led to soil compaction and the build up of pests and diseases. In response to this, farmers are beginning to adopt a no till crop rotation system (safrinha), in which early soybean is followed by rice or maize. In Lucas do Rio Verde safrinha was estimated to be adopted by 80% of farmers on a small part of their farms, the safrinha area being estimated to be 10% of the crop area. The benefits from the environmental point of view are reduced erosion and pests. The major disadvantage is increased herbicide use.

Under the regime of high interest rates, some soybean farmers may consider converting a part of their farms to pasture, to reduce recurring costs. Rotation with crops may be an option in these parts of their farms. We did not see any evidence of the establishment of pastures by soybean farmers. This may be because the investment required for a shift to livestock is impeded by the abnormally high interest rates. If interest rates decline, and if the environmental lobby is successful in blocking the export corridors to the Atlantic and Pacific, gradual conversion to pasture may occur. Discussions with farmers and key informants indicate however, that a better target for crop-pasture rotation may be the livestock fattening systems which occur in undulating areas of fertile soils with good access to markets. In these systems the relative profitability of crops and livestock may be more comparable, and therefore rotation may be more acceptable. Another niche may be the small scale milk production systems, where both pastures and crops are grown, and where a few cases of rotation were mentioned. Overall however, nowhere was crop-pasture rotation reported to be occurring on more than 10% of farms. There was widespread evidence of the adoption of grass pasture (*B. brizantha* cv. Marandu), but no evidence at all of legume adoption.

In conclusion, we hypothesize that the driving forces behind land use change in Mato Grosso are very different from those in the Colombian savanna. While the subsidy driven development path in Mato Grosso has been more spectacular than land use change in the Colombian savanna, it also appears to be less sustainable, both economically and ecologically, and could generate massive negative externalities through deforestation if the export corridor is built. On the positive side, the subsidy driven path has the capacity to generate employment, which may have relieved pressure on the Amazon. In addition, it has generated an enterprising private sector, which has, in many ways, taken on a number of the traditional services provided by the public sector. The challenge now will be to channel these energies into protection of the environment, an objective that can only be achieved through policy and institutional change which internalizes the costs of environmental degradation.

Land Use Dynamics Cerrados: *Miguel Ayarza (CIAT), Lourival Vilela (EMBRAPA) with support from Dpt. Geography, UFU and COODEPRATA.*

Introduction

During the past three years the Section carried out several activities to characterize land use systems and resource degradation in current agricultural systems in the Brazilian cerrados. The results of the work showed that the dominant land use in the flat areas is continuous monocropping with intensive use of inputs. Extensive livestock systems are present in undulating lands, and on more fragile soils. Small holdings exist on various soil types and landscape positions. Crops and milk are produced in these systems with low levels of inputs and technology.

In the present year, we collected secondary data, and visited several small dairy production systems to characterize resource use and production problems of small dairy production systems. Estimates made by the National Milk Center of EMBRAPA indicate that the Cerrados produce 40% of Brazil's total milk production. Many small farmers depend on this activity.

The characterization work was conducted in the Municipio of Prata (M.G) which is 80 km from Uberlandia. This region was selected because some preliminary information showed that: 1) milk production is the most important activity of small farmers in the region; 2) problems of pasture degradation are common in the region and 3) there is a Cooperative that plays a key role in milk marketing and technology transfer to small producers. Eighty percent of the farmers of the region are members of the Cooperative.

The operational strategy of the work consisted of the analysis of secondary information produced in 1994 by the Department of Geography of the University of Uberlandia and the use of a satellite image taken from the region in 1992 to evaluate land use systems. In addition there were available records of production provided by the Cooperative. The information was complemented with a visit to twelve small farmers selected by the Cooperative. The objective of the visit was to asses the production problems and the farmer perspective for solutions.

The preliminary results of the work are summarized below.

Environmental Characterization

The municipio of Prata is located between two main rivers: the Paranaiba and the Rio Grande. These two rivers are tributaries of the Parana River. Most of the region has sandy soils derived from sedimentary rocks. Relief is gentle in the top of the "chapadas", however it is pronounced in the vicinity of the many streams and rivers, making the region susceptible to soil erosion. Altitude varies from 866 to 631 masl. Total annual rainfall is 1500 mm following the typical distribution of most of the cerrado region. There is a strong dry season from March to October.

Native cerrado vegetation (typic cerrados and cerradaos) has mostly been replaced by cultivated pastures and reforestation (Table 5). There are small areas under crops, mostly with irrigation. The area under citrus fruits is increasing.

Population dynamics and composition

Almost half the population of the region lives in rural areas. During the last thirty years rural population has increased more than the urban population (Table 6). Contrary to many frontier regions, the population is mostly composed of local people from the region. Significant out migration to neighboring cities like Uberlandia has not occurred. Average family size is about 4-6 people.

Table 5. Major land use systems present in the municipio of Prata (MG) in 1992.

Prod. systems	Area (ha)	% of total
Pastures	323.24	67.4
Reforestation	10000	2
Annual cropping	10760	2.2
Citrics	3400	0.7
Native cerrados and Varzeas	132000	67.4
TOTAL	**479400**	**100**

Source: Relatorio Sindicato dos Productores de Prata (1992).

Table 6. Changes in rural and urban population during a period of thirty years in the municipio of Prata (M. G).

Population	1960	1970	1980	1991
Urban	10795	10557	10921	13077
Rural	5841	7944	8633	11554
Total	**16810**	**18501**	**19554**	**24531**

Source: FIBGE, Demographics Census.

Production systems

Extensive livestock and small dairy production systems are the dominant land use systems in the region. The secondary information produced by the University of Uberlandia indicated that of 192 properties surveyed, 53.9% were dedicated to milk production. The rest raised beef cattle. However, 71% of farms had both activities in the same property. Sixty percent of the 1741 rural properties of the Municipio are less than 200 ha (Table 7). Most of the production systems are run by the owners who live on their farms, and derive sixty seven percent of total income from agriculture activities.

Sustainability problems of small dairy production systems

Milk production in the region is very low especially during the dry season. Production records from the Cooperative showed that 54% of producers delivered in May, 1995 between 10-60 lt/day (Table 8). The visit to the selected farmers showed that low levels of milk production were related to biophysical and socioeconomic constraints. Soils in most farms were sandy, with low levels of available P and low CEC (Table 9). Because of the inherently low soil fertility and the lack of resources to reclaim pastures, most of the milk produced during the wet season is obtained from degraded *Brachiaria* pastures. During the dry season feed availability is limited to the use of cut-and-carry grasses and sugar cane. Animals receive concentrates produced by the Cooperative and paid back by farmers with milk.

In spite of the well-known traditionalism of farmers of this region there is an increasing perception that milk production, specially during the dry season, must increase if farmers are to improve their incomes. However, they can not afford to invest in conventional technologies with intensive use of inputs. Farmer interviews showed that there was a general lack of machinery, labor availability and credit to recuperate pastures.

The information obtained from this work showed the importance of dairy production systems for the small producers of the region. However, productivity is constrained by low soil fertility, pasture degradation and lack of feeding alternatives for the dry season. There are socioeconomic constraints to the adoption of conventional technologies of pasture recuperation. However, some agropastoral options being tested in Uberlandia may have the potential to improve milk production specially during the dry season. Future plans include the establishment of improved pastures using *Stylosanthes guianensis* cv Mineirao and *Arachis pintoi* BRA 31143 as components of agropastoral systems in small dairy production systems, as well as shrubs and trees components. A more comprehensive project is under preparation for funding. The objective of the new project is to asses the biophysical and socioeconomic impact of pasture degradation and reclamation among small dairy production systems.

Table 7. **Farm size distribution in the municipio of Prata (MG).**

Farm size (ha)	Number	Percentage	Accumulated Percentage
0-10	76	4.36	4.36
11-50	368	21.1	25.46
51-200	652	37.4	62.86
201-500	375	21.5	84.36
501-1000	161	9.2	93.56
>1000	109	6.2	99.76
TOTAL	**1741**	**100**	

Source: Prefeitura Municipal, 1993.

Table 8. Classification of milk producers according to daily production.

Classification	Number	Percentage	Production (lt/day)
Large	77	7.4	250-1000
Medium	399	39	70-200
Small	556	54	10-60

Source: Cooperative of Prata, May 1995.

Complementary subproject TD51: Alternatives to Slash-and-Burn: *Sam Fujisaka*

Land use strategies of Amazon colonists. Settlers in two Brasilian Amazon colonies, Pedro Peixoto in Acre and Theobroma in Rondonia, were interviewed about land use practices. Settlers practice slash-and-burn agriculture on relatively large, forested parcels to produce rice, maize, and beans. Deforestation rates average some 2.0 ha per year per family in Pedro Peixoto and 3.0 ha per year per family in Theobroma. Lands are then converted to pasture as settlers develop herds for beef and milk production. Settlers in the older Theobroma colony also produce coffee; while colonists in Pedro Peixoto still harvest Brazil nuts from the forest.

Cluster analysis was used to differentiate land use strategies. Four strategies in each community included from subsistence production on medium to large, mostly forested holdings in Pedro Peixoto to milk and cattle production on large, deforested holdings in Theobroma

(Table 10). It appears that land use strategies are converging into two categories: smaller, mixed agriculture and--for a few--cattle ranching. Unfortunately, both strategies imply continued deforestation. Maintaining or enhancing settler well-being after forest lands have been converted will depend on successful slash-and-burn using fallow rotations for small farmers and on sustainability of pastures for the ranchers.

Table 9. Soil fertility characteristics of the twelve small dairy farms visited in the region of Prata (MG).

Parameter	Mean	St. Dev.	High value	Min value
Sand (%)	50.0	19.2	68.4	8.8
Clay (%)	23.5	8.9	43.0	14.9
pH	5.4	0.3	5.9	5.0
P (ppm)	2.1	1.2	4.2	0.9
K (ppm)	67.5	61.5	196	20
Al (meq/100cm^3)	0.39	0.31	0.8	0.0
Ca (meq/100cm^3)	1.2	1.8	6.2	0.2
Mg (meq/100cm^3)	0.6	0.7	2.3	0.0
ECEC (meq/100cm^3)	2.4	2.4	9.0	1.0
Al Sat. (%)	31.8	28.8	74.0	0.0
OM (%)	1.65	0.89	4.2	0.9

Table 10. Resource use strategies.

	Pedro Peixoto				Theobroma			
	1	2	3	4	1	2	3	4
Land holding	2*	1	2	3	2	1	2	3
Deforested	1	2	2	3	2	2	2	3
Rate of deforestation	1	2	3	3	3	2	2	3
Role of cattle	1	1	2	3	2	1	2	3
Role of milk	0	2	1	0	2	1	3	3
Role of food crops	1	2	3	1	3	3	2	0
Role of coffee	0	0	0	0	3	1	3	0
Role of Brazil nut	3	2	3	2	0	0	0	0
Role of non-farm income	3	3	2	2	2	2	1	2

* Higher number = greater quantify or importance

Plant community diversity relative to human land uses in an Amazon forest colony. Numbers of plant species and individuals were examined relative to land use in an agricultural settlement in the Brasilian Amazon. Land uses were forest, cropped after forest, fallows, cropped after fallow, and pasture. These uses corresponded roughly to farmers' land use changes over time. As expected, species diversity was high in forest. Diversity was also high, however, in fallows of 3-5 years--as a result of both survival/reestablishment of forest species and appearance of plants not found in forest (Figure 2). Lands cropped using slash-and-burn maintained moderate numbers of species--both forest and non-forest. Not considering pastures, lands cropped for a third year after forest and the first year after fallows had the highest plant density, reflecting weed invasions. Useful (e.g., for construction, food, and medicines) forest plants decreased with land conversion; although new spieces also appeared. The least number of useful plants and the greatest losses of the forest species were encountered in pastures. Conversion to pasture rather than slash-and-burn agriculture **per se** was the main contributor to biodiversity loss.

Classification of slash-and-burn agricultural systems. Seventy-nine publications describing 107 cases were reviewed in order to develop a scheme to classify slash- and-burn agriculture systems. Four variables -- initial vegetative cover, type of user, final cover, and fallow length -- were used to describe each case. Eight groups representing the same or similar combinations of values were identified. Groups were keyed using different colors and shapes for placement of each case on a global map indicating geographic distribution (Figure 3). The method provides a way to establish similarities or differences among slash-and-burn cases (or representativeness of cases) to the degree that available literature represents what exists in the field. Researchers are invited to provide descriptors of additional cases, respective references, and case locations in order to improve and test the utility of the method and to simultaneously expand the resulting database.

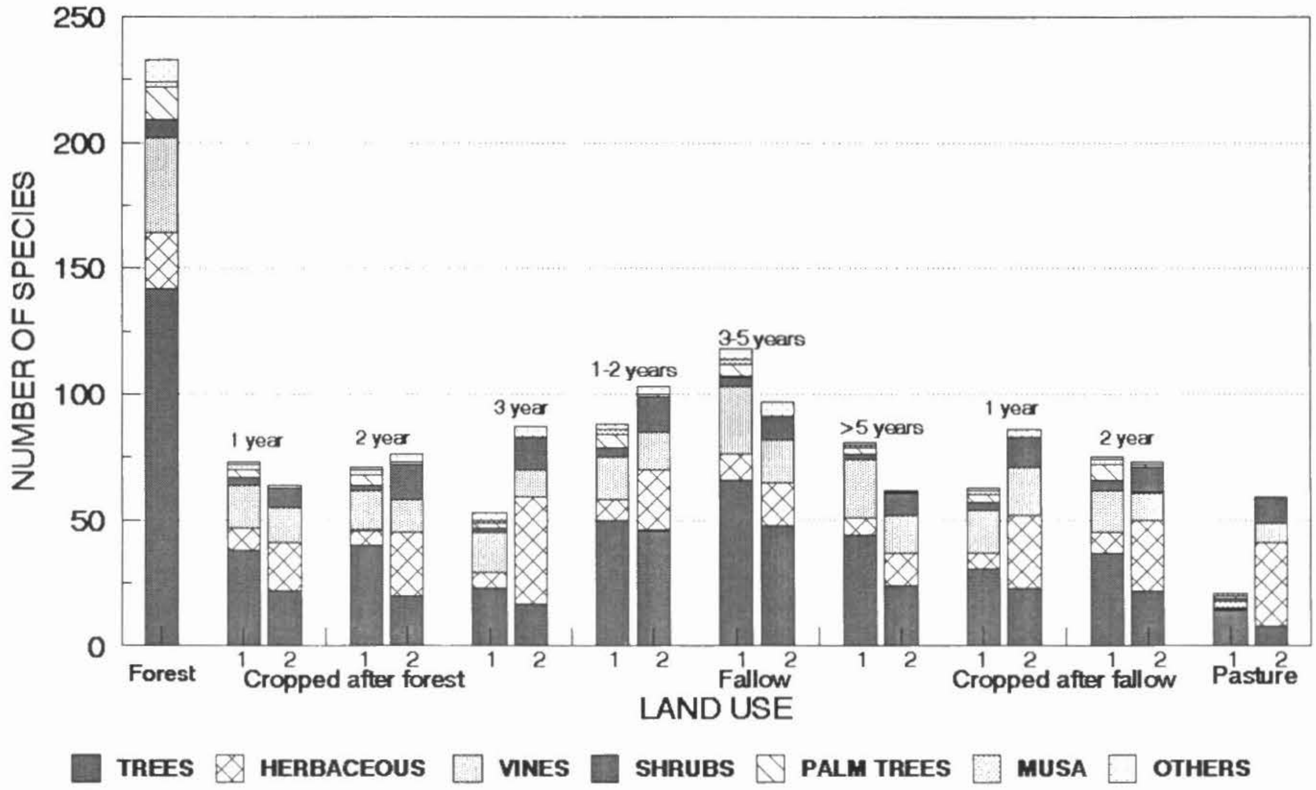

Figure 2. Number of species by plant type found (1) in forest & continuing in other uses & (2) appearing in other uses, Acre, Brazil, 1994

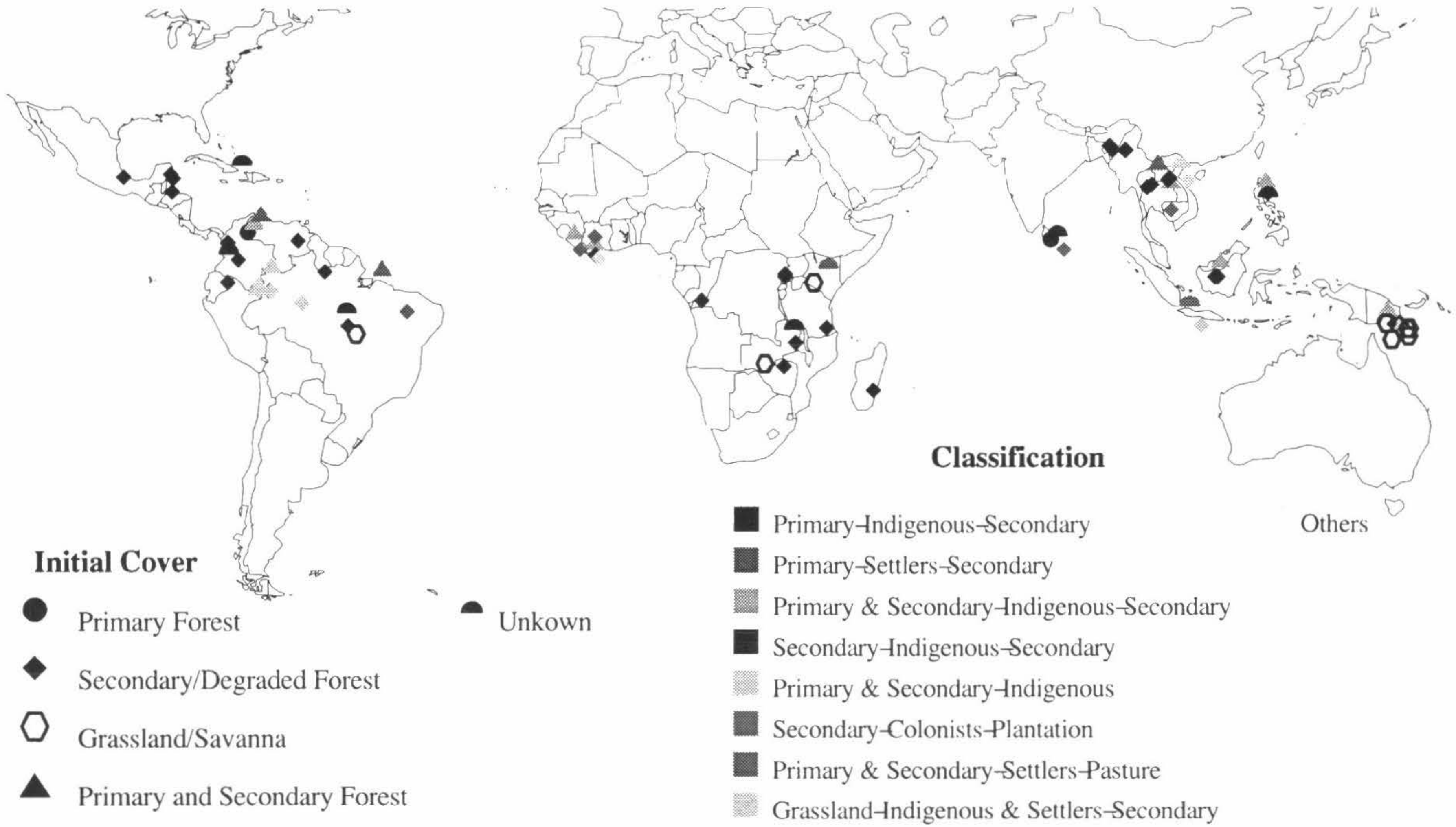

Figure 3. Location of classified slash-and-burn sites

Project TP01: Prototype sustainable cropping systems

Project Officer: ***José I. Sanz***

By (in alphabetical order): *Edgar Amézquita* (TLP), *Miguel Ayarza* (TLP), *Albert Fischer* (RP), *Arjan Gijsman* (TLP), *Peter Jones* (LM-SRG), *Esteban Pizarro* (TFP), *Georges Rippstein* (TLP), *José Ignacio Sanz* (TLP), *Michael Thung* (TLP), *Raúl R. Vera* (TLP), *Lourival Vilela* (EMBRAPA-CPAC)

Introduction

The tropical American savannas and to some extent the forest margins have been traditionally devoted to extensive grazing. In the last few years, this situation has been changing, with the introduction of annual crops and more modern systems of animal production.

Remote control and ground thruthing studies show an increase in environmental degradation in aspects such as soil erosion and loss of native species. This degradation is the result of a more intensive use of the resources as well as the adoption of inappropriate forms of land preparation and management.

Purpose

The purpose of this project is to generate technologies that allow for lasting increases in the efficiency of resource use and that control soil and water degradation. The aim is to reconcile the more intensive agricultural production with the conservation and enhancement of the natural resources for the diversity of conditions found throughout the tropical American savannas and forest margins.

Structure of the project

The project is subdivided in three subprojects, all entitled *Prototype Cropping Systems*, but each of them covering a different geographic region within the Tropical Lowlands i.e., Llanos, Cerrados and Forest Margins. Within each of these regions, the scale of coverage varies from watershed to plot level (Figure 1).

For the Llanos and Cerrados, research follows the development path expressed respectively in Figures 2 and 3, with some work in most of the different steps of the figures, expressing each a stage in the ecosystem development. The major emphasis being on Agropastoral Systems in the Llanos and Cerrados, and Slash and Burn in the Forest Margins.

A summary of results of this mostly long-term research is being presented here, highlighting some aspects along the scale of coverage, from watershed to plot level.

Watershed studies

Tropical lowland study area Meta, Colombia

We have had a rather disappointing year on this work. As previously reported, we have a wealth of information digitized, including soils and topography. We have analyzed some historic Landsat TM images in an unsupervised mode. These have given us some interesting insights into the extent of gallery forest and access to water.

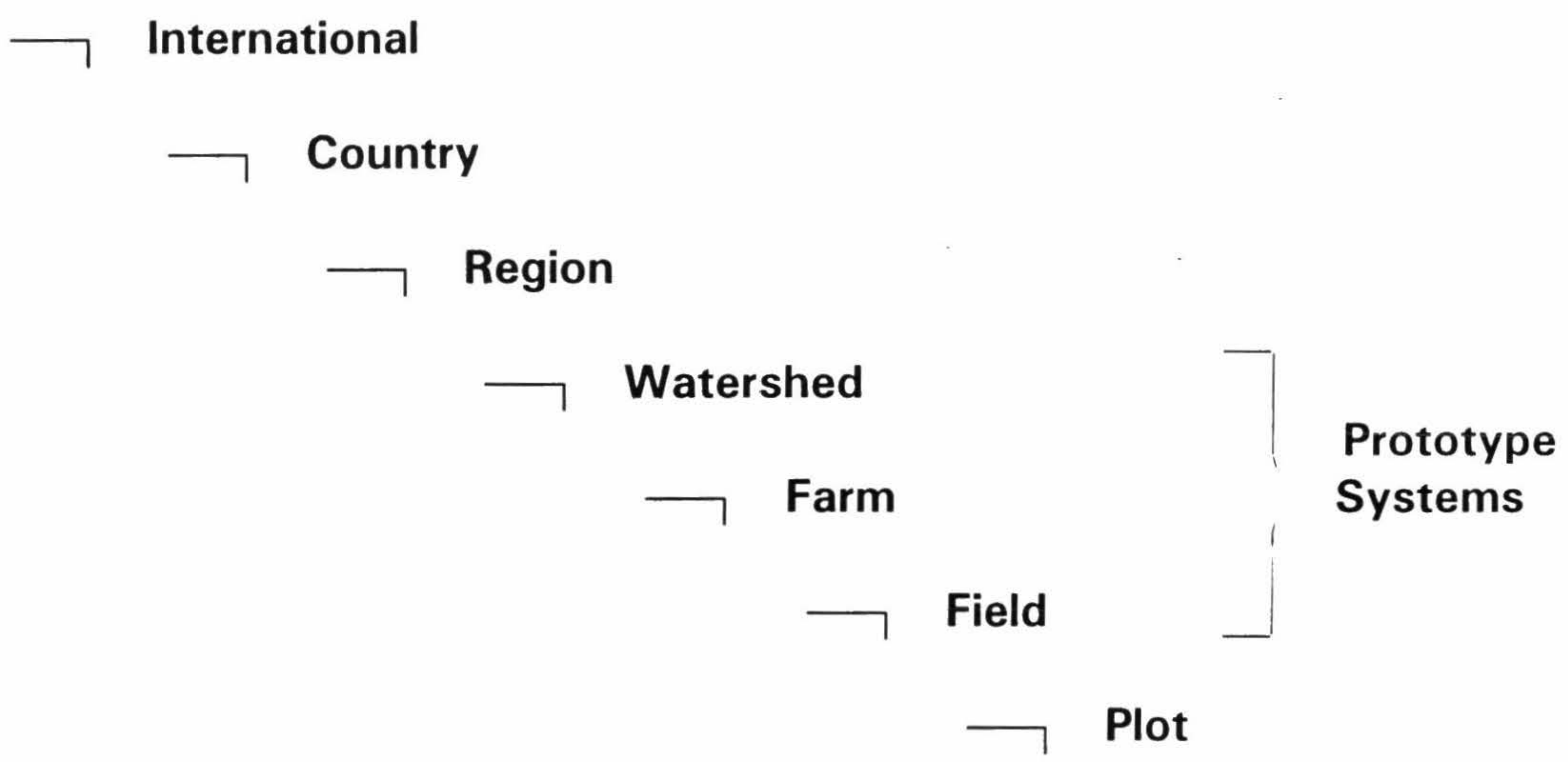

FIGURE 1. SCALES OF RESEARCH WITHIN THE PROJECTS OF THE TROPICAL LOWLANDS PROGRAM

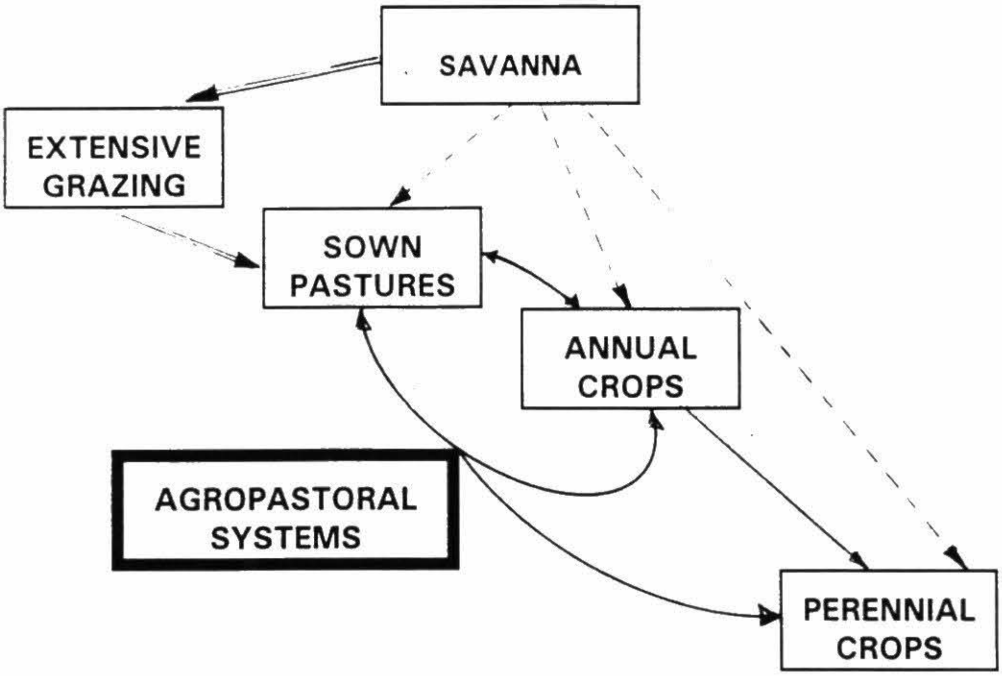

FIGURE 2. DEVELOPMENT PATH FOR THE SAVANNAS AND CERRADOS

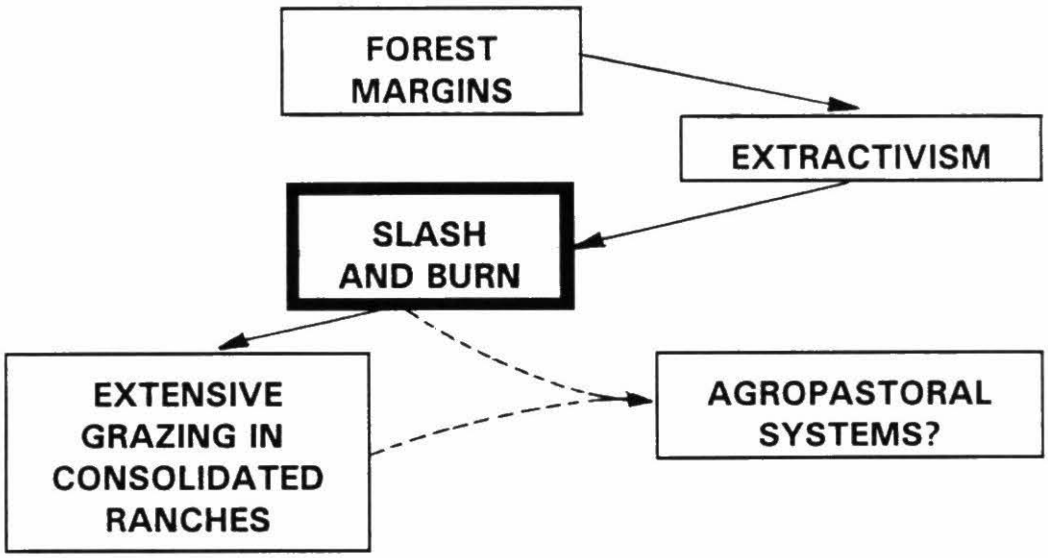

FIGURE 3. DEVELOPMENT PATH FOR THE FOREST MARGINS

The hurdle we have to cross now is to produce a current, ground-truthed image from which we can work back in time. We carried out a major ground truthing mission in February 1995. Using the Wilde System 200 GPS, we put in 35 very accurate points of photo control for georeferencing both TM images and aerial photographs. A very good coverage of actual ground truth was obtained in the process. Seven CIAT personnel spent two weeks in the field.

We had ordered a current TM image some months before. It appears that CLIRSON, the receiving station at Cotopaxi, Ecuador, is unable to process the images due to equipment failure. It is also very difficult to obtain images from EOASAT in the USA. The present landsat satellite is about on its last legs.

We still hope to rescue some data from the ground truth exercise, but the only image available has some cloud cover. It remains to be seen if this will interfere too much in our analysis.

Ecological studies and rangeland management

Phytosociological studies. Eighty to ninety percent of the Eastern Plains of Colombia (Llanos) are constituted by broad natural grass formations. These big expanses of savannas present a huge potential for extensive cattle breeding. Unfortunately, these natural pastures have low productivity and quality, due to low fertility soils with deficiency in phosphorus and high acidity.

In regard to the importance of the breeding for the region, it is essential to know characteristics of the savannas in order to ameliorate their utilization. To this end, qualitative studies of the vegetation were conducted in the region in the *altillanura* and *serrania* zones.

Initial results were reported in former annual reports (1992-93, 1994). This year, a new study was conducted in the region between Puerto López and Puerto Gaitán, in *Serrania* and *Altillanura*, to characterize the principal vegetation groups for future mapping (Grollier, 1995).

A Factorial Analysis of Correspondence, carried out with 104 floristic surveys cards elaborated during the investigation of 29 sites, allowed the characterization of eight vegetation groups (or communities). To explain these groups, soils surveys were conducted and enquiries on utilization conditions (frequency of the fire, number of animals per ha) were made.

A quantitative study has to be considered in order to classify savanna pastures potential.

Vegetation diversity. During this study, 190 species, from 114 genera and 41 families were collected (slightly more than in previous studies).

These ecological studies in the *Altillanura* and the *Serrania* of Colombia have shown high vegetation diversity, especially for the grasses (*Panicum, Paspalum* and *Axonopus* genera).

Soil humidity and soil texture are the most important factors affecting botanical diversity.

A statistical study with the vegetation data obtained in Carimagua has shown that the "Statistic Q" (Kempton & Wedderburn, 1978) can discriminate better the vegetation diversity than other indices.

Vegetation dynamics. Experimental studies with cattle have shown a rapid change in the botanical composition of the native savanna, even with low stocking rate.

There is a general and marked increase of *Axonopus purpusii, Andropogon leucostachyus* and *Tachypogon vestitus*, three important grasses, and an important decrease of *A. bicornis, Leptocoryphium lanatum, Paspalum pectinatum* and *A. selloanus*.

Frequent burning of the vegetation has also shown a slow but constant decrease of the phytomass, probably a consequence of botanical changes (Table 1).

Field and plot studies

Savannas

In the last six years of long-term experiments in the Colombian Llanos several contrasting prototype cropping systems have been tested. The benefits of well managed integrated crop-pasture systems have been documented and the negative results of continuous monocrop production or poorly managed integrated systems have also been recorded, particularly in terms of crop yields and soil nutrient balances. It is worth at this point to cut across these different land managements and observe the effect they have produced on the current land use as well as on the soil physical and biological (micro and macro) properties.

Table 2 summarizes the relationship between different variables for these long-term experiments. The different variables reflect the effect of the different land uses. In the renovated grass-legume pasture the dry matter (DM) on offer is low because of poor grass reestablishment after the renovation; no extra grass seed was added. Despite this, and having equal dry matter on offer than the native savanna, the figures for stocking rate, protein content, and animal weight gains per day are much higher, these last two even compared to the grass alone renovation.

The soil parameters reflect these conditions for the pastures as well as for the continuous yield decline in the long-term rice monocrop (3.7 t/ha in 1989 and 1.74 t/ha in 1994). The naturally packed old kaolinitic savanna soils and the more intensively grazed non-renovated *Brachiaria dictyoneura* present high resistance to penetration and higher bulk density whereas the more recently or frequently tilled pastures and rice exhibit lower values. Nevertheless, when the tillage is as frequent as needed for continuous rice production the large aggregates (>4 mm) are considerably reduced and the small ones (<1 mm) very much increased. Large aggregates are mainly cemented by sesquioxides and continuous tillage virtually destroys the aggregation in these Oxisols.

Less aggregated and therefore less porous (large and medium pores) soils have lower water retention and lower aeration. Earthworms and termites (macrofauna) biomass are reduced, as well as microbial N and P, in comparison to the renovated with rice grass-legume pasture which is so far the best proposed system for acid savanna soil management in the long-term.

Continuous rice is also so far, environmentally deleterious as it can be seen in all the shown variables, with values always below those of the naturally highly weathered soils of the native savanna.

Weed population ecology studies within prototype cropping systems are also being carried out. Diverse cropping systems have a diverse need for nutrients. The effect of nutrient levels in the soil on the species composition of the weed flora shows strong association with high or low levels of a nutrient appeared in general at low frequencies, indicating a narrow range of adaptation, and thus potential for use as indicators of fertility if their behaviour is consistent across experiments and seasons. According to our Canonical

Table 1. Production dynamics of the native savanna burnt every year. Annual biomass and one month old regrowth after fire

Weeks of rest	8			4			2			0		
Stocking rate	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
Andropogon bicornis	---	---	---	---	---	---	---	---	---	---	---	---
Paspalum contractum			+	-		-			+		-	-
Elyonurus candidus	+	-	-							+	-	-
Schizachyrium hirtiflorum	+++	+++		+++	++	---	++	---	---	+++	---	---
Leptocoryphium lanatum	-	--	---	-	---	--	---	---	---		---	---
Andropogon leucostachyus	+++		+++	+	+++	-	---	+++	++	---	++	++
Mesosetum loliiforme	+++	--	+++	+++		+++			+++	+		+++
Panicum parviflorum	+++	--		+++	---	+			+++	+	--	+++
Panicum versicolor	--	---		--	--		--	--		--	--	
Paspalum pectinatum	---	---	+++	---	---	---	+++	---	---	---	---	
Axonopus purpusii	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Panicum rudgei	++		+++		++		+++	++	-		-	-
Andropogon selloanus	---	---		---	---	--	--	--	---	---	---	---
Trachypogon vestitus	+++	+++		-	+++	+++	+++	-		+++	+++	
Trachypogon plumosus	-	-			+			+		-	++	+

+++ High increase
++ Medium increase
+ Low increase

--- High decrease
-- Medium decrease
- Low decrease

Table 2. Relationship between different variables in long-term prototypes with *Brachiaria dictyoneura* pastures, native savanna, and continuous rice monocrop. Matazul, Llanos Orientales, Colombia. 1989-1995

Variable	Savanna	*B. dictyoneura*			Continuous rice-monocrop
		non-renovated[1/]	renovated grass alone[2/]	renovated grass-legume[2/]	
Pasture on offer (DM kg/ha)	1300	2118 a*	2615 a	1300 b	-
Growth (DM kg/day.day)	-	14.40 b	27.60 a	21.00 a	-
Stocking rate (AU/ha)	0.35	1.50 a	2.17 a	1.79 a	-
% protein on offer	3.70	3.70	5.00	8.10	-
In vitro digestibility (%)	35.00	63.40	62.40	65.30	-
Weight gains (g/an/d)	74	71 c	302 b	552 a	-
Penetrability (0-17.5 cm)	16.30	18.70	12.00	12.00	11.9
Soil aggregate size (0-2.5 cm) (%)					
>4 mm	37.5	24.8	-	32.1	13.6
1-4 mm	27.8	31.6	-	29.6	29.8
<1 mm	34.7	43.6	-	38.3	56.6
Bulk density (0-12.5 cm) (g/cm^3)	1.41	1.35	-	1.33	1.29
Earthworms biomass (0-30 cm) (g/m^2)	3.41	3.93	4.61	6.03	1.46
Termites biomass (0-30 cm) (g/m^2)	2.35	7.14	3.26	2.17	1.88
Microbial N ($\mu g/g$)	53.1	-	-	62.2	34.3
Microbial P ($\mu g/g$)	9.6	-	-	12.8	9.6

* Same letters in the same line do not differ significantly ($P \leq 0.05$)

1/ Established with rice in 1989
2/ Established with rice in 1989 and renovated with rice in 1993

Discriminant Analysis (CDA) analysis some of those species have already appeared associated with the same nutrients (and levels) in more than one experiment, as is the case of *Hyptis* sp (low P), *Juncus dichotomifolius* (high P, Fe, Mg), *Croton trinitatis* (high Mg and Ca), and *Colocasia esculenta* (low Ca).

In the long-term, besides establishing associations between weeds and crop management variables, as well as with nutrient levels, the challenge ahead is to attempt to understand the ecophysiological bases for such associations, thus being able to extrapolate conclusions beyond the working environment.

Cerrados

The Brazilian Cerrados, covering 205 million hectares, have contributed importantly to the country's crop and livestock economy during the last three decades. However, the intensive use of these areas particularly for monocropping and pasture development, has given rise to forms of land use that are neither environmentally nor economically sustainable. Alternative land use systems are needed to halt and revert declining productivity and losses of soil and water. Among technologies with potential to do this, the combination of crops and pastures in space and time is one of the best options. This technology can increase overall productivity, enhance soil fertility and contribute to improve the socioeconomic condition of farmers.

Tradeoffs between crop and pasture components. The introduction of forage legumes in crop-pasture systems with high inputs has been difficult so far. *Stylosanthes mineirao*, which can be established in rice-pasture systems with low inputs, suffers from severe competition in crop-pasture systems with high inputs. Therefore, more aggressive legume species are needed, with better adaptation to competition. A small plot experiment was carried out in a sandy soil of Uberlandia to test the establishment ability of three *Calopogonium* and three *Pueraria* accessions selected by the Tropical Forages Program. They were planted alone and simultaneously with corn and with corn and *P. maximum* cv Tanzania. The experiment included as reference species *Stylosanthes mineirao*, *Arachis pintoi*, the commercial cultivar of *Calopogonium* and perennial soybeans (Neonotonia). Species were planted in 2 m rows with four repetitions. Grain yields and dry matter of the pasture components were determined at corn harvesting (120 days after planting). Population stands were determined fifty days after planting and at the harvesting time. Results were analyzed by species using the ANOVA procedure in SAS.

A similar dry matter reduction was observed among the new accessions and the control species planted either with the crop or with the crop and the grass (Table 3). Legume population also decreased (Table 4). However the percentage of reduction in the crop-legume-grass treatment was lower for *Arachis pintoi* (24%) and higher for *Stylosanthes mineirao* (66%). Percentage of reduction of the new *Calopogonium* and *Pueraria* accessions varied between 29% and 56%. Average grain yield in the corn-legume system was 8.8 ton/ha and 8.5 ton/ha in the corn-legume-grass system. Grass dry matter production at harvesting time was 2.8 ton/ha.

From the results of this experiment we can conclude that competition is a major factor interfering with forage legume establishment in crop-pasture systems with high inputs. Competition involves loss of population and reduction of growth. *Arachis pintoi* was the only species capable of maintaining its original population through the crop cycle.

Table 3. Yield reduction of ten forage legumes planted with corn and *P. maximum* c.v. Tanzania in a sandy soil of Uberlandia (values are the mean of four repetitions)

Species	Monoculture (g/2 m)	Leg + Corn (g/2 m)	Reduction (%)	Leg + Corn + Grass (g/2 m)	Reduction (%)
A. pintoi 31143	785 + 192	192 + 26	75	31.7 + 16	96
C.m. 3174	1338 + 63	325 + 63	76	86 + 16	93
C.m. 0477	1361 + 59	218 + 17	84	87 + 19	93
C.m. commercial	1424 + 63	238 + 27	83	75 + 29	95
P.p. 612	462 + 49	117 + 15	75	19 + 2.2	96
P.p. 582	531 + 138	107+6.7	80	24 + 14	95
P.p. 761	390 + 62	120 + 31	70	8.2 + 2.6	98
P.p. 817	384 + 106	106 + 29	72	24 + 5.0	94
Stylo mineirao	1083 + 115	48 + 14	85	15 + 3.5	99
Commercial Neonotonia	513 + 115	127 + 13	75	40 + 2.4	92

Table 4. Relative decrease of plant populations of ten forage legumes when planted alone and in association with corn and *P. maximum* cv Tanzania in a sandy soil of Uberlandia. Numbers correspond to the percentage decrease between two dates (53 and 141 days after planting)

Species	Monoculture	Corn + Legume	Corn + Leg + Grass
	----- percentage -----		
A. pintoi BRA-31143	0	0	24
C. muconoides BRA-3147	19	19	50
C. muconoides BRA-3174	16	13	35
C. muconoides BRA-0477	11	17	45
Commercial *P. phaseoloides*	15	16	56
P. phaseoloides BRA-582	7	17	53
P. phaseoloides BRA-761	52	25	29
P. phaseoloides BRA-817	11	26	32
Stylosanthes mineirao	25	42	66
Commercial Neonotonia	31	9	24

Table 5. Animal performance in several agropastoral systems established in Uberlandia in 1992. Individual gains (g/day) correspond to the mean value of eight evaluations during the whole evaluation period (220-300 days)

Management system	Treatments	Clay		Sandy	
		g/day	kg/ha	g/day	kg/ha
Livestock Product.Systems	Unreclaimed pasture	384 + 184	n.d	399 + 97	180
Livestock Product.Systems	Rice + grass pasture	354 + 145	226	437 + 97	180
Livestock Product.Systems	Rice + grass + legume	456 + 180	364	567 + 80	272
Continuous cropping	Corn + grass pasture	411 + 98	517	282 + 136	253
Continuous cropping	Corn + grass + legume	n.d	n.d	404 + 149	308

In spite of reduction in population and growth during the establishment phase, there is some evidence that legumes can come back after crop harvesting and initial grazing of the grass. This observation will be quantified next year.

On-farm testing of improved agropastoral systems. Large satellite plots of crop-pasture systems were established in two soil types in several farms of Uberlandia in 1992. The objective was, firstly to complement the results of the long-term crop-pasture integration experiment on progress at CPAC-Planaltina. Secondly, to measure the potential impact of crop-pasture integration on agricultural output and soil fertility under farm conditions. The work consisted on the reclamation of degraded *Brachiaria* pastures in livestock production systems with rice and a cocktail of forage legumes including *Stylosanthes guyanensis* cv Mineirao and the commercial cultivars of *Calopogonium* and perennial soybeans. The same cocktail of legumes was planted with *Panicum maximum* cv Vencedor and corn in a rotation systems with continuous cropping systems.

Establishment of the legumes in the livestock production systems with low inputs was excellent while it was poor in the crop-pasture rotation systems with high inputs.

After three years of grazing, *Stylosanthes mineirao* is still contributing largely to the total biomass of the reclaimed rice-grass-legume pasture in both sandy and clay sites. Legume proportion has been always around 50-60% and it has remained green and available for grazing during the dry season. Overall animal performance data showed that there was a 50% increase in liveweight gains in this system compared to the rice-grass pasture (Table 5).

In spite of the lack of legumes, the performance of animals on the *Panicum* pasture in the clay site has been outstanding (517 kg/ha-year). This contrasted with the lower gains of animals grazing the same species in the sandy site where *Panicum* is losing vigor rapidly. This could be related to the higher content of soil organic matter and the greater nitrogen supply over time in the clay site. Such finding has implications on the need of forage legumes in crop-pasture rotation systems in clay soils with high inputs. Factors such as soil type, organic matter content and length of the pasture cycle must be considered before making the decision.

Forest margins

The Tropical Lowlands Program in the Forest Margins is actively working towards fulfilling the overall goals of the Alternative to Slash and Burn Project: ***to reduce the rate of the deforestation caused by Slash and Burn Agriculture, recover and improve the degraded or abandoned land in the slash and burn areas, and introduce better germplasm as a way to increase biodiversity in the forest margins.***

Our research is expected to contribute to an improved understanding of nutrient and carbon dynamics in constrasting land use systems, which will serve as the basis for the design of improved farming prototypes in already intervened areas. Similarly, in the areas that have been disturbed by crops and pastures, new germplasm and crop management practices are being tested with EMBRAPA, with the expectation that they will contribute to stabilize yields and reclaim degraded lands.

Shifting cultivation effects on tropical soil organic matter (SOM). In order to measure the changes in SOM and its dynamics three farms with different soil types were selected and in all three farms the same treatments were set up in the beginning of the rainy season 1994. These experiments include standard treatments, and use standard TSBF methods, as part of a global network. On a clay soil two experiments were set up: on cleared land from primary forest, maize was planted, and on cleared land from five years old fallow, rice was grown in association with maize. On a poorly drained superficially sandy soil, rice was associated with maize, but at a lower maize density than in the previous case. On the third farm with a well drained sandy soil rice alone was established. The treatments are:

1. Primary forest or fallow vegetation cleared and burned, surface ash and non-combusted organic matter removed from that plot and the soil tilled to 20 cm depth.
2. Ash remains on the plot and incorporated to 20 cm deep.
3. As 1. above with additional 28 t/ha litter (from adjacent forest in the same quantity as would have been present before the burning happened) and tilled to 20 cm deep.
4. Farmer's practice with ash remaining on the surface and not tilled.

Due to the existence of large variations within the repetitions, there was no significant difference in rice grain yield among the treatments, but the tendency of the effect of ash management and tillage can still be observed. Yields between tilled (average of all ash managements) and no till treatment (farmers check) did not show significant differences in rice. Litter application at the rate of 28 t/ha (taken from adjacent forest and applied in the same quantity as was present when not burned), mixed with ash, gave the lowest grain yield in all three farms. Comparing all the treatments, the farmer's check always out yielded the other treatments. This suggests that farmers cultural practices obtained from many years of experience still prove to be better than what is supposed to be improved cultural practices in managing the ash after burning. In general, the harvest index of all treatments was low and the harvest index of rice from farmer's check plot was equal to the other treatments. Most of the slash and burn agriculture farmers do not incorporate the ash after clearing the land by fire, neither add litter. The ash remains on the soil surface and rice or maize are sown by hand planters. The additional litter though incorporated to a depth of 20 cm, caused temporary fixing of the nutrients especially on the poorly drained sandy soil.

In the well drained sandy soil and where ash and litter were mixed, rice yielded only 595 kg/ha. On clay soil, the additional litter had almost no negative effect on rice yields. Belowground biomass was highest in all farms where litter was added. This means that five months after adding litter to the plot, it could still be detected as undefined SOM. The high lignin content of the litter may have been associated with a low decomposition rate. The lowest extractable rice root biomass was found on sandy soils. Total rice biomass (above and belowground) during the wet season varied between 10.867 to 21.577 kg/ha.

Contrary to the rice yield, maize yields on the clay soil either from cleared land from primary forest or from five year old fallow (in association with rice) were highest on plots with ash management and tilled in comparison to the no till farmer's check plots. On the other hand, in the poorly drained sandy soil, ash and litter combination reduced maize yield by 1717 kg/ha when compared to the farmer's check. This treatment was the lowest of any other ash management treatments. These suggest that on sandy soil wet or dry, additional litter had negative effect on maize yield. Belowground biomass of the maize crop was similar to that of the rice crop. The highest belowground total SOM detected by the method was 28.824 kg/ha on plots where litter was added and in the clay soil. Maize roots constituted approximately one third of the total undefined SOM (other than rice or maize roots). The added litter could still be detected at the time of the maize harvest.

The ash management treatments, with or without the use of litter were not distinct enough in terms of nutrient quantity and quality to produce contrasting results, despite the large differences initially imposed. Thus, it would appear at this stage that in order to sustain crop yields for longer periods in cleared lands, chemical inputs will be needed. The hypothesis that legume cover crops can contribute to effective soil protection and to nutrient recycling is being tested, but these covers are unlikely to compensate for nutrients extracted by crops.

Carbon sequestration in different land-use systems. This subproject aims to assess the quantity of aboveground biomass (Carbon) that will be burnt during land clearing thus estimating CO_2 emissions. Secondly, it will assess the dynamics of belowground biomass and its relation to soil nutrient pools.

The hypothesis is that carbon pools are the main soil fraction that influences nutrient cycles in slash and burn agriculture. Quantifying the carbon and organic pools will provide estimates of nutrient stocks. Strategies for improved nutrient management can then be devised based on quantification of these pools and the respective dynamics.

Estimating vegetation biomass in different land use systems is prone to inaccuracy and uncertainty. Furthermore there is large variation in plant density among primary forest, fallows and other land use systems.

Foster et al. (1995) estimated the forest biomass in Rondonia as 325 t/ha, and still thought it was too low or underestimated.

Initial results from our samplings show that biomass in felled primary forest before burning varied between 97,323 and 249,890 kg/ha. Our highest records are still lower than the 320 t/ha estimated by Brown et al. (1995) in primary forests of Acre. In fallow land older than five years an average of 85,341 kg/ha biomass was measured. When the fallow was less than three years old, biomass was only one half that of the five years old vegetation. The total biomass (above plus belowground) of good and degraded pastures was almost the same (26,764 kg/ha versus 25158 kg/ha). The aboveground biomass of good grasslands was about 18,471 kg/ha, whereas a degraded pasture had only 12,473 kg/ha.

On the contrary the belowground biomass of the degraded pasture was higher than that of the pasture in good condition, 12,686 and 8,293 kg/ha, respectively. The higher belowground biomass in the degraded pasture may be attributed to the existence of coarser roots from shrubs and other non grass vegetation, which are much easier to extract and identify than the thinner grass roots. Abandoned land with sapé (*Imperata brasiliensis*) showed the lowest biomass above as well as belowground, both around 10.000 kg/ha.

Project TM01: Mechanistic understanding and models of soil chemical, physical and biological processes in agropastoral and sequential crop production systems

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Introduction

This project is a combination of the previous projects TL02 and TC02 described in the Tropical Lowlands Annual Report 1994 p. 147. As stated in the documentation prepared for the EPMR and ICER reviews, the project aims to improve the biophysical efficiency of agricultural production via improved use of available inputs (internal and external to the farm) while minimizing changes to the environment. Ensuring maximum efficiency requires a quantitative knowledge of the underlying processes of soil function and nutrient cycling. The project examines these processes in experiments which compare and contrast different land use systems ranging from no external inputs on native savanna to intensive sequential cropping systems with lime and fertilizer inputs. This is achieved in part by long term experiments established in both the Brazilian cerrados and Colombian llanos in collaboration with national partners and advanced research organizations (TLP Ann. Rep. 1994). Further detailed process studies utilize satellite experiments to the main long-term experiments. Models are used as tools to collate information and identify limiting processes.

The project interacts and overlaps most closely with the prototype cropping systems project described under TP. This is achieved mainly by taking measurements on key processes which are being considered as indicators of sustainability in on-farm experiments described under project TP.

Studies in the Colombian llanos

Decomposition processes and analyses

In humid tropical environments when temperature and moisture are more or less constant (excluding the dry season) decomposition of plant material is mainly a function of the quality of the resource both in physical (roots, stems leaves etc.), and chemical terms. Earlier work on forage species showed little effect of leaf litter size on decomposition suggesting that chemical factors may be more important. During decomposition different constituents of the plant will decompose at different rates with some material increasing in concentration and decomposing more slowly such as protein and lignin for example while others such as carbohydrates, hemicelluloses and cellulose may decrease in concentration or be transformed into more or less-easily decomposable material. The overall rate of decomposition is thus a summation of all these different processes. Interpretation of decomposition rates may therefore require different models to take account of these resource quality-dependent changes. Traditionally a simple negative single exponential model has been used to describe the decomposition process although other models have been suggested such as double exponential, exponential with a residue and two parameter models which assume at least two fractions, one more recalcitrant than the other and hence with a slower rate constant, (e.g., Wieder & Lang, 1982; Ezcurra & Becerra, 1987). To determine if litters of different initial resource quality need to be analyzed by separate models we compared the decomposition of leaf litter of a grass (*Brachiaria dictyoneura*) and a legume of fast decomposition (*Stylosanthes capitata*) with a legume of slow decomposition with high levels of polyphenols (*Desmodium ovalifolium*) which are known to retard the decomposition process. Three dates were compared, two in the wet season and one from the end of the wet season into the dry season. The results were essentially similar for all three dates and the first distribution during the early wet season is shown in Figure 1 together with the different equations used. Mathematically, the single exponential model with a residue function gave the best fit to all data. However biologically this is thought by some to be an unlikely occurrence as a decreasing decomposition rate is expected over time as more of the remaining material is of a recalcitrant nature. Alternatively Melillo et al. (1989) interpreted the apparent plateau in decomposition as occurring when the lignocellulose complex reaches 0.7 to 0.8, i.e., ratio of lignin to lignin plus acid soluble carbohydrates exceeds 0.7. No data are available from the samples to test this hypothesis.

The two models which imply a decreasing rate over time and an increasing fraction of recalcitrant material gave better fits than the single negative exponential model with little or no differences between them in terms of fit to the data. The main difference between these two models is that one assumes the rate decreases as a linear function of the remaining material (Fig 1c) while the other assumes a non-linear decrease (Fig 1d). There was no preference between the latter two models when different types of litter quality were used (i.e species) indicating that either could be used to adequately describe the kinetics of decomposition of forage species.

For improved precision the decomposition curves may need to be associated with chemical components of the litter which may provide a more explicit definition of the processes involved but this is likely to be difficult to justify in terms of the added effort and expense required. Further the large number of factors which interact under field conditions may confound attempts at detailed kinetic analysis. The information generated by the models tested should therefore be viewed as guides rather than as precise kinetic analyses to be used for predictive purposes.

Root decomposition

In natural and improved tropical grasslands, particularly under low-fertility conditions, more than half of the carbon assimilated by the shoots may be allocated to the roots. Not much is known, however, about the decomposition pattern of roots. The objectives of this study were to determine how soil texture and weather conditions affect root decomposition. The experiment was carried out with grass and legume

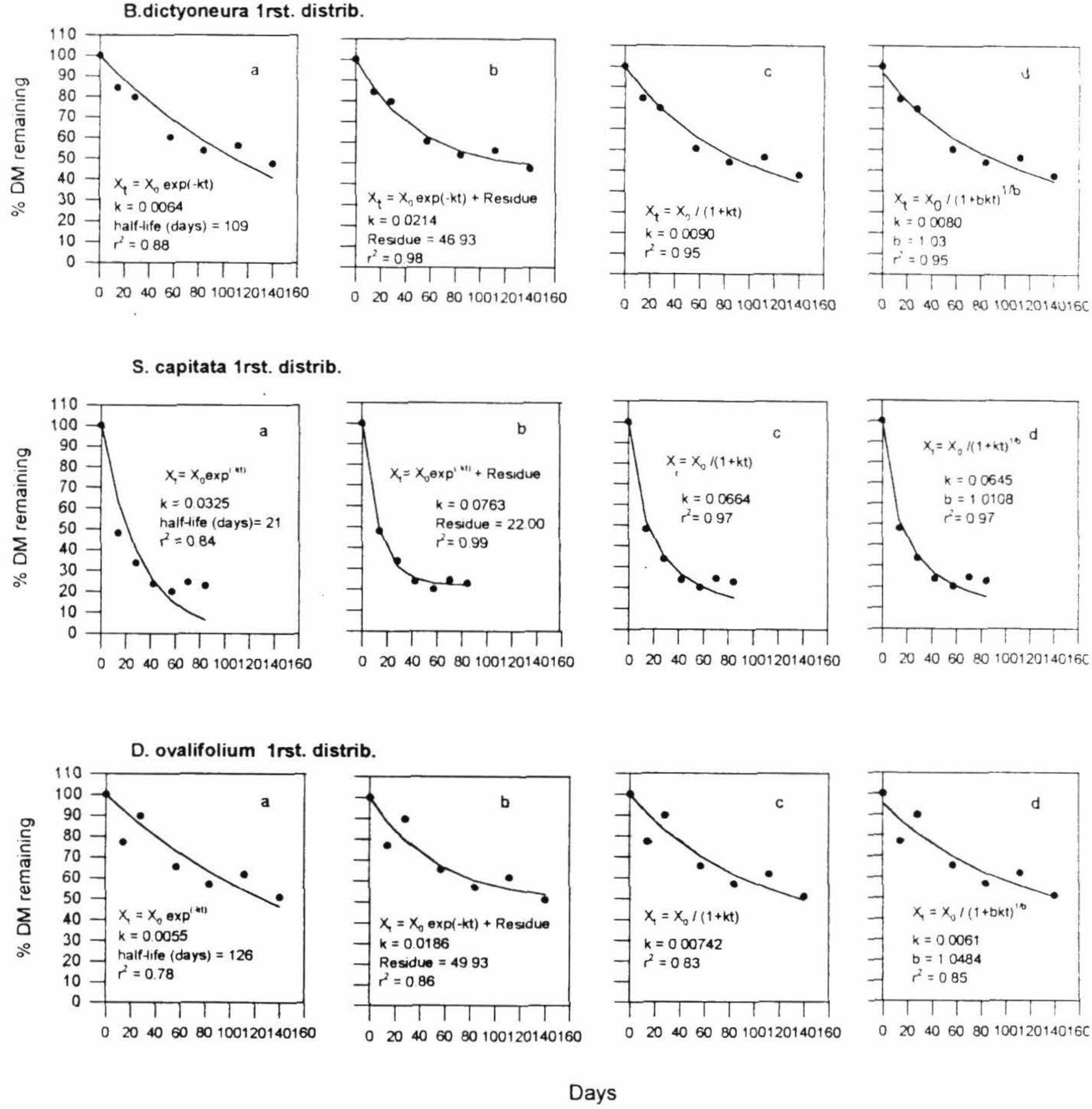

Figure 1. Fitted curves of decomposition of litter with four mathematical models.

roots buried in two Oxisols of widely different texture, during the dry and the wet season. Results were analyzed using a decay model in which the relative decomposition rate (RDR) decreases non-linearly as a function of the litter fraction left: $1/X.dX/dt=-k(X/X_0)^{1\ b}$ (Fig. 1d).

In the dry season, the RDR of all roots decreased steeply with a declining fraction of root weight remaining (Figure 2). This indicates rapid loss of a small fraction of easily decomposable material, leaving behind a large fraction of recalcitrant material. In the wet season, RDR decreased more gradually. The basic pattern of decomposition was the same in the clay-loam and sandy soil, although the absolute values for RDR and the steepness of its decrease differed. Given the wide difference between the two soils in texture and consequent water retention characteristics, it is plausible that the difference between them in RDR resulted from a difference in soil water regime. Legume roots decomposed faster than grass roots in both seasons, which is in agreement with the higher N and P concentration of the former and the consequently lower C:N, C:P and lignin:N ratios. These results are also similar to those reported previously using a litter bag methodology (Savannas Biennial Report 1992-93). The very high C:P ratios in the roots (up to 1780) reflect the low P availability in these strongly P-fixing Oxisols. Since microbial C:P ratios in these soils are in the range 34-50 (TLP Ann. Rep. 1994), a considerable P immobilization may be needed for the decomposition to proceed. Thus P may be an important rate-controlling factor in litter decomposition in these soils.

The role of improved pastures in soil organic matter dynamics

As part of a collaborative effort with Bayreuth University a study was initiated on the role of grass and grass/legume pastures in the dynamics of soil organic matter in the surface soil (0-15cm) of an oxisol of the Colombian llanos (Guggenberger et al., 1995a).

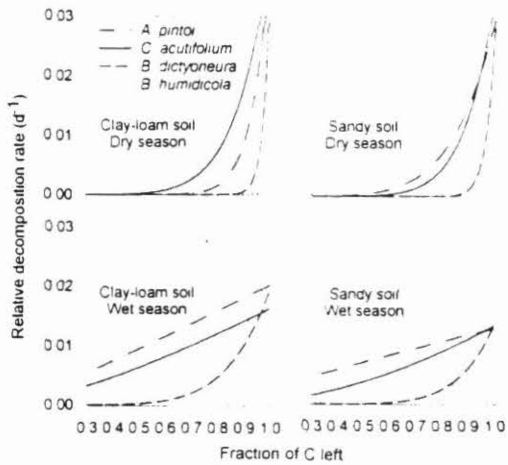

Figure 2. The relative decomposition rate of grass (*Brachiaria dictyoneura* and *B. humidicola*) and legume (*Arachis pintoi* and *Centrosema acutifolium*) roots in a clay-loam soil and a sandy soil during the wet and dry season, as a function of the fraction of carbon left.

Using a combination of soil particle-size fractionation techniques and gas chromatography a detailed analysis of soil organic matter fractions revealed significant changes mainly in organic matter associated with sand size fractions (20-2000 μm). Improved pastures tended to double the amount of carbon in sand-size fractions compared with the native savanna (Table 1). Similar results were obtained from rice-pasture and rice cropping systems in separate studies conducted on-farm (not shown).

Evidence from carbohydrate and lignin degradation products further suggest that pastures increase the amounts of recently derived plant material in soil organic matter mainly by enriching the sand fraction compared with either silt or clay fractions

(Table 2). Ratios of mainly plant-derived carbohydrates (arabinose and xylose) to mainly microbial-derived (galactose and mannose, rhamnose and fucose) indicate that plant-derived carbohydrates dominated in the sand size fractions whereas increasing proportions of microbial - derived carbohydrates were associated with silt and clay fractions (results not shown). The organic matter associated with sand size fractions is thought to be equivalent to the light fraction organic matter (Christensen, 1986). The latter is generally not associated with soil minerals and is more susceptible to mineralization than silt- or clay-bound soil organic matter. This would help explain the increased rate of N mineralization reported previously in the grass/legume pasture (Rao et al., 1994).

Table 1. Carbon contents of different particle-size separates in the top soil (0-15 cm) of native and improved pastures.

Pasture	Carbon (g kg^{-1})		
	Sand (20-2000 µm)	Silt (2-20 µm)	Clay (< 2 µm)
Savanna	1.6	25.8	38.8
B. decumbens	3.3	36.7	41.0
B. decumbens/ P. phaseoloides	2.8	32.1	43.0

The greater enrichment of plant-derived carbohydrates in the sand size separates observed in improved pastures compared with the native savanna may be indicative of improvements in soil quality and complements earlier studies which showed that increasing soil carbohydrate status is associated with improved wet aggregate stability (Gijsman and Thomas, 1995a; TLP Ann Rep 1994). The work also suggests that an analysis of sand-size or light fraction organic matter may be a better indicator of changes in soil quality than total soil organic matter. In separate on-farm studies it was shown that soils under cropping had less stable macroaggregates than those under pastures confirming the well known disruptive effect of cultivation on soil aggregate structure. Of the total soil carbon about 6 to 10% was found in the particulate organic matter fraction with lowest values under cropping compared with pastures. This fraction is believed to play a role in medium-term nutrient availability but requires further research to confirm this.

Previous studies showed a marked increase in earthworm populations and activity in improved pastures versus native savanna (Decaens et al., 1994; TLP Ann. Rep. 1994). Additional collaborative work with Bayreuth University has confirmed the dramatic effect that earthworms can have on soil organic matter. Earthworm casts showed increases in the contents of water stable aggregates and greater concentrations of carbon compared with the bulk soil. This effect was most pronounced for the sand-size fractions which are equivalent to macro-organic matter or light fraction as stated above (Guggenberger et al., 1995b). The carbon in the sand-size fractions was predominantly of slightly decomposed plant litter.

Increased earthworm activity with a grass/legume pasture may also explain some differences shown between grass and grass/legume pastures in aggregate stability (Gijsman & Thomas 1995a) and water infiltration rates (Gijsman & Thomas 1995b).

Further studies on soil macrofauna undertaken in on-farm studies in the Colombian llanos (Schneidmadl & Decaens unpub.) have confirmed the positive effect of legumes in pastures on earthworm biomass in pastures established with a rice crop but with an age of only 5 years compared with the 14 year old pasture reported earlier which had received fertilizer applications every other year (Decaens et al., 1994). These on-farm findings are reported under TP01.

Table 2. **Enrichment of carbon, lignin-derived products and carbohydrates (arabinose + xylose) in surface soils under different pastures expressed as ratios of improved pasture/native savanna.**

Pasture	Carbon				Lignin Products				Carbohydrates			
	Sand	Silt	Clay	Whole soil	Sand	Silt	Clay	Whole soil	Sand	Silt	Clay	Whole soil
B. decumbens	2.0	1.4	1.1	1.2	3.9	4.3	2.6	2.6	3.0	1.9	1.1	1.4
B. decumbens + *P.phaseoloides*	1.7	1.3	1.1	1.2	2.7	2.4	2.6	2.5	3.5	1.3	1.1	1.3

Carbon sequestration

In October, 1994, a small workshop was held in CIAT to appraise national partners of the discovery that introduced grass pastures in the neotropical savannas have the capacity to sequester large amounts of carbon, much of it deep in the soil. The delegates endorsed that CIAT should co-ordinate an approach to a donor to fund the creation of networks in both Latin America and in Africa to investigate the implications of the finding.

A formal submission was made to the Global Environment Facility for funding under Block B of their Project Development Facility in December, 1994. The objective was to hold workshops to obtain feedback from potential network collaborators about the proposed main project, appoint a steering committee, write the main project proposal, develop methodology and select sites for research in both Latin America and Africa. CIAT financed two workshops, held in CIAT 13-17 February for the Latin American network, and at King's College London for the African network. The project proposal was considered by the Operational Committee of GEF on 11 May, but further consideration is pending a decision of the GEF Council on support by GEF for research.

It was found that the soil under native savanna at Carimagua had C:N ratios of 22.5, much higher than the commonly-accepted figures of 10-12 found in many soils. After nine years of introduced pasture, five of them with a legume, the ratio had widened considerably to 33.2. It is known that the litter of both tops and roots of introduced grasses are very high, ranging from 75 to 224, which suggests that soil organic matter derived from it might be recalcitrant and have long residence times, with important implications for the long-term storage of C in soils under these pastures.

Soil physics

To assess soil degradation and identify indicators of soil quality using soil physical parameters a series of experiments have been established on-farm and on-station in the Colombian llanos. These experiments take advantage of existing trials on crop-pasture systems at Matazul and La Primavera farms reported under TP01. Other samples have been taken from La Libertad experimental station of CORPOICA and at San Carlos de Guaroa to establish soil physical limiting factors for rice upland production.

Work at Carimagua includes a study of the carbon distribution at depth and in different aggregate sizes classes and is pending funding from a project submitted to the Global Environment Facility.

Similar measurements are being taken in the prototype production systems experiment in the hillsides program.

An experiment at Matazul attempts to evaluate the influence of depth of tillage (0, 5,10, 15 and 30 cm) on upland rice yields. Preliminary data suggest a positive effect of tillage depth but the 30 cm treatment appears to be susceptible to wheel compaction.

An experiment to determine the effect of the number of passes of a harrow (0, 2, 4 and 8) on soil structure has been established. First results are expected in 1996. This experiment links with one on the determination of causal factors of rice yield decline (as an model crop).

Culticore: A long-term cropping systems experiment (Carimagua)

General observations. Details of the experimental layout and treatments are found in the TLP Ann. Rep. 1994. In 1995, the large long-term rotations experiment at Carimagua ("Culticore") was sown to its third year of the low-lime input, rice-based systems and its second of the high-lime input, maize-based systems. Agronomic problems experienced earlier in prototype systems studies at Matazul farm and Carimagua became increasingly evident in the Culticore in 1995 as well. Principal among these were weed infestations which, in the low-input systems, severely reduced rice grain yields even in the rotations with cowpeas and green manure (which were less affected in 1994). Weeds were less of a problem in the maize systems during 1995, good control being achieved with pre-emergent herbicide applications. A more uniform stand, in which the targeted plant density of about 53,000 ha^{-1} was achieved, gave maize grain yields of about 4.5 t ha^{-1}. There was no influence of the previous season's soybean or green manure crops on maize yields in 1995.

On the other hand, poor results in chemical control of weeds in the no-till maize treatment forced a re-assessment of this treatment and a decision to sow a cover crop of *Arachis pintoi* under maize this year with the view to sowing maize crops directly into the cover in subsequent years. Although there was good emergence and early growth of *Arachis* in the treatment, there followed a very dense development of weeds as the crop matured which reduced maize grain yield and arrested establishment of the *Arachis* cover. It remains to be seen if measures taken during the second semester of 1995 and the subsequent dry season will be effective in controlling weeds and allowing development of the *Arachis* cover. However, these observations and experiences illustrate the need for more effective means of weed control as well as the need to identify and develop more rapidly establishing covers for systems involving reduced tillage.

The *Brachiaria humidicola*-mixed legume (*Centrosema acutifolium/ Stylosanthes capitata/Arachis pintoi*) pasture, established under rice in the Culticore experiment in 1993, entered the 1994-95 dry season with a high population of *Stylosanthes* carrying approximately 4 beasts ha^{-1}. Essentially all of this original *Stylosanthes* growth was lost during the dry season and the pasture entered the current rainy season with a rather low content of *Arachis* and *Centrosema*. Fortunately, the legume content (especially of *Centrosema*) has increased through the season, and efforts to encourage a greater *Arachis* content are being made through increased stocking rate.

The *P. maximum* (cv. Centenario)/*A. pintoi/Glycine wightii* pasture sown late under maize in 1994 failed to establish satisfactorily. Consequently, in 1995, the plots were ploughed and re-sown with *P. maximum* and *Arachis* under rice. Residual fertility of the previous season together with fertilizer applied to rice this season contributed to a very vigorous *Panicum* pasture which virtually dominated the rice crop to the extent that there was not sufficient grain to harvest. *Arachis*, though present, was poorly established due to severe shading by the *Arachis*. The paddocks were immediately fenced at the end of the first semester (September) and very heavily stocked to reduce biomass and facilitate *Arachis* development.

Fertilizer N dynamics/balance

Fertilizer N balances using ^{15}N-labelled urea were estimated in microplots established in Culticore monoculture rice and maize treatments as well as in rice monocrop and rice agropastoral systems initiated in a field previously planted to soybean at Matazul farm in 1994. Very high N losses were recorded at Matazul in all systems. Average fertilizer N recovery in above-ground biomass was only about 10% while an additional 7% was recovered from the soil profile to 80 cm depth. Losses of urea-N may occur via leaching, volatilization as ammonia or denitrification as nitrous oxides. Periodic measurements of mineral-N concentrations in the soil profile under rice and maize monocultures in Culticore during 1995 revealed the rapid movement of a band of inorganic N (principally in nitrate form) to a depth of 40-60 cm some 8 weeks after application of the first of three splits of urea.

Effect of earthworms on P dynamics in pastoral systems

The effect of earthworms on soil P pool sizes were studied in two tropical acid-soil savanna pastoral systems. *Martiodrilis* sp. casts produced in the laboratory and the field with Oxisols from native savanna and fertilized *B. decumbens/P. phaseoloides* pastures were incubated moist or under ambient field conditions respectively for periods of 1 to 64 days, then fractionated using a modified Hedley procedure. Microbial P was also determined. Earthworms significantly increased the P contents of labile inorganic (Pi), organic (Po) and microbial (Pm) pools. Effects were generally greater for Pi than Po and in pasture compared to native savanna soil, and were more transitory in the more labile H_2O and $NaHCO_3$ fractions. Pm activity increased rapidly in pasture soil casts but only slowly in savanna soil casts. Moreover, effects were greater in field-produced casts than laboratory casts, possibly due to the incorporation and metabolization of litter present under field conditions. Together with much higher faunal activity in improved pasture systems, the data show that earthworms can greatly influence P cycling and availability in infertile Oxisols.

Fate, residual value and crop development effects of applied P. This satellite experiment has as its primary objective the development of a residual value function for soluble phosphate fertilizers applied to annual crops. Triple superphosphate applied in 1993 continued to show strong residual effects. Based on fitted Mitscherlich response functions, 1993-applied P was 60-80% as effective as the same amount applied in three equal installments in 1993, -94 and -95.

Associated objectives of this experiment include characterization of the fate of P applications in Llanos Oxisols and determination of the effect of P nutrition on crop development. Both activities provide support the development P dynamics capacity in computer simulation models for cropping systems. During 1995, we made detailed observations of maize phenological development and (in collaboration with the TFP) root growth and distribution at four levels of soil P fertility, ranging from 0 to 200 kg/ha of applied P. As expected, phenological development of maize (rate of appearance of leaves, tasseling, silking, maturity) was slowed at less than optimal levels of P applied. Quantification of these effects will be applied to the development of P subroutines in the CERES-maize crop model.

Studies in the Brazilian Cerrados

Agropastoral Systems in the Cerrados

Management practices such as land preparation , liming, fertilization and grazing management, influence the potential contribution of crops and pastures to improved output of crop-pasture systems. A long term experiment was established in a dark red latosol (Oxisol) of CPAC-Planaltina to determine the effect of integration of crops and pastures on system productivity and to identify key soil parameters related to soil improvement and degradation. The experiment was established in 1991 and included cerrado, grass pasture, grass-legume pasture, continuous cropping, crop-pasture rotations and pasture-crop-rotation. The effect of two fertility levels and two land preparation methods are studied in subplots within the main plots. On-Station research is complemented by strategic measurements made on several land management systems (including crop-pasture systems) in the Uberlandia region. Measurements are taken by researchers from CIAT, CPAC, the University of Cornell. Lately, The University of Bayreuth is collaborating in a joint project to study the impact of land management on soil organic matter fractions.

Below are results of work in the CPAC experiment. Results from on-farm studies in Uberlandia will be reported next year.

A. Crop performance and weed dynamics *(M. Ayarza CIAT and L. Vilela-CPAC)*

Soybean was planted in the fourth year of the continuous crop rotation system following a soybeans-soybeans-corn sequence. As observed in the previous croppings, soil fertility was the most important management factor influencing yields, root distribution and weed population. The corrective fertilization treatment (F2) increased crop yields significantly compared to the conventional method (F1) (Figure 3). However, yield differences between fertility and land preparation methods were influenced by weeds. Several small plots (3 x 5 m) were set up within the fertility and land preparation plots and were maintained free of weeds during the cropping season. Neighborhood areas were selected to measure grain yields of unweeded plots.

Grain production was 50% and 17.6% lower in the unweeded plots of the F1 and F2 treatments respectively, compared to weeded controls (Table 3). Smaller yield reductions in the F2 treatment were associated with a lower weed biomass produced in this treatment (half of that produced in the F1 treatment). Weed composition was also influenced by soil fertility. As an example, Carrapicho rasteiro (***Acanthospermum australe***) was the dominant species in the F1 treatment but only the seventh dominant species in the F2 treatment.

Increased soil fertility in the F2 treatment also improved root growth and root length of the corn crop. Soil core samples were taken from a profile wall opened in the F1 and F2 treatments. There was a significant correlation between exchangeable Ca^{++} in the soil and root length (r=0.82 *). Besides lime, the F2 treatment received 2.8 t/ha Gypsum. This explains the enhanced movement of Ca in the soil profile and the greater root length observed in the F2 treatment (Figure 4).

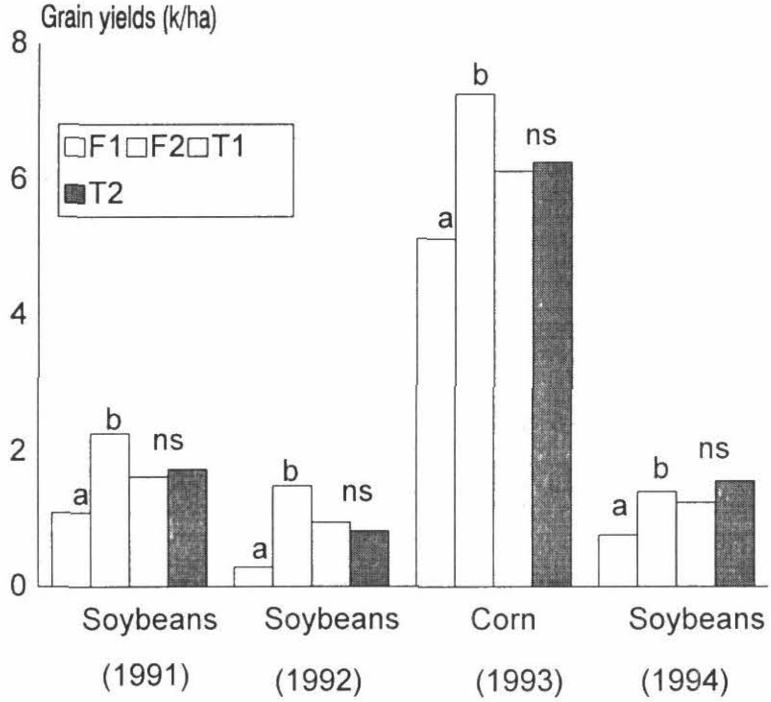

Figure 3. Effect of fertility management (F1 and F2) and land preparation (T1 and T2) on grain yields of a soybeans-corn rotation system planted in an Oxisol of Cerrado. (ns= not significant).

Table 3. **Influence of soil fertility, land preparation and weed competition on yields of a Savanna soybean cultivar planted in a latosol of CPAC- Planaltina.**

Fertility level	Land preparation	Weeded plots (kg/da)	Unweeded plots (kg/da)	Yield reduction (%)
Low (F1)	Disk plow	1413.5	634.5	55.1
Low (F1)	Moldboard plow	1621.0	896.0	44.7
Mean		1517.2	765	49.9
High (F2)	Moldboard plow	2507.5	1866.5	25.6
High (F2)	Disk plow	2465.0	2230.5	9.5
Mean		2486.2	2048.2	7.6

B. Animal production and pasture performance *(L. Vilela-CPAC)*

In comparison to the pure *Andropogon* pasture the *Andropogon + Stylosanthes cv. Mineirao* pasture increased liveweight gains by 58% in the 1992/93 period and 39% during the 1993/1994 period. A sharp decline in the legume content of the pastures was observed after the second grazing season. Legume disappeared completely from several plots by the end of the rainy season of 1995. Although there are no explanations for this, it is speculated that a heavy grazing pressure on the legume during the dry season caused severe damage to the *Stylosanthes*.

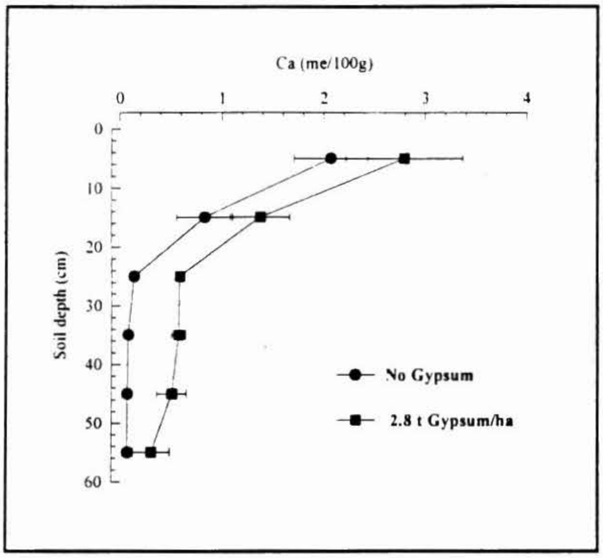

Figure 4. Effect of the addition of gypsum (F2) on exchangeable Ca in the *soil* profile.

C. Mechanical resistance *(M. Ayarza and L. Vilela)*

A profile wall was opened in several plots of the crop, pasture and cerrado treatments to examine the effect of management with depth. Mechanical resistance was measured with a hand pocket penetrometer. Trends obtained followed the same patterns observed last year (Figure 5). A higher compaction was recorded in the 0-7 cm depth of the pasture systems and in the 20-25 cm soil depth of the cropping treatments.

D. Aggregate size distribution and pore size distribution *(A. Freibauer and R. Westerhof, University of Bayreuth).*

Aggregate size distribution was determined at two dates, the beginning of the rainy season (Nov. 1994) and the peak of the rainy season (February, 1995). Aggregate size distribution was determined using a wet sieving methodology. Six soil samples were taken from the 0-12 cm soil depth from several treatments using an auger. Soil was passed through a < 8 mm sieve. Aggregates were capillary rewetted before they were sieved for 30 minutes in a Yoder apparatus. The different aggregate size classes were collected and dried.

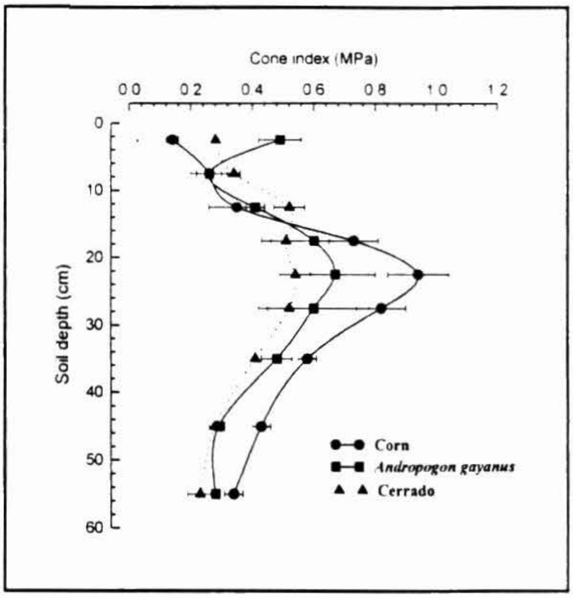

Figure 5. Effect of several land management systems on soil mechanical resistance with depth.

The results of the sampling in November showed that soil aggregates were mainly distributed in two size classes. Fifty to sixty five percent of soil aggregates of the crop, pasture and native cerrado systems were found in the 2-250 um. Thirty to forty percent was found in the macroaggregate fraction 8-2 mm. The fractions larger than 8 mm and smaller than 250 um comprised less than 8% together. Disruption of macroaggregates by plowing in the cropping systems reduced the percentage of aggregates in the 8-2 mm size fraction by only 10% after 5 years of cultivation. These results are similar to those reported above for the Colombian llanos.

Compared to November, in all land use systems the fraction larger than 8 mm and 2-250 um were higher and the fraction < 250 um and 8-2 mm were lower in February. Factors such as water content and sample handling were alike in the two sampling dates. The decrease of the fraction < 250 um and the increase in the fractions 2-250 um and > 8mm under all systems indicate a built-up of aggregates. The study indicates that the processes of aggregate formation and disruption are more intensive under pasture and cerrado than under crops. Factors such as microbial activity and mesofauna population influencing these processes are currently under evaluation.

Pore size distribution was measured following the routine methodology developed at CPAC. Briefly, soil cores were saturated with water and centrifuged at increasing rotation speeds to obtain suction pressures equivalent to pF values between 0-1.8, 1.8-2.5 and 2.5-4.2. These suction pressures are needed to extract the water from the macropores, mesopores and micropores respectively.

Total pore space varied between 57-60% in the 0-12.5 cm soil depth of all management treatments. The native cerrado control had a higher pore space than pasture and crops in the 0-5 cm depth. However, differences were not significant ($p < 0.05$). Tillage reduced the proportion of macropores and therefore increased the proportion of mesopores in the cropping systems compared to the cerrados and the pastures. The effect of these changes on water availability will be determined.

E. Arbuscular Mycorrhizal population dynamics under crop-rotation system *(J. C. Miranda-CPAC)*

The aim of this work is to evaluate the effect of management on mycorrhizal population and activity. Propagule density (number of spores/50 gm soil) and activity (% of roots infected) is evaluated three times during the year in the 0-20 cm depth fresh soil.

Native mycorrhizal population dynamics appear to be sensitive to soil management, plant type and sampling time. Results of three years of evaluation have shown that crops and pastures were capable of increasing the number of spores in the soil. However the increase was more dramatic under pasture establishment in the first year (Table 4). Root colonization was also greater in the pasture systems.

During the second year spore populations decreased in the already established pasture system and increased steadily under the soybeans crop. Corn planting in the third year resulted in an increase of spore number and root colonization. The latter was almost twice as much as that observed for the previous soybeans crop. Enhanced infection levels in corn compared to soybeans has been observed in other experiments. In the pasture treatments, although the number of spores decreased slightly in comparison to the second year, root colonization levels obtained during the dry season sampling increased to similar levels observed in the first year. Increased infection levels coincided with a strong dry season during that year.

F. Effects of Agricultural development on greenhouse gas fluxes in the Brazilian Cerrados. *(J. Duxbury, Cornell University, A. Cardoso, EMBRAPA-CPAC).*

The objectives of this study were to determine how agricultural development has influenced fluxes of greenhouse gases from/to soils of the cerrado region and to learn more about controls on the processes responsible for greenhouse gas fluxes/from to soils. Emission of nitrous oxide (N_2O) and methane (CH_4) consumption and oxidation were measured for eleven months in several land management treatments of the long term crop-pasture integration experiment.

Atmosphere concentration of CH_4 was 1.65 ppm. A clear decrease in the CH_4 concentration between the soil surface and the 60 cm soil depth was observed in all management treatments (cerrado, pastures and continuous cropping). Methane concentrations were always lower that 1 ppm, suggesting a strong sink for methane between the soil surface and the 10 cm depth. Nitrous oxide concentration remained stable with soil depth indicating a small source of N_2O at this site.

Table 4. Seasonal variation of native arbuscular mycorrhizal fungi spores number and root colonization of three different management systems used in the long-term crop-pasture.

Seasons		Spore number			Root colonization		
	NC	C1	C2	C3	C1	C2	C3
			No/50g			%	
			1991				
Dry	16	15	12	10			
			1992				
Rainy		19	42	14	44	43	23
End		288	277	69	74	29	
Dry		48	115	33	-	-	-*
			1993				
Rainy		59	63	72	36	35	38
End raining		76	120	91	27	31	38
Dry	26	49	52	63	28	19	-*
			1994				
Rainy	11	35	45	100	37	45	79
End raining	38	57	73	61	51	60	83
Dry	91	38	51	57	43	56	-*

- NC = Native Cerrado; C1 = Grass pasture; C2 = Grass legume pastures; C3 = annual crop (soybean, soybean, maize).

-* = fallow period

Methane oxidation fluxes averaged 11.24 g C/ha/day under the native cerrado and 11. 40 g C/ha/day in the cultivated soil. Pasture soils showed a smaller value. An evaluation of the total carbon oxidized during eleven months indicated consumption levels of 3.77 kg C/ha under the native cerrado and 3.83 kg C/ha under the cultivated area. Soils under pastures showed somewhat lower values. These results suggest that agricultural activities in strongly aggregated soils, such as the one used in the experiment, does not reduce methane oxidation capacity of the soil.

Nitrous oxide emissions were extremely low during the experiment, averaging 2.40 g N/ha/day in the cerrado and 4.37 g N/ha/day in the cultivated soil. For nine months period, total nitrogen emissions were 1.30 kg/ha under cultivation and about half of this amount in the native cerrado. Nitrogen values measured in the pasture treatments ranged between cultivated soils and the cerrados.

Conclusion and plan of work for the Brazilian cerrados

After four years of continuous cropping soil fertility is still the most limiting factor for crop productivity under the soil and management conditions of the experiment. Corrective fertilization including the use of Gypsum improved yields, root growth and reduced weed pressure. Weed population has increased rapidly in the last four years reducing crop yields and posing difficulties for grain harvesting in the field. Therefore sustainable cropping systems must relay on strategies such as the heavy use of herbicides and increased soil fertility to reduce weed pressure. We are observing changes in the composition of the weed population. The usefulness of the shifts as indicators is being examined.

The small changes observed in soil physical properties under crops and pastures treatments of the experiment contrasts with the rapid changes observed in on-farm studies in Uberlandia. A major difference among sites is the higher clay content of the soil used in the CPAC experiment. Soil aggregation, according to the work conducted by students from the University of Bayreuth is very strong. Besides, it appears that there is a continuous process of disruption and aggregation going on in this soil. As a consequence, of this there has been little changes in soil porosity and other physical parameters. This must have a relationship with the high oxidation capacity observed in the cropping systems after four years of tillage.

The experiment enters an important phase next year, since crop-pasture rotations treatments will start. We will focus on key processes in crop-pasture and pasture crop-rotations, compared to our reference continuous systems. One of the students involved in the SOM project will look at the short-term processes in relation to mineralization/immobilization of nutrients derived from SOM oxidation. Changes in aggregate size classes and partitioning of SOM in each aggregate size will be estimated.

Soil biological activity has so far been focused on mycorrhizal activity. Work will be expanded to mesofauna population and composition as affected by land management. Soil microbial biomass and activity will be measured in several land management systems including crop-pasture rotation systems.

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