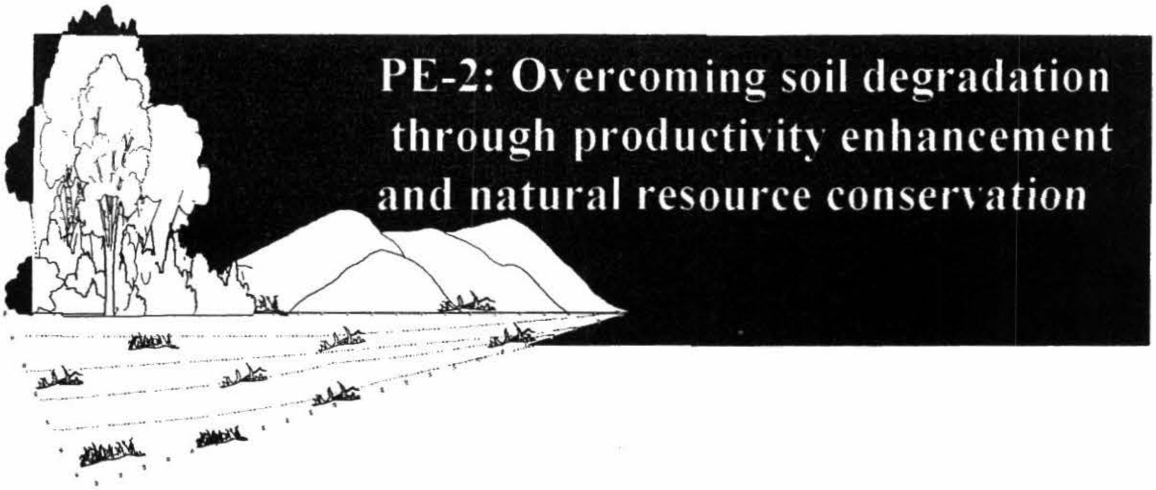

PE-2: Overcoming soil degradation through productivity enhancement and natural resource conservation

Annual Report 1999

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

Table of Contents

Page No.

Output 3: Improved decision making for combating soil degradation and greater agricultural productivity

Output 4: Institutional capacity for SWNM enhanced through the dissemination of concepts, methods, tools and training

Executive Summary

This year has seen a continued switch of emphasis from the savanna agroecosystem to the Andean and Central American hillsides. Reasons for this are;

i) transfer of the out-posted staff member (M. Ayarza) from Brazil to Central America.

ii) restricted access to the savanna sites as a result of increasing public disorder and armed conflict in the Colombian llanos.

iii) lack of consistency in the prioritization of requirements and opportunities in the llanos by the national program (Corpoica) in Colombia and continuing uncertainty over the future of the Carimagua Research Station.

iv) completion of the Managing Acid Soils Consortium project in the Brazilian cerrados.

Nevertheless the work on the savannas by the project team and partners was collated and published in two books this year. The first entitled " Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of land quality", brings together the biophysical research undertaken mainly in the Brazilian cerrados but also includes some aspects of the work in the Colombian llanos. Partners in this work include EMBRAPA-Cerrados, the University of Uberlandia, the University of Bayreuth and staff of PE-2. The dynamics of soil organic matter under different land management practices are described in detail and indicators of soil degradation are identified in 19 chapters. The second book entitled " Sistemas agropastoriles en sabanas tropicales de América Latina" is a synthesis of the state-of-the-art of agropastoral systems in the savanna-containing countries of the region. The 19 chapters include contributions from NARS partners in Brazil, Bolivia, Colombia and Venezuela. The book provides information on the potential and prospects of agropastoral systems for NARS researchers, extension agents and policy makers.

Members of the project team have contributed to the development of concepts for research on natural resource management including the problem of scaling up in research approaches and the design of the SOL experiments (Supermercado de opciones para laderas). The latter are currently being implemented in Colombia, Honduras and Nicaragua. Decision support trees are being developed for the use of organic matter resources (with TSBF under the SWNM program) and for land use of the Colombian savannas (with PE-4). Erosion risks maps, based on the physical characterization of the watershed have been produced for the Rio Cabuyal via a collaborative activity between PE-2 and PE-4. This latter activity links with the continuing development of strategies to control soil erosion (project previously reported in PE-5).

Two special projects were initiated this year. The first concerns the collection and characterization of *Tithonia diversifolia* for its use as a biofertilizer and to determine mechanisms of phosphorus acquisition. This international project involves the University of Wales, Bangor, UK, CATIE in Costa Rica and ICRAF in Kenya. The second is an ACIAR-funded project on improved modeling of phosphorus in soil-plant systems. This latter project is part of the SWNM program (project SW-2) and involves collaboration with TSBF, Kenya, CSIRO, Australia, IBSRAM, Thailand, Michigan State University, USA and ICRISAT, India. Under the SWNM program a new 3-year project, financed by BMZ, Germany, was initiated in Africa. The project focuses on integrated nutrient management practices for small holders in Sub-Saharan Africa and will complement the project's activities in this area in Latin America.

The project manager contributed to the development of 8 new collaborative research areas by the FAO/IAEA Joint division on Soil and Water Management and Crop Nutrition and in particular to a new program on the management of tropical acid soils. NARS are the main partners in these programs but links have been established with other IARC's that will result in closer collaboration and exchange of information and experiences.

These international activities are improving the profile of the group in the wider fora of global agricultural research. For example in June, 1999, the project received an invitation to attend a World Bank expert consultation on integrating soil fertility and pest management into one theme (integrated land and pest management). A CIAT scientist with an IPM perspective from project SN-3 also attended. A concept paper on this topic is being finalized. Similarly the group received an invitation to attend a workshop to define a project on the management of soil biology sponsored by the Rockefeller Foundation and held in March, 1999, in Nairobi, Kenya (with TSBF). A project document entitled "Managing the Soil Biota for sustainable agricultural development in Africa: a collaborative initiative" has been submitted to donors. If successful this will facilitate the exchange of experiences and expertise between scientists in Latin America and Africa (a south-south interchange) and will allow the dissemination of our results on macrofauna to a wider audience. Members of the project team also represent the project and CIAT on the Inter-Centre Working Group on Global Climate Change and a paper and poster on the effect of land use changes in the tropical lowlands of Latin America on greenhouse gas fluxes was presented at an international meeting in September, 1999.

Publication output remains high within the group with 25 refereed journal articles, 5 refereed book chapters, 2 edited books, 27 non-refereed book chapters either published or accepted for publication and 9 articles in proceedings of the conferences. Training of students also remains a priority of the group with 44 students undertaking under-graduate or post-graduate research projects this year.

Future challenges for the project team include the further development and dissemination of decision making tools for land users, closer cooperation with on-going activities at the local community level and further focusing of the strategic research issues in soil management.

PE-2: Overcoming soil degradation through productivity enhancement and natural resource management

PROJECT OVERVIEW

Objective: To identify strategic principles, concepts and methods for protecting and improving soil quality through the efficient and sustainable use of soil, water and nutrient resources in crop-livestock systems.

Outputs: Crop/forage components characterized for compatibility in systems and resource use efficiency in acid soils; methodologies and indicators for assessing soils quality; strategic principles for managing crop residues and green manures, macrofauna, and soil erosion; process-oriented simulation models calibrated and validated to overcome site specificity; strategies for confronting soil degradation disseminated to NARS and NGOs (Table 1A).

Gains: Guidelines for selecting productive and resource use efficient crop/forage components and combinations; guidelines for managing nutrients, crop residues and green manures, and controlling erosion and improving soil structure; a diagnostic kit of soil quality indicators to assist farmers and extensionists in assessing soil health and making resource management decisions; a decision support system for resource conservation and productivity enhancement; strengthened NARS capacity in strategic research on soil, water and nutrient management (Table 1B).

Milestones:

1998 Nutrient release rates of maize, rice, forage legume residues and green manures quantified; soil physical properties susceptible to degradation identified; soil N and P fluxes quantified in rice and maize monocultures, rice-green manure, maize-green manure rotation systems in the Colombian savannas.

1999 Nutrient cycles and budgets and soil organic matter accumulation in crop rotation and pasture systems quantified; management guidelines for minimizing erosion and increasing productivity defined for hillsides; strategies for managing soil fauna identified; plant attributes identified for greater nutrient acquisition and use efficiency.

2000 Indicators of soil fertility, biological health, and physical quality identified for hillside and savanna agroecosystems; demonstrated benefits of crop rotations and pasture systems on soil quality and productivity; guidelines for maintaining soil structure produced.

Users: Principally crop and livestock producers and agriculture extensionists (advisors) in acid soil agroecosystems of LAC. Relevant also to farmers on similar soils in tropical Africa and Asia.

Collaborators: NARS/NGO's: CORPOICA; EMBRAPA; CIPASLA;
Universities: Uberlandia (Brazil), Nacional (Colombia), Paris (France), Bayreuth (Germany), Bangor (Wales, U.K.), Complutense de Madrid (Spain), Cornell, Michigan State, Ohio State (USA), ETH (Switzerland.);
International Research Institutes: Macaulay Land Use Research Institute (U.K.), IFDC (USA); ORSTOM, CIRAD (France); CATIE (Costa Rica).

CG system linkages: Enhancement & breeding - 15%; Crop Production Systems - 60%; Biodiversity - 5%; Stengthening NARS- 20%; Co-convenor Systemwide Program on soil-water-nutrient management (SWNM) and lead institute for the Managing Acid Soils consortium, and contributes to Tropical America Ecoregional Program.

CIAT Project linkages: Diversity in systems of rhizobia and mycorrhizae populations (SB-1), acid soil adapted components received and adaptive attributes identified for compatibility in systems (IP-1 to IP-5), strategies to mitigate soil degradation (PE-3 to PE-5), strengthening NARS via participation (SN-2).

Financing plan: 60% unrestricted core, 40% restricted core

Table 1A. Project work breakdown structure

Project title: Overcoming soil degradation through productivity enhancement and natural resource management

Purpose
To identify strategic principles, concepts and methods for protecting and improving soil quality through the efficient and sustainable use of soil, water and nutrient resources in crop-livestock systems

↓

Output 1 Soil, water and nutrient management constraints assessed and plant components characterized for improved production and resource conservation	**Output 2** Strategies developed to protect and improve soil quality	**Output 3** Improved decision making for combating soil degradation and greater agricultural productivity	**Output 4** Institutional capacity for SWNM enhanced through the dissemination of concepts, methods, tools and training
1.1 Determine and characterize edaphic and climatic constraints. 1.2 Survey native plants and their potential use as biofertilizers. 1.3 Survey land users for soil and crop management knowledge 1.4 Characterize plant components for production potential, nutrient use efficiency (phosphorus and nitrogen) and improvement of soil physical conditions. 1.5 Determine rooting strategies of crop and forage components 1.6 Test compatibility of plant components in different systems (including farmer participation)	2.1 Develop a concept of, and strategies for, the establishment and maintenance of an "arable layer" for sustainable production. 2.2 Develop strategies for nutrient acquisition and replenishment via efficient nutrient cycling and integrated nutrient management. 2.3 Develop appropriate and diverse strategies for controlling soil erosion. 2.4 Develop strategies to maximize C sequestration in soils and minimize emissions of green house gases. 2.5 Characterize soil biodiversity and develop strategies to manage beneficial soil biological processes.	3.1 Identify dynamic soil properties and test their suitability as soil quality indicators 3.2 Develop and test a soil quality monitoring system (including indigenous knowledge) for use by farmers and extensionists in hillsides and savannas. 3.3 Compile data bases to feed into simulation models and decision support systems 3.4 Develop decision support tools for improved soil, water and crop management. 3.5 Develop and test a decision support system for organic materials. 3.6 Develop soil degradation risk assessment maps (with PE-4).	4.1 Organize and coordinate field days and workshops 4.2 Prepare guidelines/pamphlets on soil, water and nutrient management concepts 4.3 Promote and participate in specialized training courses, prepare training materials 4.4 Publish research results in refereed journals and other publications 4.5 Supervise postdoctoral research, graduate and undergraduate theses 4.6 Foster research linkages with institutions in the region and advanced research organizations

Table 1B. Project: PE-2 - Logframe 1999

Narrative Summary	Measurable Indicators	Means of Verification	Important Assumptions
Goal Overcoming soil degradation through productivity enhancement and resource conservation	• Yields in farmers fields increased. • Land degradation halted/reduced. • Yields per unit area and input increased. • Land use changed	• Farmers surveys. • Regional/national production statistics. • Land use surveys (satellite imagery, rapid rrural appraisal) .	• Land survey data available • Farmers adopt new technologies Socioeconomic conditions are favorable for achieving impact
Purpose Strategic principles, concepts and methods for protecting and improving soil quality through the efficient and sustainable use of soil, water and nutrient resources in crop-livestock systems, developed and disseminated to clients.	• Technologies for soil improvement/ management developed. • Limiting soil-plant-water processes identified. Compatible plant components identified for low fertile soils in crop-livestock systems. Guidelines, manuals and training materials for soil management produced.	• Scientific publications • Soil and crop management guidelines published • Decision support systems developed • Annual reports	• Economic analysis of options available • Effective linkages within CIAT and to partners in the region • Socio-economic inputs available from other projects (e.g., PE-3, BP-1) • Field sites accessible
Outputs 1. Soil, water and nutrient management constraints assessed and plant components characterized for improved production and resource conservation.	• Soil and water management constraints identified with farmer and NARS participation. • Questionnaire produced and farmers interviewed in at least two agroecosystems. • Tables of constraints in the three agroecosystems (first AES will be savannas, then hillsides). • Plant components identified and matched to edaphic/climatic constraints.	• Annual Report • Reviews published • Document of synthesized results • Detailed tables published in Annual Report.	• Literature available • Farmers continue to participate. • Projects SN-2, PE-3 and PE-5 actively participate. • Collaboration of Project PE-4 and NARS. • At least one assistant is assigned to the activity in Honduras/Nicaragua • SN-3 (IPRA) plans work with EB (BID poverty project).
2. Strategies developed to protect and improve soil quality.	• Recommendations of soil and crop management practices for efficient nutrient use and erosion control in systems. • Data of N cycles and budgets determined for at least four cropping systems. • Soil properties, management practices and plant components *that affect* N capture and fluxes identified.	• Project reports/ publications. • Management guidelines published • Document of synthesized results	• Sufficient operational funds available for chemical analyses. • Continuity of long-term experiments. • Modeling expertise available from partners e.g. Michigan State Univ. USA, IFPRI,CSIRO • Soil biology expertise from ORSTOM/Univ. of Paris available.

Narrative Summary	Measurable Indicators	Means of Verification	Important Assumptions
3. Improved decision making for combating soil degradation and greater agricultural productivity.	• List of Soil Quality indicators prepared and available to monitor degradation in reference sites. • Tools designed for estimating soil erosion and training manual written. • Decision-making tool for soil and water management produced. • Map of risk assessment of soil degradation (erosion, soil nutrients) for hillsides and savannas produced. • Decision making tools for use of organic materials produced. • Decision tree to create/maintain an arable layer produced. • Correlations established between local soil quality indicators and objective measurements. • Improved crop and soil models developed and validated	• Annual Reports/ publications. • Training manual for use with tools • Kit available to farmers and NARS. • Maps published. • Pamphlet published detailing decision tree.	• Collaboration from partners. • Information from questionnaires synthesized comparisons made with available PE-3 results. • Collaboration with PE-3 on soil erosion in CA. • Collaboration with SN-2, PE-4, PE-3, TSBF and SWNM Program. • Collaboration with MW (UNEP) on land quality indicators at reference sites. • Collaboration with PE-4.
4. Institutional capacity for SWNM enhanced through the dissemination of concepts, methods, tools and training.	• At least 9 undergraduate, three Master's and 2 Ph.D. theses submitted. • Workshop held on soil physics. • Workshop on C sequestration held. • At least three projects with partners submitted to donors. • ELABS initiated • At least 10 field days and four training workshops held on local soil quality indicators	• Theses available in library. • Reprints available. • ELAFIS Workshop report • Workshop report on C sequestration. • Project documents	• Continuing interest/participation of NARS and ARO partners. • Continued support for collaborative activities e.g. systemwide SWNM program.

Main highlights of research progress in 1999

Output 1. Soil, water and nutrient management constraints assessed and plant components characterized for improved production and resource conservation

- Found that 8 disc harrow passes per year are better for maize in terms of shoot biomass production and nutrient acquisition. Two and four disc harrow passes per year seem to be better for grass alone pasture and *Crotalaria juncea*, respectively.
- Up to 24 passes of a disc harrow did not adversely affect soil moisture status.
- Soil physical and chemical constraints for savanna Oxisols in Colombia were identified and target values for various parameters have been determined. These are being used to develop a decision tree for land use in the "llanos".
- Showed that: (i) modest physical improvement of the soil results in higher rice productivity; (ii) pasture components, particularly legumes increase the uptake of nutrients; and (iii) physical soil improvement plus grass legume pasture could contribute to greater land productivity.
- Showed that the use of rotations of maize or rice with legumes (soybeans and cowpeas respectively) slightly improves soil physical conditions.
- Isotopic exchange kinetic method is being adapted to highly P sorbing, acid tropical soils and is also being applied to assess the nature of P taken up by a selection of crop and forage components for crop-pasture rotational systems in low P acid soils.
- Established adaptation trials for 48 plant species (naturalized and exotics) with potential as biofertilizers in the Colombian hillsides reference site.
- Initiated search for native plants with biofertilizer potential at hillside reference sites: San Dionisio-Nicaragua, Yorito-Honduras and Cauca-Colombia.
- Showed that the establishment of Tithonia by plantlet results in better mycorrhizal association and shoot biomass production.
- Produced a list of recommendations for future mapping of soil condition based on local perceptions of the soil condition.
- Establishment of the SOL concept and network: A supermarket of options for the ecologically sound intensification of Production in the hillsides.

Output 2: Strategies developed to protect and improve soil quality

- Showed that the decrease in water infiltration and increase in weed infestation could cause a decline in upland rice yields.
- Showed that water infiltration is improved in savanna soils by use of the chisel plow and that dolomitic lime at a rate of 3.5 t/ha incorporated by use of the chisel plow is adequate for the first maize crop.
- Improved fallow species provided first indications of faster recuperation of soil fertility than natural regeneration.

- Established on-station and on-farm experiments to test the farm nutrient recycling approach by the strategic combination of double-purpose live barriers in a hillside agroecosystem.
- Establishment of *Tithonia* by plantlet increased P availability in soil due to increased P cycling via plant residues.
- Showed that the contribution of root turnover to nutrient cycling and soil carbon accumulation in introduced pastures, particularly legume-based pastures, could be significantly greater than that of the native savanna pastures.
- Live barriers permit a good control of soil erosion and conservation of water. Crop rotation and minimum tillage are important practices to maintain the productive capacity of the soils.
- Developed a case study of land use changes in the central lowlands of tropical South America.
- Showed that soil in earthworm casts are enriched in carbon by 1.5 to 1.9 times that of the surrounding bulk soil and are enriched in nitrogen by 1.4 to 1.6 times. Carbon contents of casts increased significantly over time resulting in a build up of active but physically protected C pools. When total casting activity per ha is taken into account we estimate that up to 8.6 tons C/ha/yr may accumulate in casts on improved grass/legume pastures compared with 0.6 t C/ha/yr on native savanna.

Output 3: Improved decision making for combating soil degradation and greater agricultural productivity

- Showed the value of a soil organic matter fraction related to soil nutrient availability that is able to detect soil quality changes not captured by conventional measures like total soil C and N.
- Showed that water soluble P fertilizers have a high residual value and Bray-II could be a useful method to estimate P availability in Colombian savanna Oxisols
- Showed that microbially-bound phosphorus could be an indicator of changes in soil fertility with respect to phosphorus.
- Tillage of savanna soils improved the relative distribution of pore sizes compared with native savanna soil.
- Produced a training guide on "Participatory Methods for the Identification and Classification of Local Indicators of Soil Quality at the Watershed Scale".
- Developed a preliminary decision support tool using the MapMaker GIS software and a spreadsheet to evaluate land suitability for crop-livestock systems in the Llanos of Colombia.
- Produced erosion risk maps for the Rio Cabuyal watershed in Cauca, Colombia.
- Evaluated the risk of soil erosion over the municipality of Puerto López using two methods and showed that INPE method could be better suited for areas with limited information on soils and climate.

Output 4. Institutional capacity for SWNM enhanced through the determination of concepts, methods, tools and training

- Organized and coordinated 12 field days for 265 visitors (64% farmers and extensionists, 36% students).
- Participated in two training courses (Santander de Quilichao – Colombia, Santiago de los Caballeros – Dominican Republic) using the guide "Participatory Methods for the Identification and Classification of Local Indicators of Soil Quality at the Watershed Scale".
- Published 25 refereed journal articles, 5 refereed book chapters, 2 edited books, 27 non-refereed book chapters and 9 articles in conference proceedings.
- Supervision of 20 undergraduate theses, 13 MSc theses and 11 Ph.D. theses.
- Established and maintained collaborative links with partners

Progress towards achieving output milestones of the project logframe 1999

Output 1: Soil, water and nutrient management constraints assessed and system components characterized for improved production and resource conservation

- ***Plant attributes identified for greater nutrient acquisition and use efficiency***

Savannas: Phosphorus deficiency and aluminum toxicity are two major soil constraints to crop-livestock production in tropical savannas. Field studies conducted at Carimagua and Matazul contributed to define lime and nutrient requirements for acid soil tolerant varieties of rice, maize, cowpea and soybeans in rotational production systems on heavy-textured Oxisols. Several studies were conducted to define the adaptive attributes of crop and pasture components to infertile acid soils. This knowledge is useful to match the plant components to overcome edaphic constraints. Field and glasshouse studies on crop and forage components indicated that forage legumes are more efficient in acquiring P per unit root length. Comparative studies of a forage grass (*Brachiaria dictyoneura* CIAT 6133) and a legume (*Arachis pintoi* CIAT 17434) demonstrated that the legume could acquire P from relatively less available P forms from oxisols of Colombia.

Field research carried out at Carimagua showed marked differences in rooting strategies of native savanna and introduced pasture species and field crops (maize and upland rice). Introduced grasses developed abundant root systems compared to native savanna species. Both native savanna and introduced pastures developed deep root systems compared to field crops such as maize. Studies on root distribution of maize showed that most of the roots are in top 20 cm of soil depth. Application of higher amounts of lime did not improve subsoil-rooting ability of maize but contributed to greater nutrient acquisition. Cultivation with disc harrow (8 passes) markedly improved maize growth and nutrient acquisition. Studies are in progress to determine the impact of tillage on the rooting strategies of field crops, green manure crops and pasture species.

Hillsides: Soil loss is a major edaphic constraint in sloping lands of Latin America. Field studies on root and shoot attributes of crop and forage components has identified elephant grass as an effective fodder grass for sloping lands which can minimize soil loss and also could acquire greater amounts of N, P and K from low fertility acid soil due to its abundant fine root production. Studies on rooting strategies of naturalized and introduced pastures indicated that naturalized pasture is adapted to low soil fertility conditions due to its ability to produce finer root system. Inter-cropping of Cassava with cover legumes reduced soil loss and improved nutrient acquisition by cassava. Studies are in progress to evaluate the role of *Tithonia diversifolia* as an improved fallow species to minimize nutrient loss and improve nutrient cycling.

Forest margins: Declining soil fertility and excess soil moisture are two major constraints to livestock production in Forest margins agroecosystem. Field studies on native and introduced pastures conducted in Caqueta, Colombia yielded similar results on rooting differences found in the Llanos of Colombia. Spittlebug-resistant tropical grasses with fine roots and subsoil rooting ability are needed to mitigate pasture degradation in this agroecosystem.

Output 2: Strategies developed to protect and improve soil quality

- ***Nutrient cycles and budgets and soil organic matter accumulation in crop rotation and pasture systems quantified***

Savannas: P acquisition and recycling were quantified in crop rotations and ley pasture systems experiment (CULTICORE) on the Colombian eastern plains. Comparison of rooting patterns of crop and forage components indicated that introduced legume-based pastures are more deep rooted than crops and acquire considerable amounts of P despite a much lower level of available P in the surface soil. Observed differences in crop/forage residue decomposition and P release rates suggested that managing the interaction of residue with soil may help reducing P fixation reactions. Measurements of soil P fractionation indicated that applied P moves preferentially into labile inorganic P pools, and then only slowly via biomass production and microbes into organic P pools under both introduced pastures and crop rotations.

Similar observations have been made on the Cerrado soils. Examination of P fractionation under different systems of land use (crops, pastures, tree plantations and native Cerrado) found that applied P accumulated primarily in labile and moderately labile inorganic pools and entered into organic pools only in heavier soils that support a higher level of microbial and biological activity. Tree plantations seem to be very efficient in maintaining fertilizer P available to plants, whereas crops and pastures need regular P applications to keep available P high in soil.

Studies on P cycling in long-term (16-year-old) introduced pastures in the Llanos of Colombia indicated that legume-based pastures maintain higher organic and available P levels more consistently than the grass alone or native pastures. Greater turnover of roots and above-ground litter in legume-based pastures could provide for steadier organic inputs and, therefore, higher P cycling and availability. Failure of P to enter organic P pools is thought to indicate a degrading system due to low level of P cycling. If that is true, work done so far in the Llanos and Cerrados indicate that legume-based pastures and tree plantations could be considered as important land use options to stimulate P cycling, reduce P fixation and minimize soil degradation in tropical savannas.

Field studies demonstrated that the presence of legume in the introduced pastures not only improved N cycling but also contributed to greater acquisition and cycling of Ca and K. Knowledge on differences in rooting strategies and nutrient acquisition among plant components is being utilized to develop strategies to improve nutrient cycling and minimize nutrient losses in crop-pasture systems in savannas.

Output 3: Improved decision making for combating soil degradation and greater agricultural productivity

- ***Indicators of soil fertility, biological health, and physical quality identified for hillside and savanna agroecosystems***

Soil quality indicators have been developed for the savannas and include chemical, physical and biological parameters. These are being incorporated into a guide for assessing soil quality that combines local or indigenous indicators with scientific parameters. This research forms "guia 1", one of 9 guides that have been prepared in project PE-3 and which are currently being tested in the hillsides of Colombia and Central America.

Maps of soil erosion risk assessment are available for the Rio Cabuyal watershed. Data on the decomposition of organic materials has been entered into the Organic Resource Database (TSBF/Wye College) and is available on the internet.

An improved sub-model for soil phosphorus is currently being tested with Michigan State University.

Output 4: Institutional capacity for SWNM enhanced through the dissemination of concepts, methods, tools and training

- ***Five Ph. D. theses completed, training workshops and field days held on soil quality indicators***

Twelve field days held at the San Isidro farm in Colombia. Forty four students supervised, 20 undergraduate theses, 13 M.Sc. theses and 11 Ph.D. theses in preparation or completed.

Linkages expanded with national and international institutions. Two new special projects initiated in 1999.

Output 1. Soil, water and nutrient management constraints assessed and plant components characterized for improved production and resource conservation

Activity 1.1 Determine and characterize edaphic and climatic constraints

1.1.1 Identify changes in water storage capacity under different management systems

Highlight:

- Up to 24 passes of a harrow plow did not adversely affect soil moisture status.

Purpose:
To identify changes in the water regime of a soil subjected to different intensity of tillage by harrowing in the Llanos.

Rationale:
In soils of weak structure tillage intensity influences the amount of water storage in the soil, as it produces negative changes in the pore size distribution. As the intensity of harrowing passes increases, several changes in the soil physical conditions are produced. There is a reduction in the volume of macropores at the depth of tillage, the soil surface is sealed as a consequence of the combined effect of weak structure and rainfall impact, which in turn is due to high rainfall intensity. These factors: tillage, weak structure and high rainfall intensity were examined in one experiment at the Matazul farm, close to Puerto López in the Llanos.

Changes in moisture content of different tillage treatments at different depths were studied over the day and rainy season.

Materials and Methods:
The soil is a Typic Haplustox Isohyperthermic Kaolinitic. In plots that had previously received different harrowing passes: 0, 2, 4 and 8 for each year and that at the moment of evaluation had accumulated 0, 6, 12 and 24 passes, sampling for moisture content determinations at the following depths: 0-5, 5-10, 10-20, 20-30, 30-50 and 50-70 cm were made in each of four replications, during the middle of the rainy season, final of the rainy season and at the end of the dry season, to characterize the field capacity (rainy season) and the lower limit of available water (dry season) of a soil subjected to different management practices in the Llanos.

Core samples (50 × 50 mm) of soil at each depth were taken from hand-dug pits of 1 m by 1 m to ensure the depth of sampling. The samples were hermetically closed to avoid losses of water before sending to the laboratory. Other soil physical determinations were directly measured in the pit and disturbed samples taken for other determinations.

Results and Discussion:

Results show that there were no large differences in moisture content between the different tillage treatments, both in terms of gravimetric or volumetric moisture content, when they were compared in the same season (Table 2). The highest moisture content values were found during the middle of the rainy season. The values found represent the average moisture content at "field capacity" or maximum moisture content held by the soil after drainage. The values found are of great interest as with them it is possible to calculate the amount of water that could be used by a crop. A practical average value of 21% of gravimetric moisture content can be taken as a good approximation of "field capacity" of the clay loam soils represented by the experimental site.

Table 2. Changes in gravimetric and volumetric moisture content as a function of intensity of disk harrowing and season.

	Number of passes			
Season	0	6	12	24
Gravimetric moisture content (%):				
Middle of rains	22.2 a	22.1 a	21.9 a	22.0 a
Final of rains	20.8 a	20.5 ab	19.7 b	20.2 ab
Final of dry	10.4 a	10.5 a	9.5 b	10.5 a
Volumetric moisture content (%):				
Middle of rains	28.8 b	30.2 a	28.7 b	29.0 b
Final of rains	26.8 a	27.7 a	25.6 b	26.9 a
Final of dry	14.7 a	14.5 a	12.8 a	14.2 a

Different letters in the same row mean significant differences by Duncan ($P<0.05$)

Volumetric moisture contents during the middle of the rainy season were of about 29% which represent field capacity. Although, statistical differences were found between number of passes, they were so close that for practical purposes could be considered that differences did not exist.

The moisture content at the end of the dry season, represents the minimum value at which soil gets dry under natural conditions. It represents the "lower limit of available water" or "wilting point". The gravimetric moisture contents at this state for the different treatments varied from 9.5% to 10.5%. A value of 10% well represents a practical level for wilting point, independently of the intensity of tillage treatments. When this important property is expressed in volumetric terms its average value is of 14%.

From the data collected and analyzed it is possible to have now, the average percentage of available water, which is 11% when expressed as gravimetric moisture content and of 15% as volumetric moisture content. This gives a moisture storage capacity of available water of 105 mm for the 0-70 cm of depth studied. Thus the maximum amount of rainfall the soil can retain against gravity is only 105 mm of the 2500 mm of rainfall that falls in this area. Considering an ETP of 6 $mm.day^{-1}$ during 5 months of growing period, a crop could be using 900 mm of rainfall; the rest is lost by runoff.

An analysis of the behavior of moisture content by depth was also made. Table 3 shows the results. It can be seen that the values of moisture content in the profile (0-70 cm) both in gravimetric and volumetric terms were close. This means that an equilibrium was reached. Some statistically significant differences in depth were found, meaning that upper layers hold more water than deeper ones, which is true as the upper layers accept rainfall more frequently than the lower ones. The uniformity of the moisture content in depth shows that an equilibrium was reached and therefore that those values represent the upper value of available water or field capacity.

Table 3. Changes in gravimetric and volumetric moisture content as a function of depth and season.

	Soil depth					
Season	**0-5**	**5-10**	**10-20**	**20-30**	**30-50**	**50-70**
Gravimetric moisture content (%):						
Middle of rains	23.3 a	22.9 a	22.3 b	21.8 c	20.9 d	21.0 d
Final of rains	20.6ab	20.2 b	20.9 a	20.1 b	19.9 b	19.9 b
Final of dry	7.0 f	8.7 e	9.7 d	11.1 c	11.9 b	12.9 a
Volumetric moisture content (%):						
Middle of rains	29.3 a	29.2 a	29.0 a	29.4 a	29.3 a	28.9 a
Final of rains	25.8 b	25.8 b	27.0ab	26.7ab	28.1 a	27.3 a
Final of dry	8.8 a	11.4 b	12.7 c	15.0 d	17.3 e	19.0 f

Different letters in the same row mean significant differences by Duncan ($P<0.05$)

During the dry season higher values of moisture content occurred at depth, showing that the advance of the drying front had not reached those depths. This finding is important for the understanding of the hydrology of these soils in relation to water use and supply. Most of the water dynamics occurs in the first 0-20 cm depth. Below this depth the dynamics is less. This finding is in agreement with the low values of hydraulic conductivity found before on these soils.

Impact:
The results obtained are applicable to the area of clay-loam soils in the Llanos. They allow the calculation of the amount of available water at different depths. These results indicate that the determinations of field capacity and wilting point must be done under field conditions.

Contributors
I. Valenzuela and G. Perea (Universidad de Los Llanos), D.L. Molina, E. Amézquita and P. Hoyos (CIAT).

1.1.2 Determine critical soil properties for savanna Oxisols

Highlight:

- Soil physical and chemical constraints for savanna Oxisols in Colombia were identified and target values for various parameters have been determined. These are being used to develop a decision tree for land use in the "llanos".

Purpose:
To identify and characterize changes in soil physical, chemical and biological characteristics under different landscapes in savanna soils.

Rationale:
Specific soil management practices need to be applied to savanna soils with different textures and productive properties.

Material and Methods:
A soil sampling covering different toposequences and textures was made in the Altillanura. Samples were taken at different depths to characterize soil profiles. Several soil physical, chemical and biological properties were determined. Some of them are summarized here.

Results and Discussion:
Some properties of soils of different textures are shown in Table 4. The right part of the table includes the suggested values that should be reached through soil management practices to improve the productive capacity of these soils.

The physical characterization of these soils shows that they have high values of bulk density, which means that they have constraints for root penetration and land preparation (Table 4). Organic matter contents are very low in clay-loam and sandy-loam soils. This means low productivity, low aggregate stability, low microbial activity, high erosion risks, etc. Infiltration capacity is also low and therefore runoff is high. Available water is low, especially in the sandy soils; therefore, rainfall frequency is very important for plant growth. Hydraulic conductivity and total porosity are also low. The general panorama of the soil physical condition, suggests the need for constructive tillage systems.

Chemical behavior shows that the soils are very poor in availabity of P, Ca, Mg and K (Table 4). By analyzing the physical and chemical conditions of these soils it became clear that improvement of these soils would require an adequate combination of vertical tillage (chisels) and addition of soil amendments and fertilizers.

Table 4. Some physical and chemical characteristics of soils of different texture in the Llanos.

	Texture			Suggested
	Clay	Loamy clay	Sandy loam	value (Goal)
Sand (%)	21.0	37.0	65.0	
Bulk density (Mg/m^3)	1.28	1.46	1.61	1.2
Organic matter (%)	4.58	2.98	1.14	> 5.0
Infiltration rate ($cm.h^{-1}$)	4.5	8.0	14.0	>15
Field capacity (% v/v)	32.0	28.0	15.0	35
Wilting point (% v/v)	16.0	14.0	6.0	12
Available water ((% v/v)	16.0	14.0	9.0	23
H. conductivity ($cm.h^{-1}$)	1.0	1.4	9.0	10
Total porosity (%)	51.0	45.0	40.0	50
P (ppm)	1.0	1.27	3.85	20
Ca (meq/100 g)	0.29	0.11	0.20	1.5
Mg (meq/100 g)	0.09	0.07	0.07	0.6
K (meq/100 g)	0.09	0.06	0.04	0.15
Al (meq/100 g)	2.69	2.31	0.91	1.0

Impact:

Soil physical and chemical constraints for savanna Oxisols in Colombia were identified and target values for various parameters have been determined. These are being used to develop a decision tree for land use in the "llanos". To have a big impact in the general area, an extension program on methods of vertical land preparation and amendments should be supported.

Contributors:

PRONATTA; P. Hoyos, E. Amézquita, D.L. Molina and R.J.Thomas (CIAT); E. Almanza and C.R. Salamanca (CORPOICA).

Activity 1.2 Survey native plants and their potential use as biofertilizers

1.2.1 Plants with biofertilizer potential in the Colombian hillsides

Highlight:

- Established adaptation trials for 48 plant species (naturalized and exotics) with potential as biofertilizers in the Colombian hillsides reference site.

Purpose:
To select better adapted species with high nutrient content and a range of slow to rapid nutrient release rates when used as a soil amendment.

Rationale:
As part of the work to identify better components for improved cropping systems, adaptation trials were established with several plant species differing in their growth habit and chemical composition of their residues.

Materials and Methods:
A collection of 21 fast growing leguminous trees and shrubs whose organic residues vary in chemical composition has been set up in San Isidro farm as well as at CIAT headquarters in order to select better adapted species (Table 5). These plants will be also used as a source of seed and plant material for process studies on decomposition and nutrient release dynamics in order to guide their use in cropping systems arrangements.

A collection of 28 herbaceous cover crops and green manures of widely varied chemical qualities has been set up in San Isidro farm as well as at CIAT headquarters in order to select better adapted species (Table 6.). These plants will be also used as a source of seed and plant material for process studies on decomposition and nutrient release dynamics in order to guide their use in cropping systems arrangements.

Table 5. List of N-fixing shrubs and trees with details on *Rhizobium* strains for legumes.

Species	Rhizobium strain (CIAT number)
Trees	
Calliandra calothyrsus CIAT 20400	4910
C. calothyrsus ICRAF	4910
Indigofera constricta CIAT-Cauca	5071
Leucaena leucocephala ICRAF	1967
Gliricidia sepium ICRAF	3920
Senna siamea ICRAF	
S. pectabilis CIAT-Cauca	
Albizzia lebbeck ICRAF	79 + 4910
Sesbania sesban ICRAF	5090
Shrubs	
Desmodium velutinum CIAT 23984	35

Tithonia diversifolia CIAT-Cauca	
Rynchosia schomborgkii CIAT 19235	79
Acacia angustima IAPAR 61	4910
Tephrosia vogelii ICRAF	79
Tephrosia candidans CIAT-Cauca	79
Flemingia macrophylla ICRAF	4099
Cajanus cajan CIAT 17522	371 + 400
C. cajan CIAT 21507	371 + 400
C. cajan CIAT 18701	371 + 400
C. cajan CIAT 18700	371 + 400
C. cajan (Honduras)	371 + 400

Note: All plants were inoculated with the mycorrhizal fungi (*Acaulospora longula*). Species with no Rhizobium added are non-nodulating.

Table 6. List of cover crops and green manures with details on *Rhizobium* strains.

Species	Rhizobium strain (CIAT number)
Galactia striata CIAT 889	840 + 3040
G. striata CIAT 17971	840 + 3040
Galactia sp CIAT 21676	427 + 1814
Calopogonium mucunoides CIAT	453 + 770
Canavalia brasiliensis CIAT-Honduras	273 + 4461
C. ensiformis CIAT-Honduras	273 + 4461
C. café CIAT-Honduras	273 + 4461
Crotalaria mucronata IAPAR	4461
C. spectabilis IAPAR	4461
Crotalaria sp (Represa Salvagina)	4461
Flemingia stricta CIAT 21089	4099
Mucuna georgia var velvetbean	382 + 383
M. pruriens var IITA – Benin	382 + 383
M. deerengianum CIAT-Honduras	382 + 383
M. anã IAPAR	382 + 383
M. cinza IAPAR	382 + 383
Pueraria phaseoloides CIAT 9900	3918
Centrosema macrocarpum CIAT 25522	3101
C. macrocarpum CIAT 5713	3101
C. pubescens CIAT 15160	3101
Phaseolus coccineus CIAT-Honduras	889
P. polyanthus	889
Cajanus cajan IAPAR 43 (guandu anão)	371 + 400
Ervilha IAPAR 74	334 + 3685
Amendoium cavalo IAPAR	3101
Nabo forrajero IAPAR	
Aveia preta IAPAR	

Note: All plants were inoculated with the mycorrhizal funghi *Acaulospora longula*. Species with no Rhizobium added are non-nodulating.

Contributors:
N.Asakawa, G. Ocampo, C.A. Trujillo, E. Barrios and R.Thomas

1.2.2 Local plants with biofertilizer potential at hillside's reference sites

Highlight:

- Initiated search for native plants with biofertilizer potential at hillside reference sites: San Dionisio-Nicaragua, Yorito-Honduras and Cauca-Colombia.

The survey of native plants with biofertilizer potential has started in the hillsides reference sites (San Dionisio-Nicaragua, Yorito-Honduras and Cauca-Colombia) in collaboration with local universities (through student theses) with two main activities: a) survey of native flora of microwatershed reference sites and b) survey of local knowledge on the topic.

This activity is relatively new and at this point in time further reporting is considered premature.

Contributors:
E. Escobar (Universidad Nacional, Palmira-Colombia), A.Grijalva (Universidad Centro Americana, Managua – Nicaragua), R. Zúñiga (Escuela Panamericana Zamorano – Honduras) and E. Barrios (CIAT)

Activity 1.3 Survey land users for soil and crop management knowledge

1.3.1 Development of maps of the distribution of soil conditions as perceived by the farmer

Highlight:

- Produced a list of recommendations for future mapping of soil condition based on local perceptions of the soil condition.

Purpose:
Graphic synthesis of soil condition information derived from an extensive baseline questionaire in the Cabuyal watershed.

Rationale:
A questionaire survey was carried out in 1993 by the Hillside Program in the Cabuyal Watershed, Cauca (Figure.1). We report on the activity to determine whether farmer responses to questions about soil conditions and farm practices could be used to derive maps of soil qualities in the watershed based on the local perception.

Materials and Methods:
Several of the questions thought to be relevant where extracted and analyzed by deriving the % of all farmers' responses in each 'vereda' (a political administration unit). Maps were drawn by classing the percentage values into categories of less than 10%, 10-20%, 20-50% and more than 50% (or proportional to the number of responses). The perception of good or bad soils was complemented by the answers to three basic questions linked to

soil fertility: a) fertilizer use, b) observed earthworm activity and c) observed dominance of the fern *Pteridium aquilinum*.

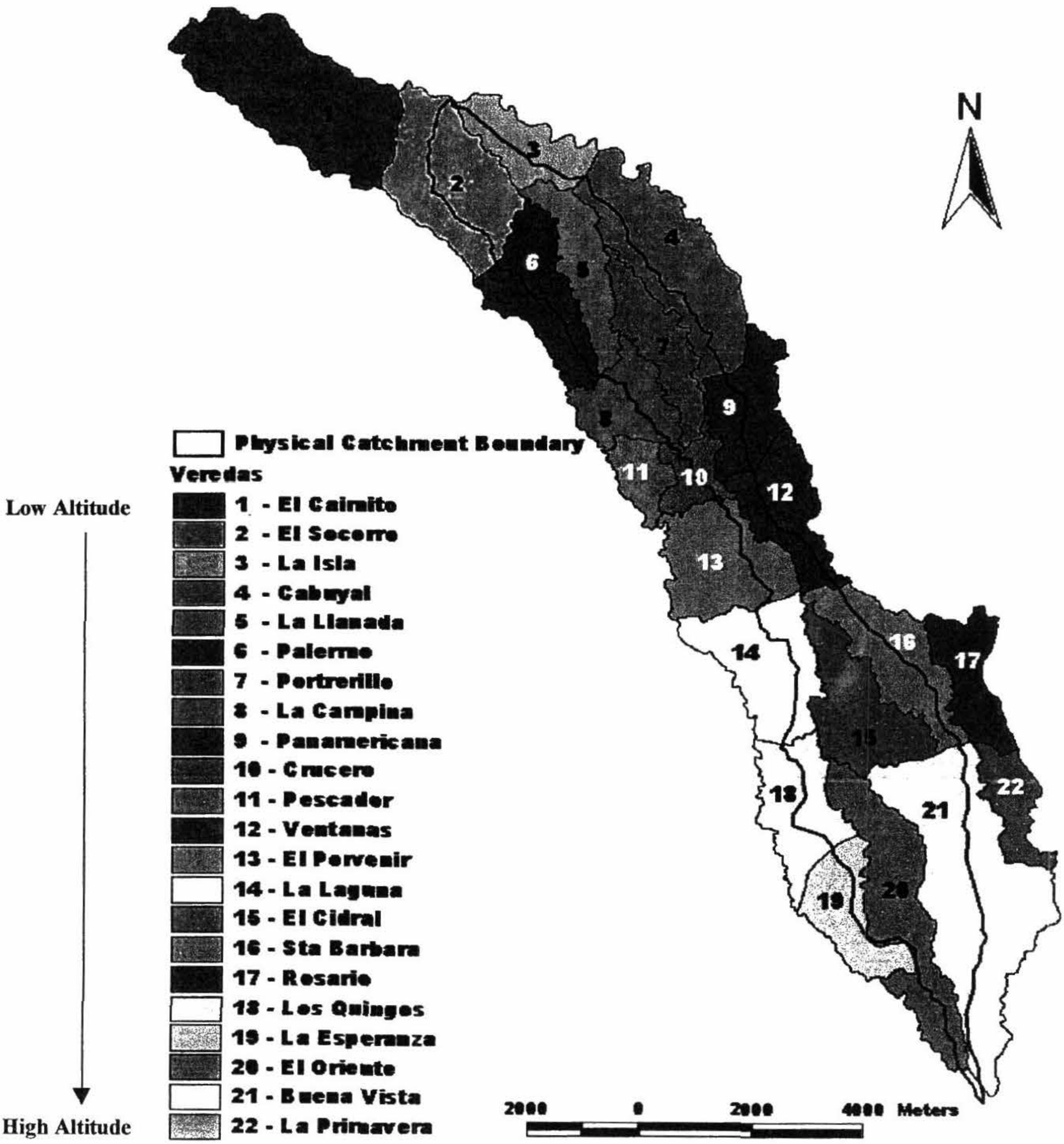

Figure. 1 Administrative and physical catchment boundaries of Cabuyal Watershed.

For the sake of this study several assumptions were made based on information in the literature: a) areas with greater fertilizer use were those with less natural soil fertility, b) greater earthworm activity was associated with good soils receiving considerable organic matter inputs and maintaining adequate soil moisture and c) the dominance of the fern *Pteridium aquilinum*, a local plant indicator of soil acidity, was associated with infertile soils.

Results and Discussion:
Information derived from the questionnaire related to the perception of good soil conditions, earthworm activity as an important local indicator of soil quality and information about the use of fertilizers was put together into individual maps (Figure 2.). This procedure enabled the evaluation of coherency of gathered information. In general, it is locally perceived that the soils in higher parts of the watershed have a better soil condition than those from lower altitudes. In general, earthworm activity did not correspond to better soils. This result is attributed to the difficulty in setting up a comparable measure of earthworm activity across farmers interviewed and the extent to which generalization at 'vereda' level is accurate. On the other hand, the lack of fertilizer use coincided better with areas which apparently have good soil conditions. The use of fertilizers over the area provides a reasonable first indication of the distribution of better soils in the upper part of the catchment where generally fewer farmers use fertilizer.

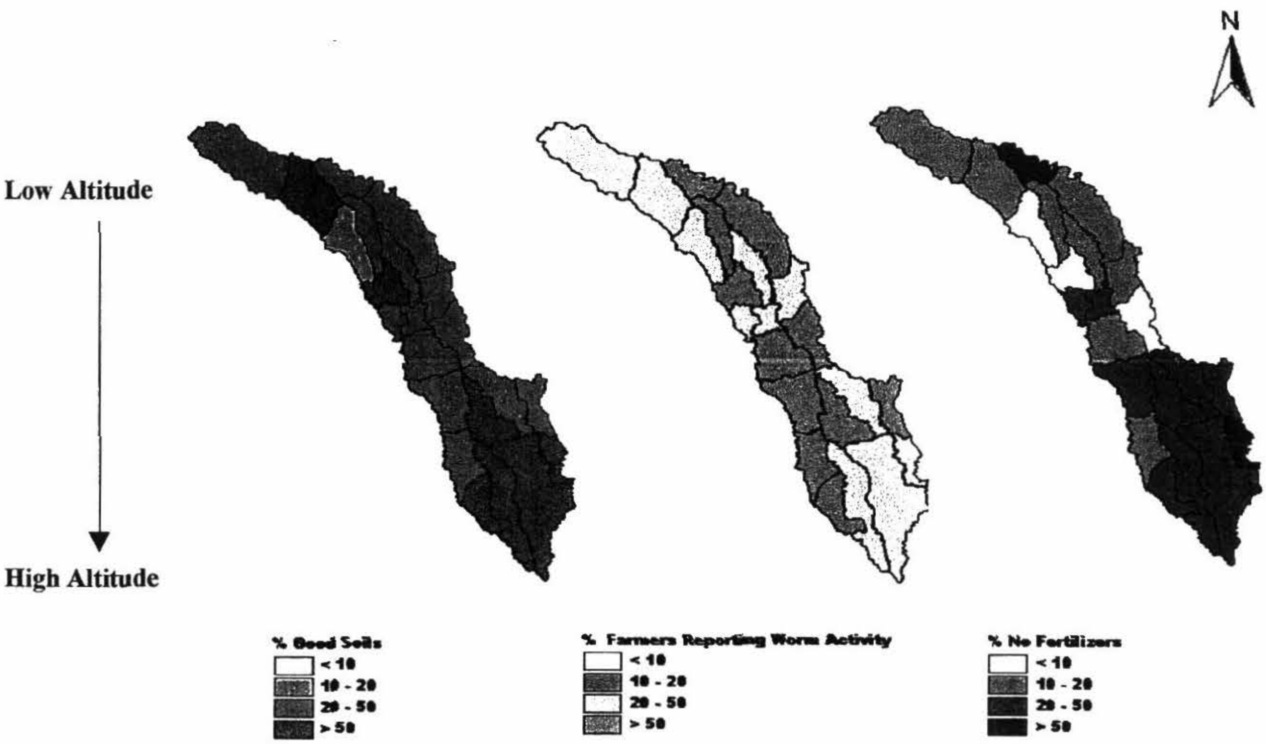

Figure 2. Relationship among good soils, earthworm activity and no fertilizer application in the Cabuyal Watershed.

However, accessibility in this relatively remote area may be a significant factor explaining this distribution.

Maps were also derived from information related to the perception of bad soil conditions, fern predominance as an important local indicator of soil acidity and the use of fertilizers (Figure 3.). Despite common knowledge of considerable areas with bad soil conditions in the Cabuyal watershed, very few farmers reported bad soils on their farms. The low response may be associated to the way the questionnaire approached this apparently sensitive issue. Fern abundance was generally high all over the watershed suggesting that this indicator was not able to discriminate different levels of soil acidity at the scale used. In general, the use of fertilizers was high in the lower part of the watershed. It can also be seen that the region with the highest use is found in the high altitude area, thus appearing to contradict Figure 2. Nevertheless, it is still possible that half the farmers in this particular vereda used fertilizers while the other half did not. In addition, some reported both use and non-use depending on which plot in their farm they were referring to.

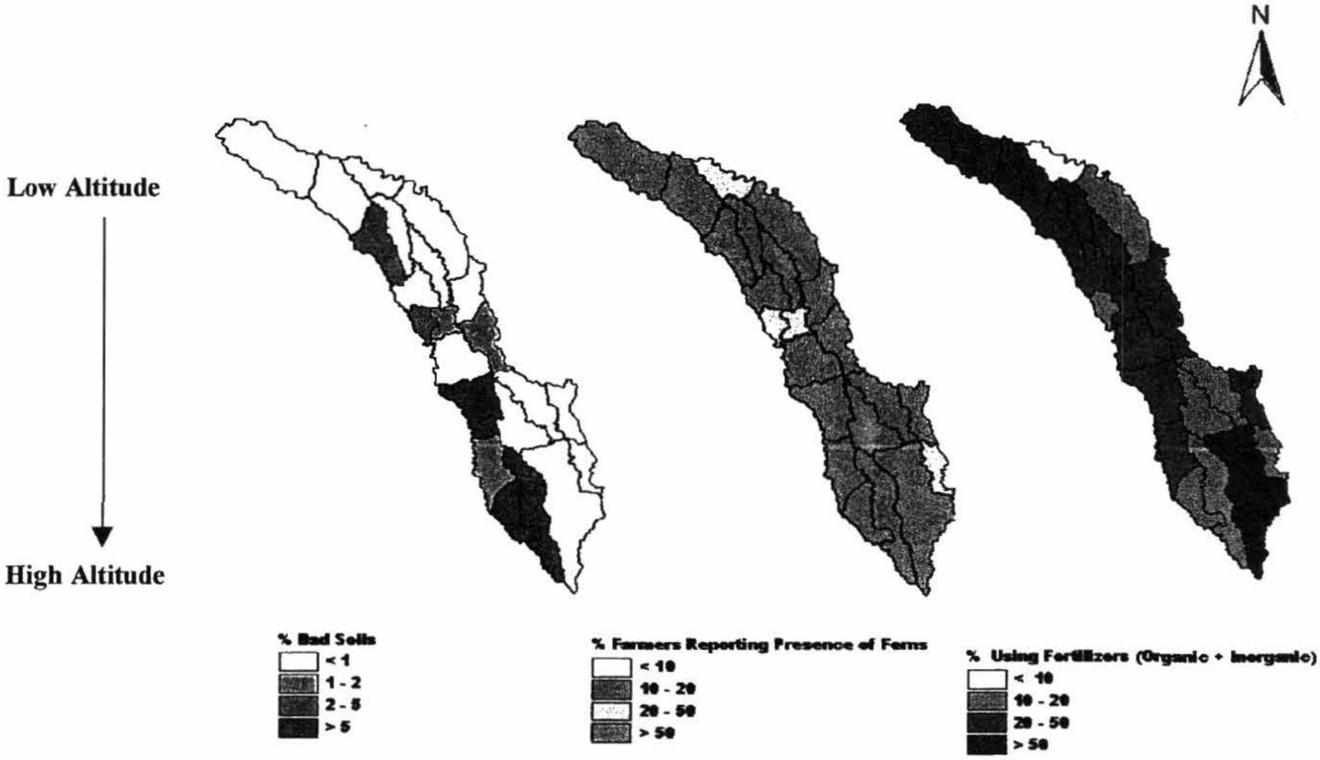

Figure 3. Relationship among bad soils, Fern presence and fertilizer application in the Cabuyal Watershed.

As a result of this analysis we found several points for consideration in future work:

1) The use of a study case approach with key informants rather than a questionnaire approach may improve the quality of the information gathered and thus provide greater coherency among perceptions of soil conditions and local indicators.
2) Based on a literature review and experience in the region, there is a need to initially adjust questions and the expected range of answers, as well as using a scale at which the answers remain valid during synthesis of results in the form of maps.
3) Experience shows that farmers are unlikely to give a negative connotation of their farms and practices. It is necessary to elaborate several less direct ways of getting to the same answer which are complementary and allow validation of answers. A study case guide titled "Local Knowledge about Soils and their Management" has been produced and appears as an annex in Guide#1 of Methodological Instruments for Decision Making in Natural Resource Management mentioned in activity 3.2 below.
4) There is a need to conduct future local knowledge studies and georeferencing of land use at the farm level. It is important to include as much land use history as possible since this information would be helpful during the interpretation of results.

Contributors:
K. Pallaris (King's College London), J. Rubiano(PE-3), G. Hyman(PE-4), E. Barrios and R. Thomas

1.3.2 Development of a georeferenced land-use baseline at farm level at the hillsides reference sites

Highlight:

- Initiated geo-referenced land use baseline at farm level at the hillsides reference sites.

A more focussed geo-referenced land-use study at farm level has also started in each of the hillsides reference sites in collaboration with local universities. This activity has been guided by a group-generated guide for case studies about local knowledge of soil and their management.

This activity is relatively new and at this point in time further reporting is considered premature.

Contributors:
M.Prager (Universidad Nacional, Palmira – Colombia), M.Somarriba (Universidad Nacional Agraria, Managua – Nicaragua), R. Zúñiga (Escuela Panamericana Zamorano – Honduras) and E. Barrios (CIAT).

Activity 1.4: Characterize plant components for production potential and nutrient use efficiency (phosphorus and nitrogen) and improvement of soil physical conditions

1.4.1 Characterize genetically adapted crop and forage components for their ability to access soil P pools using isotope exchange techniques

Highlight:

- Isotopic exchange kinetic method is being adapted to highly P sorbing, acid tropical soils and is also being applied to assess the nature of P taken up by a selection of crop and forage components for crop-pasture rotational systems in low P acid soils.

Purpose:

To determine the differences among crop and forage components in the ability to acquire P from less available P forms in soil.

Rationale:

One of the prerequisites to the development of sustainable crop-pasture rotational systems is the identification of crops or forage plants that are adapted to low phosphorus (P) supplying soils since P is often the most limiting nutrient for plant production in the tropics. There is a need to identify such plants and to understand how these plants adapt to low P acid soils either by an improved P acquisition efficiency from soil or fertilizer P reserves or by an increased P use efficiency. To achieve that objective, it is essential to compare the ability of the plants to acquire P with the ability of the soil to release orthophosphate into the soil solution. However, if such plants have adapted to low P acid soil only by improving their P acquisition efficiency then on the long term, the danger of P mining has to be considered, and appropriate agronomic practices have to be implemented in order to avoid P mining. On the other hand adapted crop and forage plants could reduce movement of applied P sources to unavailable soil P fractions.

The overall aim of this work, supported by special project funds from SDC/ZIL, Switzerland, was to contribute to the development of sustainable crop-pasture rotational systems by using germplasm adapted to low phosphorus-supplying soils. In order to evaluate the sustainability of these systems the main objectives of this work were: (1) to devise methodology to evaluate the characteristics and origin of the P taken up by genetically adapted varieties, (2) to assess the effect of genetically adapted crop and forage components on different organic and inorganic soil P pools, and (3) to test their ability to use and recycle P from various organic and mineral P sources.

Plants take up P by roots as orthophosphate from the soil solution, and the concentration of P in the solution represent, even in well supplied soils, less than 1% of plant needs. Thus the amount of plant available P in a given soil can be defined as the amount of P which can leave the solid phase of the soil and arrive in the soil solution. This could occur either through abiotic or biotic processes, within a time frame compatible with the duration of plant growth. The isotope exchange kinetics technique has been shown to provide an accurate description of the quantity of P that can arrive through homoionic exchange in the soil solution within 4 months (E value) both in temperate soils and in tropical soils with a low P fixing capacity. In high P fixing tropical soils, the application of this isotopic approach has in the past led to a strong overestimation of soil available P. This could be related either to the specific adsorption of the added radioactive P onto soil surfaces and/or to an overestimation of the inorganic P (P_i) concentration in the soil solution. Also this might be due to the application of a simplified formula to describe isotopic exchange kinetics. We evaluated the ability of the isotopic exchange kinetics method to assess soil P availability in low P acid soils. Additionally a preliminary experiment was carried out to compare L values of rice (*Oryza sativa*), *Brachiaria decumbens* and *Arachis pintoi*.

Materials and Methods:

Soils, sites and treatments -- The soils included in the study were sampled from field experiments located at two sites in Colombia.

a) *Santander de Quilichao:* Santander de Quilichao is situated at the southern end of the Cauca valley, south-western Colombia, at 990 m above sea level. Annual mean temperature is 23.7° C and the annual average precipitation is 1799 mm. The parent material consists of fluvially translocated volcanic, partly weathered material. The soil has a loamy clay texture and has been classified as an Oxisol. The soils were cropped since 1983 with cassava, and received different fertilizer amounts. All treatments were limed with 500 kg dolomite (54 % $CaCO_3$ and 46 % $MgCO_3$) ha^{-1} every two to three years. Annual fertilizer (kg ha^{-1}) treatments were T1: no fertilizer applied; T5: 100 N, 100 P, 100 K; T6: 100 N, 100 K; and T8: 100 N, 100 P.

b) *Carimagua, Llanos Orientales (Culticore):* The Carimagua research station is situated in the eastern plains of Colombia, at 200 m above sea level. Mean annual temperature is 27° C with an annual average rainfall of 2200 mm. The soils are well drained Oxisols (tropeptic haplustox, isohyperthermic). Soil samples were taken in the long-term "culticore" field experiment to test the effect of different farming systems on plant productivity and soil fertility. The following treatments (established in 1993) were selected:

- SA ('Native Savanna'): not grazed and fertilized but managed by burning annually during the dry season;
- RGL (Rice-Grass-Legume pasture): *Brachiaria humidicola, Centrosema acutifolium, Stylosanthes capitata, Stylosanthes guianenesis, Desmodium ovalifolium* and *Arachis pintoi* sown with rice in the first year and since then maintained as grass-legume pasture, grazed to maintain legume content with a total input of 80 kg P ha^{-1};
- CR (Continuous Rice): rice grown in monoculture; one crop per year followed by weedy fallow turned in with early land preparation at the end of the rainy season with a total input of 240 kg P ha^{-1};
- RGM (Rice Green Manure): Rice (1st semester) and Cowpea (2nd semester) in 1-year rotation. Cowpea as green manure crop was incorporated at maximum standing biomass level in the late rainy season with a total input of 400 kg P ha^{-1}.

To all treatments, with the exception of the native savanna, basal fertilizer (kg ha^{-1}) was applied at 80 N, 99 K, 15 Mg, 20 S and 10 Zn at the beginning of the field experiment.

Topsoil samples (0-20 cm) were air-dried and sieved at 2 mm before they were used for chemical analysis (Table 2).

Adapting isotopic exchange kinetics to low P (highly P-sorbing) acid soils: The procedure of isotopic exchange kinetics is based on the measurement of the specific activity ($^{33}PO_4/^{31}PO_4$) of phosphate ions in the soil solution after an addition of carrier free $^{33}PO_4$ in a soil-solution system at steady state. Following the equilibration of 15 g of soil in 148.5 ml deionized water for 16 hours, using four replicates per sample, at t=0 1.5 ml of $^{33}PO_4$ tracer solution containing 5.8 MBq were added and mixed with a magnetic stirrer. Nine subsamples were then taken from each bottle after 1, 10, 100 min, 1 and 3 days and 1, 2, 3 and 5 weeks, immediately filtered through a 0.2 µm pore size micropore filter, and the radioactivity in solution was measured by liquid scintillation counter. Additionally, after 100 minutes, 3 days, 1 week and three weeks, 10 ml of the solution were filtered through a 0.025 µm filter to determine the $^{31}PO_4$ concentration in the soil solution (cp) using the method of Murphy and Riley (1962). The isotopically exchanged P (E_t) was calculated assuming that, at any given exchange time, the specific activity of phosphate in solution is equal to the specific activity of the exchangeable phosphate on the solid phase:

$$r_t/10\ c_p = R/E_t \qquad \text{[Eq. 1]}$$

or:

$$E_t = R \times 10\ c_p/r_t \qquad \text{[Eq. 2]}$$

and r_t/R is extrapolated as:

$$r_t/R = r_1/R\{t+[r_1/R]^{1/n}\}^{-n} + r_\infty/R \qquad \text{[Eq. 3]}$$

Where R is the introduced radioactivity in MBq ml^{-1}, r_1 and r_∞ are the radioactivity remaining in the solution after 1 minute and infinity, respectively, and *n* is a parameter calculated as the regression equation between $\log(r_t/R)$ and $\log(t)$ for $t \leq 100$ minutes.

Pot experiment: The L-values were determined by growing *Agrostis capillaris* under controlled conditions on the same soils for which isotopically exchangeable P (Et values) had been determined. For the pot experiment, exchangeable soil P was labelled with a quantity, R, of $^{33}PO_4$ of 7.4 MBq/kg, and portions of 600 g labelled soil were filled into pots. Then a P-free nutrient solution, providing N, K, Mg, Ca and S was added, the soils were sown with 100 mg of bentgrass seeds and left in a growth chamber. During the experiment soil humidity was kept at 50 % of the water holding capacity (≈500 mg water kg^{-1} soil for Carimagua, ≈600 mg water kg^{-1} for Quilichao soils). Aerial parts were harvested at 4, 8, and 12 weeks after sowing. Dry matter and ^{31}P (p) and ^{33}P (r) contents were measured. Five replicates were made for each soil.

The L-values could be calculated with the experimental data obtained at each harvest, but as the first harvest is most affected by P derived from seeds, and as in the third harvest there was almost no more growth for the SA and RGL soils, the L values were calculated using the second harvest:

$$L_{obs} = R/(r_2/p_2) \qquad \text{[Eq.4]}$$

Where R is the quantity of $^{33}PO_4$ used to label exchangeable soil P (MBq kg^{-1}), r_2 is the quantity of $^{33}PO_4$ (MBq kg^{-1}) and p_2 is the quantity of $^{31}PO_4$ (mg kg^{-1}) in the shoots of the bentgrass at the second harvest, respectively. As a part of the P present in the seed was taken up by the shoot material during re-growth for the second cut and could dilute the available P taken up from the soil, the following correction was made on the L value:

$$L_{th}=L_{obs}[p_2/(p_2+axP_{seeds})] \qquad [Eq.5]$$

Where L_{th} is the corrected value, L_{obs} the value calculated with Eq. 4 and P_{seeds} the P content of 100 mg seeds sown. For the factor two values were chosen: 0.5 and 0.25, assuming that between 25 and 50% of the seed P was taken up in the second cut. This interval seems likely with 50 % representing an upper limit of possible P uptake in the second cut.

Further analysis: Several chemical properties of the used soil samples have been assessed according to the standard methods of the analytical laboratory at CIAT (Table 7). Additionally to the commonly used Bray II soil test, resin extractable P was determined with HCO_3^- charged resin strips for an additional estimate of available P. Total P was extracted with concentrated H_2SO_4 and H_2O_2.

Table 7. Chemical properties of soil samples taken at the Carimagua and Quilichao site. Values are the average of three (resin extractable P) or four replicates (all other characteristics).

Soil Treatment	Organic matter (g kg^{-1})	Bray P (mg kg^{-1})	pH	Al-Saturation (%)	N (g kg^{-1})	Resin extr. P (mg kg^{-1})
SA	47	0.9	4.8	86.8	1.64	0.30
RGL	50	2.0	4.9	71.7	1.55	0.48
CR	45	17.2	4.3	75.4	1.45	3.91
RGM	45	35.5	4.3	76.3	1.49	8.27
T1	60	9.0	4.6	28.8	2.27	3.03
T5	61	40.6	4.5	26.5	2.42	19.3
T6	62	14.0	4.4	34.8	2.48	4.50
T8	62	40.1	4.4	32.2	2.34	15.8

Carimagua site - SA: Native savanna, RGL: Rice-agropastoral rotation, CR: Rice monoculture, RGM: Rice-green manure rotation.

Quilichao site - Cassava monocultture with (N, P, K)- annual applications: T1 (0,0,0), T5 (100,100, 100), T6 (100,0,100), T8(100,100,0)

Results and Discussion:

P availability as assessed from soil analysis: The results showed that the tested soil samples have a high P sorbing capacity ($0.02<r1/R<0.05$, $0.38<n<0.51$) and that water extractable P content was lower than 50 μg P l^{-1} (Table 8). Extrapolated values for E_{5wk} have been compared with the measured E_{5wk} values (data not shown) and were found to be in agreement. E_{1min} and E_{8wk} values, and r_1/R logically increase with total inorganic P, i.e. with P increasing positive P balances, while n decreased with increasing P balance (data not shown). Similarly Bray-P and resin extractable P increased with positive P balance (Table 7). When comparing the non fertilized soils, available P was higher for the Quilichao soil samples than for the samples from Carimagua, indicating fundamental differences between the two sites. Finally a close relationship can be found for both soils between P availability as assessed by the isotopic approach (E_{1min}, E_{8wk}) and P availability as determined by extractions (P_{resin} or P_{Bray}). The equations for the linear regression models, including all soils were $E_{8wk} = 8.5\ P_{resin} + 35.7$ and $E_{8wk} = 3.4\ P_{Bray} + 25.5$ with $r^2 = 88.4$ and 82.5, respectively.

P availability as assessed from the pot experiment: The results from the second harvest are presented (Table 9). The biomass production on the SA and RGL soils was very low, and the P uptake from seeds had therefore a high impact on the L value. On these two soils, the correction (Eq. 5) was very important (Table 9) and the assumption that 50 or 25% of total seed P was taken up by the second harvest makes an important difference, too. On all other soils, however, L_{obs} and L_{th} did not differ much.

Table 8. Parameters of isotopic exchange, and total P content. Values are the average of three replications. Standard error values are shown in parenthesis.

Soil/Treatment	r_1/R	n#	E_1 * (mg/kg)	E_{8wk}* (mg/kg)	C_p (mg/l)	P_{tot}" (mg/kg)	Pi♣
SA	0.02 (0.0008)	0.51 (0.01)	0.5 (0.02)	11.7 (0.21)	0.001 (0.0004)	175 (10)	13
RGL	0.03 (0.0005)	0.43 (0.002)	1.7 (0.02)	25.5 (0.31)	0.005 (0.0016)	213 (7)	30
CR	0.03 (0.0008)	0.41 (0.03)	2.0 (0.05)	66.3 (1.59)	0.006 (0.0007)	293 (25)	98
RGM	0.04 (0.001)	0.41 (0.01)	3.2 (0.11)	112.5 (2.89)	0.011 (0.001)	376 (10)	167
T1	0.02 (0.0013)	0.42 (0.01)	0.7 (0.06)	84.7 (7.3)	0.025 (0.0003)	429 (13)	182
T5	0.05 (0.011)	0.38 (0.01)	6.9 (0.71)	190.8 (6.81)	0.035 (0.0007)	671 (14)	361
T6	0.03 (0.0029)	0.43 (0.001)	2.8 (0.29)	91.9 (9.07)	0.008 (0.0008)	486 (14)	180
T8	0.04 (0.0025)	0.43 (0.003)	4.5 (0.05)	160.6 (4.92)	0.021 (0.0011)	594 (23)	338

calculated as slope of the regression between ln (rt/R) and ln(time) of the values between 1 and 100 minutes, * calculated as $E_t=10\ c_P\ R/r_t$, and $rt/R=(r_1/R)xt^{-n}+r_{indef}/R$, " Total P, extracted with conc. H_2SO_4 and H_2O_2, ♣inorganic P measured with the method of Saunders and Williams (1955).

Carimagua site - SA: Native savanna, RGL: Rice-agropastoral rotation, CR: Rice monoculture, RGM: Rice-green manure rotation.

Quilichao site - Cassava monoculture with (N, P, K)- annual applications: T1 (0,0,0), T5 (100,100, 100), T6 (100,0,100), T8 (100,100,0).

Table 9. P uptake, biomass production and L values of *Agrostis capillaris* at the time of second harvest.

Soil Treatment	Dry matter Per pot (g)	P uptake Per pot (mg)	L_{obs}	$L_{th0.5}$	$L_{th0.25}$
SA	0.13	0.04	143	22	38
	(0.01)	(0.00)	(10.1)	(2.2)	(3.6)
RGL	0.45	0.35	42	25	31
	(0.01)	(0.01)	(1.2)	(0.5)	(0.7)
CR	2.61	3.15	91	84	87
	(0.07)	(0.14)	(7.1)	(6.6)	(6.9)
RGM	3.35	3.71	118	110	114
	(0.13)	(0.19)	(3.7)	(3.4)	(3.5)
T1	3.43	3.68	95	89	92
	(0.17)	(0.16)	(5.4)	(5.0)	(5.2)
T5	4.27	6.91	198	191	194
	(0.09)	(0.34)	(1.8)	(2.0)	(1.9)
T6	3.58	3.28	96	86	89
	(0.09)	(0.16)	(1.7)	(1.7)	(1.7)
T8	4.48	4.85	149	142	146
	(0.17)	(0.33)	(9.0)	(8.1)	(8.6)

L_{obs}=L value without, L_{th}=L value with correction with either a=0.5 or a=0.25, assuming that either 50 or 25% of seed P was taken up by shoot material during the second cut. Standard error values are shown in parenthesis.
Carimagua site - SA: Native savanna, RGL: Rice-agropastoral rotation, CR: Rice monoculture, RGM: Rice-green manure rotation.
Quilichao site - Cassava monocultture with (N, P, K)- annual Applications: T1 (0,0,0), T5 (100,100, 100), T6 (100,0,100), T8 (100,100,0).

Relation between E and L values: For the comparison with the E_{8wk} values the $L_{th0.25}$ were used, assuming that a P uptake of 25 % of total seed P at second harvest might be more realistic than 50 %. The E_{8wk} values, determined with the theoretical Eq. 3, were highly significantly correlated with the $L_{th0.25}$ values of the second harvest (see data in Tables 8 and 9). Regression models were calculated for the two sites separately and for the whole data set (Table 10).

Within both sites the L_{th}- and E_{8wk}-values are well correlated. However there seems to exist a small tendency towards an overestimation of the L_{th} value by the E_{8wk}-value, expressed by the coefficient of the linear regression of 0.88 which might be due to an overestimation of water extractable P. Besides, the c parameter is significantly different from 0 whereas this should theoretically not be possible. Therefore, the L value approach might not be suitable on soils where P limitation is so severe that biomass production is highly limited and the P uptake from seeds may form the main P source for the plants struggling for survival, like the ones observed on the SA and RGL soils with E_{8wk} values lower than 30 mg P kg^{-1}.

Table 10. Estimation of the regression coefficients of the equation $L_{th}=bE_{8wk}+c$.

Data	Coefficient	Estimated values	SE	r^2 (p=0.05)
Carimagua	B	0.84	0.08	0.87
	C	22.1	5.10	
Quilichao	B	0.88	0.09	0.84
	C	14.7	12.2	
All data	B	0.84	0.04	0.91
	C	21.3	4.68	

SE = standard error.

These results confirm previous observations that *Agrostis capillaris* uses mostly isotopically exchangeable P (i.e. isotopically exchangeable P is plant available P). Additionally these results also show that parameters from the isotopic exchange kinetics experiment can be used to extrapolate the amount of P which will get into the soil solution during at least 8 weeks, i.e. the isotopic exchange kinetics can be used to determine plant available P on these low P supplying tropical soils.

Results from the preliminary pot experiment that compared L values of a rice variety (Savanna-6), *Arachis pintoi* (CIAT 18744) and *Brachiaria decumbens* (CIAT 606) were promising but not conclusive at this point. This was mainly because the biomass production on the RGL soil was very small and the source of seed P strongly diluted the specific activity of the plant tissue P. However, the results indicated that the two forage species, *Brachiaria decumbens* and *Arachis pintoi*, could acquire P from normally not exchangeable P pools. Another pot study is required to quantify differences among crop and forage components. This study should include an additional application of some P fertilizer to RGL soil and a longer growth period to enhance dry matter production.

Impact:
The isotopic exchange kinetic method is being adapted to highly P sorbing, acid tropical soils. This method is also being applied to assess the nature of P taken up by a selection of crop and forage components for crop-pasture rotational systems in low P acid soils. Available soil P was assessed using a range of acid soils from Colombia and determining the isotopic exchange kinetics. The decrease of radioactivity in the soil solution, and the increase in isotopically exchangeable P with time (E(t) value) in these soils were then successfully modelled. In parallel, the same soils were labelled with carrier free radioactive P, used for a pot experiment with *Agrostis capillaris* (common bentgrass), and the amount of soil isotopically exchangeable P (L value) was calculated using the quantities of radioactivity and P removed by the plant. Since common bentgrass has been

shown in previous research to take up mostly isotopically exchangeable P, the results of this study suggest that the isotopic exchange kinetic approach can be successfully applied in these soils to assess the rate of P release to the soil solution.

Contributors:
S. Buehler, A. Oberson, E. Frossard, S. Sinaj (ETH), G. M. Rodriguez (CIAT), D. Friesen (IFDC-CIMMYT) and I. M. Rao (CIAT)

The project links with 4 other CIAT projects IP-1, IP-3, IP-4 and IP-5.

1.4.2 Determine the impact of tillage on plant growth and nutrient acquisition by different crop and forage components in the llanos of Colombia

Highlights:

- Found that 8 disc harrow passes per year are better for maize in terms of shoot biomass production and nutrient acquisition. Two and four disc harrow passes are better for grass alone pasture and *Crotalaria juncea*, respectively.

Purpose:
To determine plant growth attributes and nutrient acquisition as affected by the intensity of land preparation.

Rationale:
Soils of the llanos are susceptible to physical, chemical and biological degradation once brought into cultivation. Intensive use of machinery in the preparation of soil for monocrops drastically reduces water infiltration rates as a result of loss of soil structure plus sealing of the surface layer (Preciado et al., 1998). The consequence of increased land preparation by machinery is a constant break down and reduction in soil aggregate size. The action of rainfall and gravity results in re-packing of these aggregates and consequently the total soil porosity and pore sizes are reduced. The resulting changes in macroporisity impacts negatively on the productive capacity of the soil and affects water flow, which in turn affects nutrient availability. Three important phenomena related to plant nutrition are negatively affected by macropores reduction; root growth, nutrient interception by roots, and soil drainage and aeration (Preciado et al., 1998). Soil porosity of below 10% will generally limit crop and pasture production.

Reduced water infiltration also encourages surface water run-off and consequently soil and plant nutrient losses brought about by soil erosion. This implies that land preparation practices should be planned to take into account of the drastic reduction in size of soil aggregates and it's resultant negative effect on biomass production brought about by excessive use of machinery.

In 1995 an experiment was established at Matazul farm to study the effect of intensive use of machinery (disc harrowing) on soil physical properties by contrasting cropping systems including grass alone pasture, green manure (*Crotolaria*) and maize. The aim of the experiment was to develop adequate soil tillage practices that could avoid soil degradation. Preliminary observations indicate that the bulk density is reduced in the vicinity of disc harrowing (0-10cm). However, in the lower soil depth (below 10 cm) it increased as the number of disc harrow passes were increased indicating that the soils in the llanos are unsuitable for intensive cultivation as it results in reduced water infiltration rates (less acceptance of rainfall).

Plant nutrients such as P are likely to be greatly affected by tillage practice. Low total and available P content, and a relatively high P retention capacity characterize the Oxisols of the Llanos. The main aim of this study was to determine the impact of tillage practices on different cropping systems to enhance plant growth and nutrient acquisition. It is aimed at augmenting results on soil physical characterization.

Materials and Methods:

Soil samples were taken from an experiment that was established in 1995 on Matazul (4° 9′ 4.9″ N, 72° 38′ 23″ W at 260 m.a.s.l.) farm to study the effect of intensive use of machinery (harrowing passes) on soil physical properties. The soil is classified as a Typic Haplustox Isohyperthermic Kaolinitic (Oxisol) in the USDA classification system. The climate in the area has two distinct seasons, a wet season from the beginning of March to December and a dry season from December to the first week of March (Santa Rosa station, located at the Piedmont of the llanos).

The treatments included:

- 3 Cropping systems (Grass alone pasture, *Crotolaria juncea* and maize).
- 3 levels of harrowing (2, 4 & 8 disc harrow passes per year x 3 years – to date) per cropping system.

We determined the biomass production and contents of N, P, K, Ca and Mg of the shoot (or plant parts) by the methods of Salinas and Garcia (1985).

Results and Discussion:

Two passes of disc harrow per year (6 passes in 3 years) are sufficient for superior performance of grass alone pasture. Additional disc harrowing resulted in a depressed shoot biomass production and reduced nutrient uptake (Table 11). Amézquita et al (1998) reported a reduction in soil moisture content in the first 0-5 and 5-10 cm as the number of disc harrow passes were increased. The increased harrowing is likely to create a marked reduction in soil volume (Amézquita et al, 1998). In a greenhouse experiment, Meléndez (1998) found that *Brachiaria* grass growth and N uptake were greatly influenced by the size of soil aggregates. He found that N uptake from soil was a function of aggregate size indicating that any excess preparation of soil could negatively affect the uptake of this nutrient. These findings are consistent with the results obtained under the grass alone pasture treatment. It seems that the grass alone pasture has been affected by the reduced size of soil aggregation. It is possible that excessive tillage might have reduced moisture content in the upper soil layer that could decrease the ability to acquire nutrients.

Maize showed greater aboveground production and nutrient acquisition with 8 disc harrow passes per year (Table 11). This result, especially for maize, is unexpected considering the negative attributes of reduced soil moisture content and soil compaction resulting from increased harrowing as mentioned earlier. The better performance of maize under high disc harrow passes could be attributed to its superior rooting ability. Previous research indicated maize is very shallow rooted compared to introduced pastures (Friesen et al., 1997). Data on root distribution are being analyzed. *Crotalaria* had superior yields with 2 disc harrow passes per which also resulted increased in higher nutrient (N, P, Ca and Mg) uptake.

Table 11. Plant growth and nutrient acquisition by grass alone pasture, *Crotalaria* and maize as influenced by the number of disc harrow passes per year over three years.

Disc harrow Passes per year	Cropping system	Leaves	Stems	Total shoot biomass	Nutrient uptake				
					N	P	K	Ca	Mg
		kg/ha							
2 Passes	Grass alone pasture	726	1030	1756	19a	4.7a	34ab	3.6	6.0a
4 Passes	Grass alone pasture	506	1107	1613	17a	4.8a	43a	2.4	4.8a
8 Passes	Grass alone pasture	415	1079	1494	12b	2.5b	28b	2.0	3.7b
2 Passes	*Crotalaria juncea*	5076	1257	6333b	185b	18ab	81	90b	21b
4 Passes	*Crotalaria juncea*	6154	1679	7833a	227a	20a	88	135a	35a
8 Passes	*Crotalaria juncea*	4923	1091	6014b	192b	14b	70	82b	22b
2 Passes	Maize	4472b	1855b	6327c	40b	10b	65b	12b	9b
4 Passes	Maize	5417b	2049b	7466b	54b	8b	94b	18ab	12ab
8 Passes	Maize	8803a	3316a	12119a	99a	16a	141a	23a	14a

Grass alone pasture = cv. Llanero (*Brachiaria dictyoneura* CIAT 6133). Means followed by different letters within a column and within a cropping system are significantly different ($P < 0.05$)

Impact:

Eight disc harrow passes per year are found to be better for maize in terms of above ground production and nutrient acquisition. Two disc harrow passes per year are better for *Crotalaria* nutrient acquisition and biomass production. *Brachiara* is sensitive to land preparation methods that reduce soil aggregate size. Further work is needed to determine why maize does better with greater number of disc harrow passes.

References:

Amézquita, E., Barrios, E., Rao , I. M., Thomas, R., Sanz, J. I., Hoyos, P., Molina, D., Chavez, L. F., Alvarez, A., and J, B. (1998). Improvement of some soil physical conditions through tillage. International Center for Tropical Agriculture (CIAT) PE-2 Annual Report 1998., 57-59.

Friesen, D. K., Rao, I. M., Thomas, R. J., Oberson, A. and Sanz, J. I. (1997). Phosphorus acquisition and cycling in crop and pasture systems in low fertility tropical soils. Plant and Soil 196: 289-294.

Meléndez, A., Amézquita, E., and Sanz, J. I. (1998). Effect of size of aggregates and N addition on the growth of Brachiaria decumbens in the Oxisol of "Los Llanos". International Center for Tropical Agriculture (CIAT) PE-2 Annual Report 1997., 49.

Preciado, G., Amézquita, E., and Galviz, J. (1998). Effect of time of use of soil with rice on the physical conditions. International Center for Tropical Agriculture (CIAT). PE-2 Annual report 1997., 87-88.

Salinas, J. G., and García, R. (1985). Métodos Químicos para el Análisis de Suelos Acidos y Plantas Forrajeras. CIAT, Cali, Colombia.

Contributors:

S. Phiri, B. R. Singh (AUN, Norway), E. Amézquita, D. Molina and I. M. Rao

1.4.3 Determine the impact of the buildup of arable layer on plant growth and total nutrient acquisition by different agropastoral systems in the llanos of Colombia

Highlight:

- Showed that: (i) modest physical improvement of the soil results in higher rice productivity; (ii) pasture components, particularly legumes increase the uptake of nutrients; and (iii) physical soil improvement plus grass legume pasture could contribute to greater land productivity.

Purpose:

To determine the influence of an arable layer development on plant growth and nutrient acquisition by different agropastoral systems.

Rationale:

Previous research in the llanos of Colombia has shown that the natural soil physical conditions of savanna soils do not offer an optimum environment for root growth for crop and pasture production. The soils are susceptible to degradation due to the vulnerability of their structure to disruption by machinery, especially under wet conditions. Work on shallow tillage (0-10 cm depth) practices on these soils has shown that these soils are unsustainable for crop and pasture production when subjected to heavy machinery use. With increase in machinery use the soil layer immediately below 10 cm soil depth exhibited an increase in bulk density and a decrease in total porosity than the other layers (Amézquita et al., 1998). The reduced bulk density of this soil layer could diminish the entry of water and the flux of air into the profile. Thus to achieve better crop and pasture production this soil physical constraint must be managed by adequate tillage/cropping practices.

As part of the development of remedial measures to this soil degradation problem, a field experiment was established in 1995 on Matazul farm to assess the influence of biological and physical treatments on the building up of an arable layer in the llanos. The experiment tested two methods to build an arable layer: i) by deep tillage (using chisel) at different intensities to improve the soil physical conditions of a crop rotation (rice/soyabean) system, and (ii) by using agropastoral (rice/grass/legume) systems to improve soil biological activity.

Tillage systems have a direct bearing on soil water flow and nutrient availability. One nutrient mostly likely to be affected is P. Phosphorus is limiting for increased and sustainable production on savanna Oxisols because it is sorbed on oxidic clay mineral surfaces, which render it to be less available to plants.

This study is meant to augment preliminary results from the field experiment, which so far indicated that one pass of chisel results in a better water infiltration rate than three passes, which caused a marked decrease in soil volume. Previous research also indicated that two chisel passes and inclusion of pasture components with upland rice could improve the rate of water infiltration. It is necessary to evaluate different systems, or system components that are superior in acquisition of nutrients. The main focus is to find a cultivation system that increases plant productivity as well as improves the physical, chemical and biological conditions of soil. These cultivation systems could then be integrated into crop-pasture production systems to more effectively cycle native or applied nutrients, particularly P.

Material and Methods:

Location: The experiment was established at Matazul farm (4° 9′ 4.9″ N, 72° 38′ 23″ W) on an Isohyperthermic Kaolinitic Typic Haplustox (Oxisol) at 260 m.a.s.l. . The area has two distinct climatic seasons, a wet season from the beginning of March to December and a dry season from December to the first week March and has annual average temperature of 26.2°C. The area has mean annual rainfall of 2719 mm, evapotranspiration potential of 1623 mm and relative humidity of 81% (Santa Rosa weather station, located at the Piemont of the Llanos).

Treatments

- Rice (cv. Sabana 6) /soyabean (cv. Soyica altillanura 2) rotation with one pass of chisel.
- Rice (cv. Sabana 6) /soyabean (cv. Soyica altillanura 2) rotation with two passes of chisel.
- Rice (cv. Sabana 6) /soyabean (cv. Soyica altillanura 2) rotation with three passes of chisel.
- Rice + grass alone (*Andropogon gayanus* (Ag)) pasture
- Rice + grass + legumes [*Pueraria phaseoloides* (Pp)+*Desmodium ovalifolium*(Do)] pasture

The experiment was laid down in a RCBD and was replicated three times. We determined dry weights of shoot biomass of individual components and the contents of nitrogen, phosphorus, potassium, calcium and magnesium of the plant parts by the methods of Salinas and Garcia (1985).

Results and Discussion:

Rice grain and biomass production was less when associated with pasture components than under chisel treatments (Table 12). The higher rice production under the chisel treatments could be attributed to the reduced bulk density, reduced soil strength, increased aeration porosity (macroporosity) and increased water infiltration rate observed with chisel treatments (Amézquita et al, 1998). A good porosity is of great importance for soil management purposes as it regulates root growth and rainfall acceptance, water entry and its movement in the soil, which in turn affects nutrient availability and acquisition by plants. Increase in number of chisel passes from 1 to 3 did not significantly affect rice biomass or its gain yield production. Land preparation with one pass of chisel could be sufficient because Amézquita et al (1998) reported that three passes could be excessive for these soils as it could cause a reduced soil volume.

Table 12. Effect of the buildup of arable layer on plant growth and total nutrient acquisition by different agropastoral systems on an Oxisol at Matazul farm in the llanos of Colombia.

Cultivation system	Rice grain yield	Rice biomass	Total shoot biomass	Nutrient uptake (rice + grass + legume)				
			(Rice + grass + legume)	N	P	K	Ca	Mg
	kg/ha							
One pass of chisel + rice	2503a	3992a	3991	41.0	7.2	39.7c	6.1c	7.3
Two passes of chisel + rice	2439a	4213a	4213	50.0	8.0	42.9bc	7.2bc	8.1
Three passes of chisel + rice	2448a	4368a	4368	50.3	7.3	42.8bc	6.6c	7.7
Rice + grass + legumes (Pp+Do) pasture	926b	2419b	5881	65.0	7.7	71.6a	12.9a	8.6
Rice + grass alone (Ag) pasture	747b	2275b	5147	54.0	6.6	66.3ab	10.3ab	7.7
LSD (0.05)	320	1482				26	3.4	

Ag = *Andropogon gayanus*; Pp = *Pueraria phaseoloides*; Do = *Desmodium ovalifolium*.
Means followed by different letters within columns are significantly different (P < 0.05).

Total biomass and nutrient acquisition (K and Ca) was generally improved by pastures especially when a legume was included (Table 12). This implies that pasture legumes could be of great importance in nutrient cycling and addition of organic matter to the soil, which have beneficial effects on the production system.

Impact:

It is possible to increase upland rice production on degraded llanos soils through modest physical improvement of the soil (with 1 chisel pass). However, physical improvement alone without chemical and/or biological improvement is not adequate. The addition of a pasture legume to the production system brings in the added advantage of improved nutrient recycling, high nutrient uptake and the addition of organic matter of greater quality.

References:

E. Amézquita, E. Barrios, I.M. Rao , R Thomas, J. I. Sanz, P. Hoyos, D. Molina, L.F. Chavez, A. Alvarez, and Galviz, J. (1998). Improvement of some soil physical conditions through tillage. In CIAT PE-2 Annual Report 1998. CIAT PE-2 Annual Report 1998., 57-59.

Salinas, J. G., and García, R. (1985). Métodos Químicos para el Análisis de Suelos Acidos y Plantas Forrajeras. CIAT, Calí, Colombia.

Contributors:

S. Phiri, B. R. Singh (AUN, Norway), E. Amézquita, D. Molina and I. M. Rao (CIAT).

Activity 1.4.4 Effect of different land management practices on soil physical conditions

Highlight:

- Showed that the use of rotations of maize or rice with legumes (soybeans and cowpeas, respectively) slightly improves soil physical conditions.

Purpose:

To evaluate the cumulative effect of some soil and crop management practices in the physical and chemical condition of the soil (Culticore-Carimagua).

Rationale:

Low productive soils can be improved if adequate soil tillage systems are used in combination with soil amendments, crop rotation and cover crops. The Culticore experiment in Carimagua combines all these factors.

Materials and Methods:

A sampling in each one of the four replications of the experiment was made, to evaluate the effect of the treatments in some physical and chemical conditions at different depths. The treatments are mentioned in the tables of results.

Results and Discussion:

a) Some physical changes. The cumulative effects of the treatments measured through some physical characteristics are shown in Tables 13 to 15. Table 13 shows the values of bulk density at different depths for each treatment. There are some statistically significant ($P<0.05$) differences among treatments especially in the 0-5 and 5-10 cm depth, where the soil received the maximum impact by land use and management. Below 10 cm depth no large differences were found except for the maize + soybean (green manure treatment) which presented the lowest value (1.05 $Mg.m^{-3}$). Under field conditions this treatment showed the best physical environment for root growth.

Table 13. Bulk density ($Mg\ m^{-3}$) at different depths under the management systems used in the experiment

Treatment	Soil depth (cm)					
	0-5	5-10	10-15	15-20	20-30	30-40
Rice monocrop	1.10 c	1.20 abc	1.27 a	1.27 a	1.29 ab	1.41 a
Rice + cowpea (grain)	1.20 abc	1.27 ab	1.29 a	1.27 a	1.28 ab	1.36 a
Rice+cowpea (green manure)	1.26 ab	1.17 bc	1.28 a	1.24 a	1.34 ab	1.34 a
Maize monocrop	1.18 abc	1.23 ab	1.21 a	1.23 a	1.23 b	1.36 a
Maize + soybean	1.22 abc	1.29 a	1.26 a	1.27 a	1.32 ab	1.36 a
Maiz e+ soybean (green manure)	1.15 bc	1.11 c	1.05 b	1.17 a	1.25 ab	1.36 a
Native savanna	1.21 abc	1.26 ab	1.29 a	1.32 a	1.31 ab	1.33 a
Brachiaria humidicola pasture	1.21 abc	1.28 a	1.27 a	1.32 a	1.31 ab	1.32 a
Panicum maximun pasture	1.29 a	1.30 a	1.29 a	1.30 a	1.37 a	1.31 a

Means followed by different letters within the column are significant at 0.05 probability level.
Brachiaria humidicola pasture is associated with a cocktail 3 legumes
Panicum maximum pasture is also associated with 2 legumes

Table 14. Total porosity at different depths under the management systems used in the experiment

Treatment	Soil depth (cm)					
	0-5	5-10	10-15	15-20	20-30	30-40
Rice monocrop	57.76 a	54.28 abc	52.08 b	51.89 a	51.32 ab	46.78 a
Rice + cawpea (grain)	54.10 abc	51.89 bc	51.41 b	51.62 a	51.23 ab	48.87 a
Rice+cawpea (green manure)	51.72 bc	55.68 ab	54.80 b	52.85 a	48.85 ab	49.53 a
Maize monocrop	54.98 abc	53.33 bc	54.26 b	53.31 a	53.49 a	48.58 a
Maize + soybean	53.53 abc	51.14 c	54.54 b	51.43 a	49.91 ab	49.06 a
Maize + soybean (green manure)	56.11 ab	57.86 a	60.47 a	55.32 a	52.38 ab	49.06 a
Native savanna	53.61 abc	51.72 bc	50.72 b	49.81 a	50.09 ab	49.33 a
Brachiaria humidicola pasture	53.02 abc	50.77 c	51.62 b	49.91 a	50.00 ab	49.72 a
Panicum maximun pasture	47.71 c	50.10 c	50.71 b	50.57 a	47.71 b	50.28 a

Means followed by different letters within the column are significant at 0.05 probability level

Total porosity showed some statistically significant differences between treatments especially in the top soil (0-5 cm) (Table 14). The lowest value (47.7%) was found in the

Panicum maximum treatment, which is subjected to trampling by cattle. It has lost almost 6% of total porosity in comparison to native savanna, showing that it is undergoing compaction. In the second depth (5-10 cm), there are also some changes, but the amplitude of values is less. After 10 cm depth few changes were found except for the maize + soybean (green manure) which showed the highest values until 20 cm depth. The positive changes produced by the application of the treatments made the soil more suitable for root growth and crop production.

Table 15 shows the behavior of hydraulic conductivity with different treatments and depth. Here again, the big changes in conductivity were found in the top 0-5 cm depth. The higher values were found in those treatments and crops that required more tillage and possible increase in the organic matter content of the soil. *Brachiaria* and *Panicum maximum* pastures presented the lowest values and loss of macroporosity due to trampling effect.

Table 15. Hydraulic conductivity ($cm.h^{-1}$) at different depths under the management systems used in the experiment.

Treatment	Soil depth (cm)					
	0-5	5-10	10-15	15-20	20-30	30-40
Rice monocrop	5.99 ab	2.56 b	1.43 ab	1.51 ab	0.69 a	0.26 a
Rice + cowpea (grain)	10.71 a	2.05 b	8.75 a	2.13 ab	1.18 a	0.90 a
Rice+cowpea (green manure)	5.19 ab	4.80 b	4.80 ab	2.86 ab	0.44 a	0.40 a
Maize monocrop	3.86 ab	1.14 b	4.28 ab	1.92 ab	1.39 a	0.19 a
Maize + soybean	6.94 ab	0.70 b	1.56 ab	1.40 ab	2.74 a	1.71 a
Maiz + soybean (green manure)	10.42 a	12.55 a	4.57 ab	4.28 a	0.65 a	0.48 a
Native savanna	2.28 b	2.57 b	0.89 ab	0.37 b	1.49 a	0.79 a
Brachiaria pasture	0.28 b	0.19 b	0.46 b	0.35 b	0.76 a	0.51 a
Panicum maximun pasture	0.20 b	0.48 b	0.46 b	0.40 b	0.31 a	0.37 a

Means followed by different letters within the column are significant at 0.05 probability level

b) Some chemical changes. In comparison with native savanna Al-saturation has diminished as a function of the treatments (Figure 4). Less percentages of Al-saturation were found in the first 0-20 cm of maize than in rice treatments at the same depth. *Brachiaria humidicola* and *P. maximum* also showed less aluminium in the 0-20 cm layer in relation to native savanna. When the experiment started in 1993 maize plots received lime application of 2000 $kg.ha^{-1}$ and rice and pasture of 500 $kg.ha^{-1}$. Lime was incorporated with disc harrow and for this reason the effect of the lime on the Al-saturation is only reflected in the 0-20 cm layer. The dynamics of Al-saturation as a function of time (1993-1998) deserve a more detailed study.

The higher values of Ca occurred in the top 20 cm under maize, which correlates with the amount of lime that was added (Figure 5). Rice and *B. humidicola* present lower values than maize, but *P. maximum* presented values even higher than maize, which could be due to the demonstrated effect that pastures have in the accumulation of bases by roots. Magnesium (Figure 6) had a similar behavior as calcium.

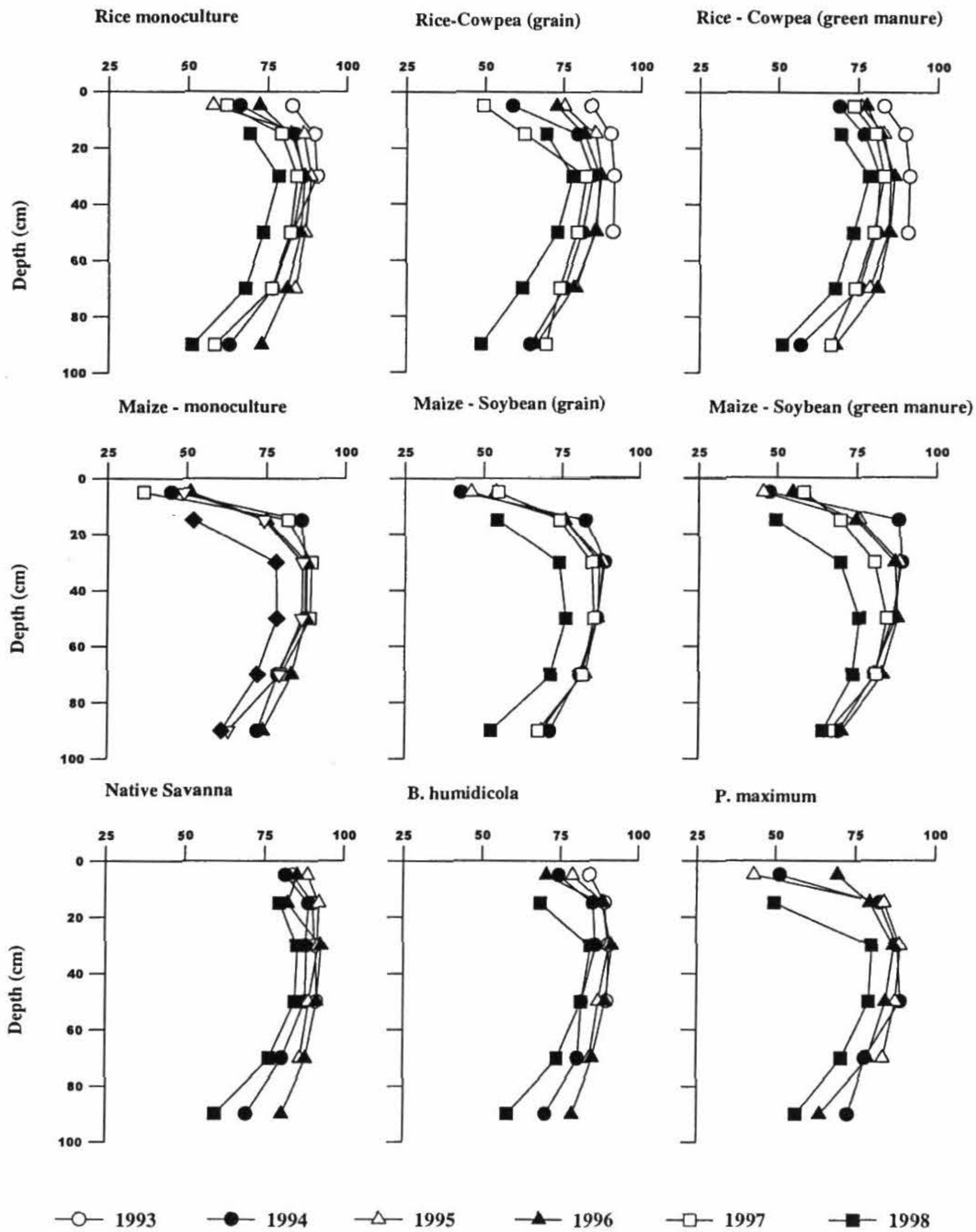

Figure 4. Changes in Al-Saturation (%) at different depths and times in the Culticore treatments.

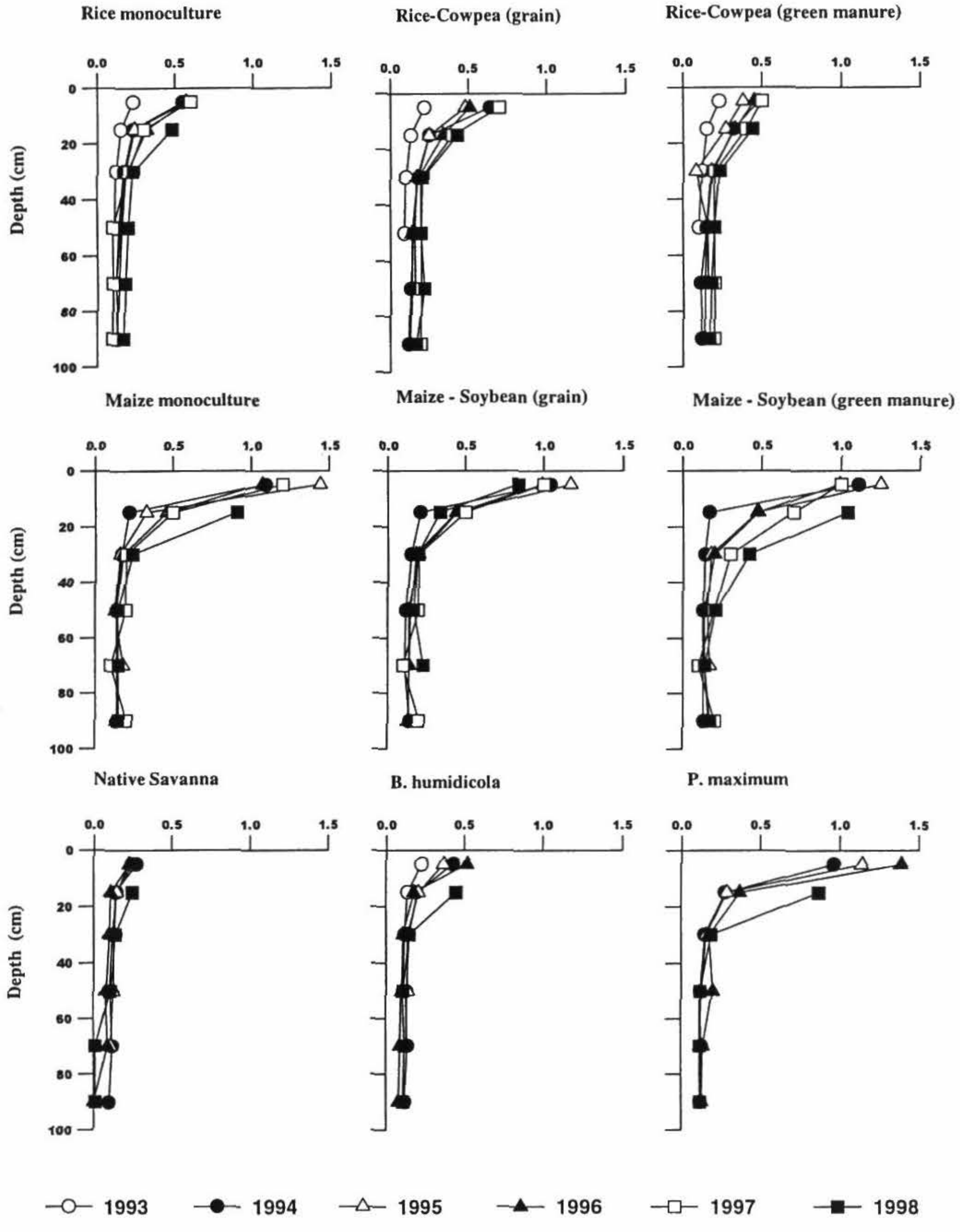

Figure 5. Changes in exchangeable Ca (meq/100 g) at different depths and times in the Culticore treatments.

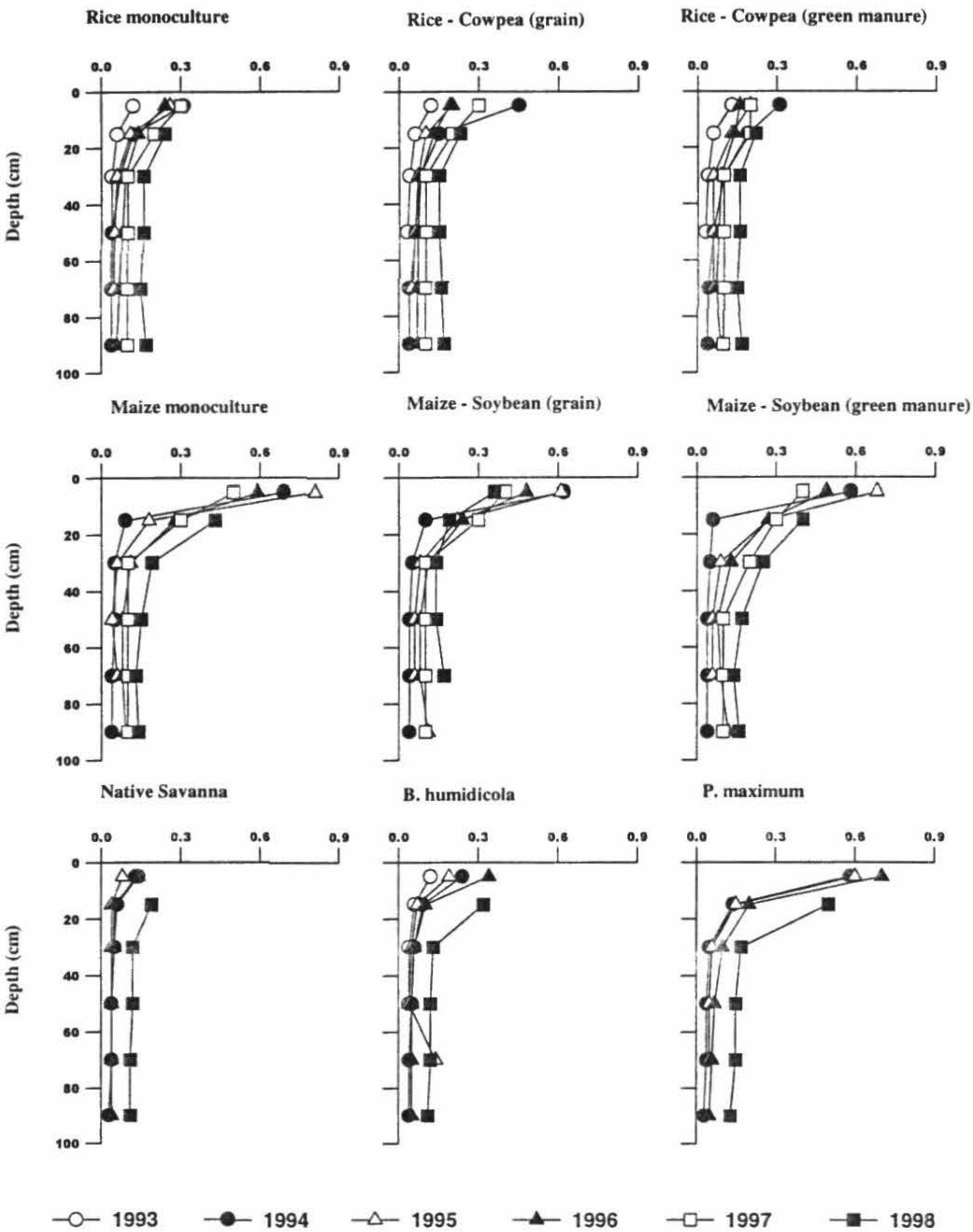

Figure 6. Changes in exchangeable Mg (meq/100 g) at different depths and times in the Culticore treatments.

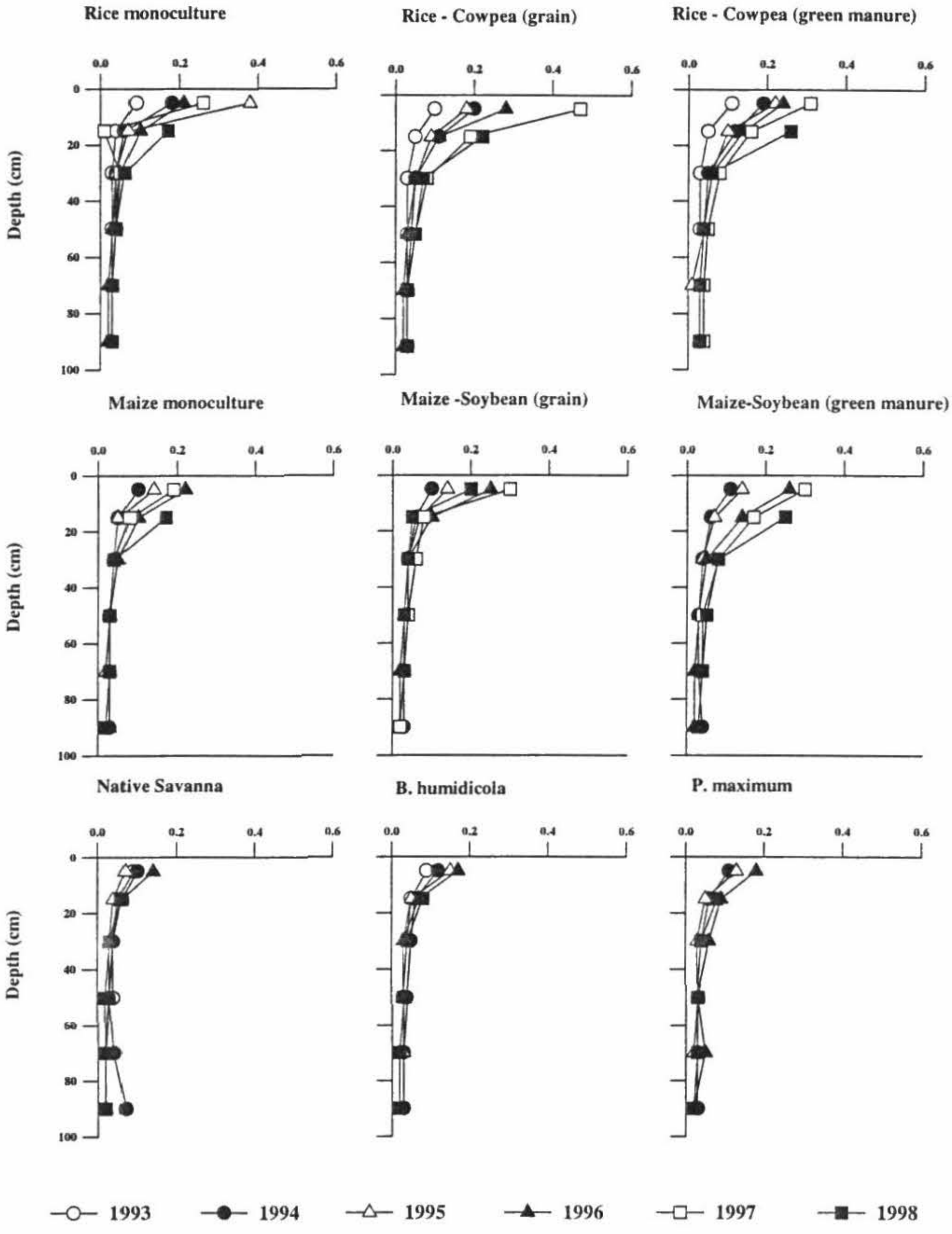

Figure 7. Changes in exchangeable K (meq/100 g) at different depths and times in the Culticore treatments.

K has been accumulated in all treatments except to native savanna but there were no differences between maize or pastures (Figure 7). Under rice K was almost double the amount found in savanna in the first 20 to 30 cm depth. It seems that the rotation of maize or rice with soybean (green manure) may be more effective than the other treatments to allow K to move into deeper soil layers. This could be due to the incorporation of the green manure and to the easy mobilization of K with infiltrated water due to its greater solubility.

Impact:
This study indicated that the use of rotations of maize or rice with legumes (soybeans and cowpeas, respectively) slightly improves soil physical conditions. Thus soil conditions can be improved through the use of green manures in rotation with cereals. The findings of this study also confirm the concept of a need to develop an arable layer. These results are applicable to the Altillanura region.

Contributors:
D.K. Friesen (IFDC, CIMMYT), M. Rivera, C.G. Meléndez, E. Amézquita, R.J. Thomas, L.F. Chávez, J. Galviz, and A. Alvarez (CIAT).

Activity 1.5: ***Determine rooting strategies of crop and forage components***

1.5.1 Determine differences in rooting ability among fallow components in the Andean Hillsides

Highlight:
- Showed that the establishment of *Tithonia* by plantlet results in better mycorrhizal association and shoot biomass production.
- Plantlet results in a better nutrient uptake utilization.

Purpose:
To determine the effect of method of establishment (vegetative stem cuttings or plantlets) of *Tithonia diversifolia* on shoot and root growth characteristics, mycorrhizal (VAM) association, nutrient uptake and utilization.

Rationale:
Tithonia diversifolia (Hemsfey), commonly known as Mexican sunflower, is a non-N_2-fixing shrub of the family Asteraceae, which grows 1 to 3 m in height and bears several yellow flowers. *Tithonia* is widely distributed throughout the humid and sub-humid tropics. It frequently grows along field and farm boundaries and roads and it also occurs in indigenous fallow systems. It produces large quantities of leaf biomass and tolerates regular pruning. Recently, there has been increased awareness of the use of *Tithonia diversifolia* as an indigenous fallow species to improve soil fertility. Evidence indicates that this spontaneous invader shares an ability accumulate labile soil nutrients -- that might otherwise be lost to runoff and leaching -- and store them in its rapidly accumulating shoot biomass.

Research done by institutions such as Kenya Agricultural Research Institute (KARI), Tropical Soil Biology and Fertility Programme (TSBF) and International Centre for Research in Agroforestry (ICRAF) in the highlands of western Kenya has dramatically raised awareness and expectations of *Tithonia* green biomass for soil fertility replenishment (Niang et al., 1996). There is also growing interest in apparent ability of *T. diversifolia*, probably in association with mycorrhizae, to mobilize and accumulate soil P. Release of P from *Tithonia* green biomass is rapid, and *Tithonia* supplies plant available P at least as effectively as an equivalent amount of P from soluble fertilizer.

Leaving land as fallow with native vegetation is a traditional practice of land management throughout the tropics to restore soil fertility that could be lost during cropping. In the mid-altitude hillsides, agriculture is typically based on fallow-rotation system in which forest or bush fallow is cleared, for cropping with annuals (maize, bean, cassava, upland rice etc.) or perennials. They are returned to pasture or bush fallow once crop yields decline to a level that is not economical to farmers to continue cultivation because of nutrient depletion and loss of soil structure. On these soils, the successful restoration of soil fertility normally requires a long period (6-10 years) for sufficient regeneration of native vegetation.

Tithonia diversifolia is deliberately being introduced in the mid-altitude hillside agriculture system (Pescador) to enhance soil fertility (in a chemical, physical and/or biological sense) and to some extent to suppress weeds. To facilitate rapid establishment of *Tithonia* at a large scale, there is a need to investigate the establishment method. Therefore the main objective of the present study was to determine the effect of method of establishment (vegetative stem cuttings or plantlets) of *Tithonia diversifolia* on shoot and root growth characteristics, mycorrhizal (VAM) association, nutrient uptake and utilization.

Materials and Methods:

This study was done at the San Isidro experimental farm in the village of Pescador located in the Andean hillsides of Caldono municipality, in the Cauca province of south-western Colombia (2° 48′ N, 76° 33′ W) at an altitude of 1505 m.a.s.l. Temperature ranges from a day average of about 24°C to a night average of about 17°C, with little variation during the year. Whereas the dry season lasts about three months, from June to August, with a minimal monthly precipitation of as low as 69 mm, two wet seasons cover the rest of the year in which monthly rainfall reaches to a maxima in April (230 mm) and in October (268 mm). The average annual precipitation varies between 1600 and 2000 mm. The annual potential evapotranspiration varies from 1306 to 1106 mm (De Fraiture et al., 1997).

The soil is derived from volcanic-ash deposition and is a medium to fine textured Oxic Dystropept (Inceptisol) in the USDA soil classification system and an Andic Dystric Cambisol in the FAO classification. It has a medium to fine texture (45% sand, 27% silt and 38% clay) (IGAC, 1979) of high fragile and low cohesion with humic shallow layers. The bulk density of the first 5 cm of the soil in the area of this work is 0.53 g/cm^3. It has the following chemical characteristics (0-20 cm soil depth): pH 5.1 (water), 4.96 % C (Walkley-Black), 3417 ppm Total N (Kjeldahl), 12 and 42 ppm of N-NH_4 and N-NO_3

respectively (KCl 1N), 4.63 ppm P (Bray II), 1.14, 2.54, 0.86 and 0.63 $cmol.kg^{-1}$ of Al, Ca, Mg and K respectively (Perchloric-nitric digestion), 0.31 and 5.06 ppm of B (hot water) and Zn (Perchloric-nitric digestion), respectively. P availability in soil is low because of its allophane richness (52-70 g kg^{-1}) which increases its P sorbing capacity. The soil organic matter content varies from 8.0 to 12.1%.

The leaf area (cm^2) was determined by measuring fresh leaves with LI 3000 Area Meter (LI-Cor Inc., Lincoln, NE). The leaf area index (LAI, m^2 of leaf area per m^2 of ground area) and the specific leaf are (SLA, m^2 of leaf area per kg of dried leaves) were calculated. Root length was measured with the Comair Root Length Scanner and then expressed in km of root length per m^2 of ground area. The specific root length was calculated in m of root length per g of dried roots. A number of other plant attributes including nutrient status of plant parts, VA mycorrhizal root infection and VAM spores per 100g soil, total P acquisition (shoot + root), P acquisition efficiency (mg of P uptake in shoot biomass per unit root length), P use efficiency (g of shoot biomass production per g of total P acquisition) were determined (Salinas and Saif, 1990; Rao et al., 1997). The experiment was laid down as RCB design with establishment method as treatment. The experiment was replicated three times. Data from the experiment were subjected to an analysis of variance using the SAS computer program (SAS/STAT, 1990). Least-significant differences were calculated by an F-test. A probability level of 0.05 was considered statistically significant.

Results and Discussion:

Mycorrhizal (VAM) association: Establishment of Tithonia by plantlet resulted in better mycorrhizal (VAM) association. Mycorrhizal root infection was significantly greater (P=0.05) under plantlet in both coarse and fine roots which represent differences of 21 and 31% respectively (Table 16). The number of spores per 100g of soil was 30 % greater under plantlet but not statistically significant (P=0.05). The high VAM infection of plants established with plantlets contributed to greater acquisition of nutrients (Table 16). This is because mycorrhizal hyphae extend the root system resulting in an exploitation of a larger soil volume for nutrient acquisition, particularly P. The efficiency of the plantlet to associate with mycorrhizae may be related to the initial physiological competence of the plantlet compared to the vegetative stem cutting (stake). The plantlet has all the basic components of a mature plant and is able to start photosynthesis soon after transplanting and is likely to associate with VAM faster as it already has roots and produces photoassimilates that are an essential component for an effective plant-mycorrhizal symbiosis. This symbiosis is likely to proliferate quite fast once established. Meanwhile on the other hand the stake has to initiate root and shoot growth before it can associate with VAM. This will result in a time lag for symbiosis to establish, at least for some time. How long will this lag period lasts is not known.

Growth attributes: Tithonia established by plantlet had a biomass of 16.5 t/ha, which was significantly greater (P=0.05) than 7 t/ha under stake establishment (Table 17). Total root length was almost the same (0.90 and 0.82 km/m^2 for stake and plantlet, respectively), total root biomass was more under Plantlet although not statistically significant (P=0.05).

Table 16. Effect of method of establishment (Stake or Plantlet) on mycorrhizal (VAM) association and P uptake efficiency of *Tithonia diversifolia* grown at San Isidro farm, Pescador, Cauca, Colombia.

Plant Attributes	Method of establishment		
	Stake	Plantlet	$LSD_{(P=0.05)}$
VAM infection in fine roots (%)	49	79	11
VAM infection in coarse roots (%)	48	69	12
Number of spores in 100g of soil	418	509	ns
P uptake efficiency (µg/m)	30	48	12
N uptake efficiency (µg/m)	167	331	128
K uptake efficiency (µg/m)	379	662	130
Ca uptake efficiency (µg/m)	116	184	56
Mg uptake efficiency (µg/m)	37	61	19

ns = not significant

Table 17. Effect of method of establishment (Stake or Plantlet) on shoot and root attributes and nutrient uptake of *Tithonia diversifolia* grown at San Isidro farm, Pescador, Cauca, Colombia.

Plant Attributes	Method of establishment		
	Stake	Plantlet	$LSD_{(P=0.05)}$
Photosynthetic efficiency (Fv/Fm)	0.82	0.82	-
Leaf area index (m^2/m^2)	1.12	2.30	0.37
Leaf biomass (kg/ha)	814	1387	209
Stem Biomass (kg/ha)	5568	13880	1807
Reproductive structures (kg/ha)	630	1279	320
Total shoot biomass (kg/ha)	7012	16546	2296
Total root biomass (kg/ha)	839	989	ns
Total root length (km/m^2)	3.5	5.2	ns
Specific root length (m/g)	54	60	ns
Root length/leaf area (m/cm^2)	0.37	0.23	0.15
Shoot N uptake (kg/ha)	67	148	43
Shoot P uptake (kg/ha)	12	21	3
Shoot K uptake (kg/ha)	153	296	26
Shoot Ca uptake (kg/ha)	47	82	17
Shoot Mg uptake (kg/ha)	15	27	6
N use efficiency (g/g)	88	104	15
P use efficiency (g/g)	529	741	119
K use efficiency (g/g)	45	56	7
Ca use efficiency (g/g)	132	187	16
Mg use efficiency (g/g)	442	581	96

ns = not significant

Tithonia established by plantlet had greater shoot uptake and use efficiency of N, P, K, Ca and Mg (Table 17). The high values of these attributes could be due to greater mycorrhizal (VAM) association under this establishment method that might have increased the effective volume for nutrient uptake. Tithonia established by plantlet had a significantly greater available P (Bray-II) in the 0-5 and 5-10 cm soil depth (Table 18). Plantlet resulted in higher pH, higher Ca, Mg, and K in the profile up to 20-cm soil depth (Table 18) and had a lower content of exchangeable Al (not shown). The total root length was almost the same between the two methods of establishment although on the average establishment by plantlet had high root biomass indicating that *Tithonia* under this method of establishment had developed thicker root system that may be more favorable for mycorrhizal association.

Table 18. Effect of establishment method on root distribution, mycorrhizal association and nutrient availability across soil profile.

Soil depth (cm)	Method	VAM infection (%) Fine roots	Coarse roots	Spores per/100g soil	PH (H_2O)	Ca (meq/100 g soil)	Mg (meq/100 g soil)	P-Bray II (ppm)	SOM (%)	Root length (km/m^2)	Root biomass (kg/ha)
0-5	Plantlet	81	67	647	5.4	3.76	0.93	10.2	11.4	1.3	121
	Stake	67	61	543	5.1	2.18	0.51	5.63	11.3	0.9	269
		(12)†					(0.17)	(0.9)		(0.2)	(121)
5-10	Plantlet	65	76	481	5.0	1.42	0.31	10.1	10.1	1.0	277
	Stake	36	62	497	4.9	0.81	0.21	3.8	9.6	0.7	151
		(10)	(11)			(0.29)	(0.04)	(2.31)		(0.2)	(65)
10-20	Plantlet	72	83	590	5.2	2.91	0.56	7.97	11.0	1.3	377
	Stake	59	54	587	5.0	1.39	0.30	3.94	11.7	1.0	237
			(21)			(0.68)	(0.16)	(2.31)			
20-40	Plantlet	75	81	198	5.1	0.86	0.22	4.82	7.0	0.8	148
	Stake	29	38	283	5.0	0.89	0.28	4.62	5.4	0.6	141
		(16)	(13)	(38)							
40-60	Plantlet	67	86	167	5.3	0.85	0.18	3.77	3.2	0.8	66
	Stake	33	16	106	5.0	0.67	0.16	3.54	3.2	0.3	41
		(18)	(9)	(38)						(0.3)	

Figures in parentheses represent LSD values at 0.05 probability level.

Impact:

Establishment of *Tithonia* by plantlet resulted in better mycorrhizal (VAM) association and biomass production. Other plant and soil attributes were generally better under plantlet establishment. Because of spatial variability at this site, results from the present study can only indicate the possible benefits of establishment by plantlets.

References:

De Fraiture, C., Rubiano, J. C., and Alvarez, C. (1997). Actual versus potential water use in Cabuyal watershed- Colombia. *Hillside Program Report, International Centre for Tropical Agriculture.*

IGAC (1997). Estudio general de suelos de la parte alta de las cuencas de los rios Piendamo Cajibio y Ovejas (Departamento del Cauca). *Ministerio de Hacienda y Crédito Público, Bogotá, Colombia* 302.

Niang, A., Amadalo, B., Gathumbi, S., and Obonyo, C. (1990). Maize yield response to green manure application from selected shrubs and tree species in western Kenya: a preliminary assessment. *In: Proceedings of the first Kenya agroforestry conference on people and institutional participation in agroforestry for sustainable development*, 50-358.

Rao, I.M., V. Borrero, J. Ricaurte, and R. Garcia. 1997. Adaptive attributes of tropical forage species to acid soils. V. Differences in phosphorus acquisition and utilization to varying phosphorus supply and soil type. J. Plant Nutr. 20: 155-180.

Salinas, J. G., and Saif, S. R. (1990). Nutritional requirements of Andropogon gayanus. *In:J.M. Toledo, R. Vera, C. Lascano, and J.M. Lenne (eds.), Andropogon gayanus Kunth: A Grass for Tropical Acid Soils, pp. 99-155. CIAT, Cali, Colombia.*

SAS/STAT (1990). SAS/STAT User's Guide. Version 6. *Statistical Analysis System Institute, Inc., Cary, NC.*

Contributors:
S. Phiri, B. R. Singh (AUN, Norway), E. Barrios, J. Ricaurte and I. M. Rao (CIAT).

Activity 1.6 Test compatibility of plant components in different systems (including farmer participation)

1.6.1 Establishment of the SOL (Supermercado de Opciones para Laderas) concept and network at Hillside reference sites

Highlights:

- Establishment of the SOL concept and network: A supermarket of options for the ecologically sound intensification of production in the hillsides.

Purpose:
To provide a supermarket of options for the ecologically sound intensification of production in the hillsides.

Rationale:
The experience generated by the alternative cropping systems work in Colombian hillsides is one of the ingredients to the SOL (Supermercado de Opciones para Laderas) network in Nicaragua and Honduras. The success of this new initiative is based on the integration of information from different approaches through a close articulation among several CIAT projects (PE-2, PE-3, PE-4, IP-5, SN-1, SN-3, CIRAD, IP-1) and also globally via the SWNM program (SW-2) (Figure 8.). It intends to generate a *modus operandi* that optimizes farmer adoption of natural resource-friendly management technologies. A basic component of this approach is local participation. This is expressed by local community and stakeholders identification and prioritization of problems, formulation of demands within the realm of CIAT mandate and expertise, and by joint identification of potential solutions and exploration of the potential synergy of joining local and external approaches to problem solving. The results of these initial steps are made operational at experimental farms or SOLs where identified potential

solutions to local demands as new technological options are established. Participatory evaluation of the merits and weaknesses of proposed solutions are carried out on-SOL and also on-farm by local farmers. The SOL initiative rests on the belief that the sustainable management of natural resources depends on the strengthening of the local population in the management of natural resources. The recognition of the importance of local knowledge and demands as a necessary complement to external knowledge for the generation of hybrid technologies constitutes an important basis of our strategy to improve the adoption of new technologies. The SOL facilitates greater interaction between the commodity improvement projects and natural resources management projects and also allows for strategic research issues to be investigated under realistic on-farm conditions.

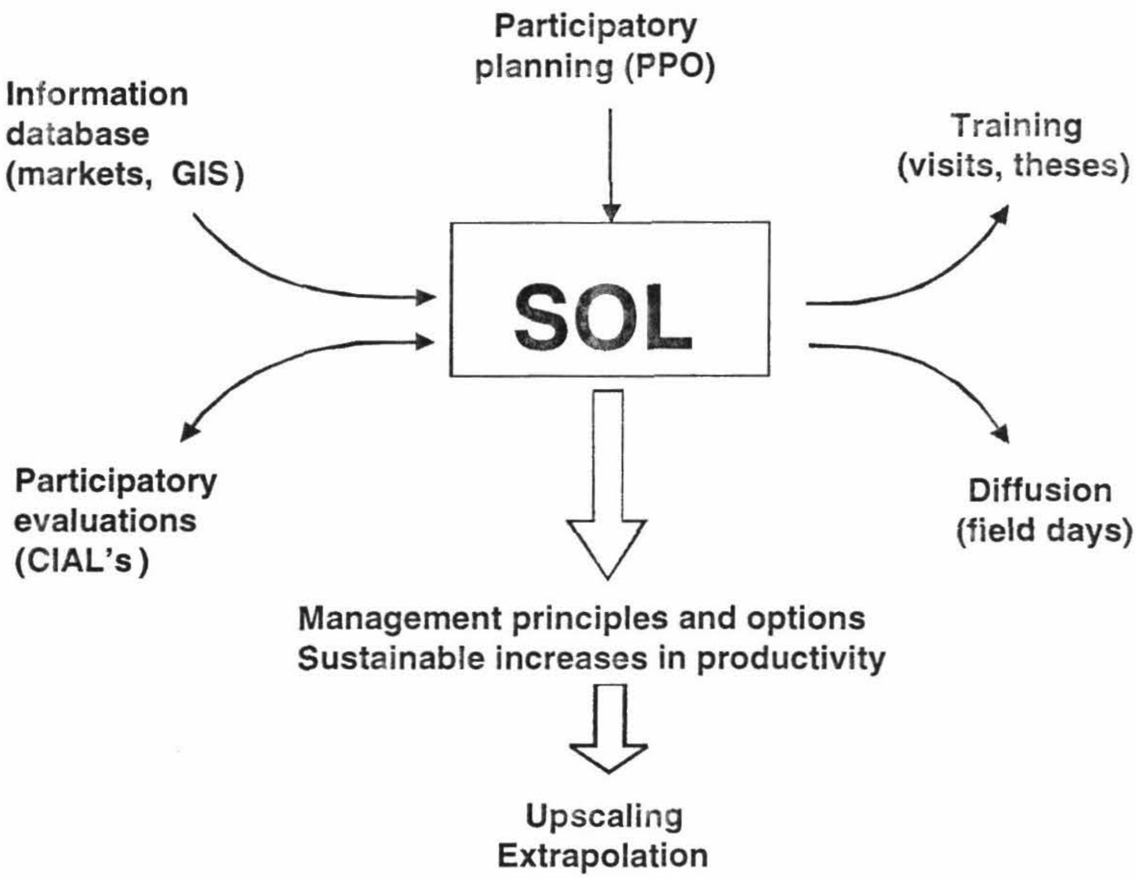

Figure 8. Conceptual model of the SOL's *modus operandi*.

Contributors (alphabetical order):
M. Ayarza, E. Barrios, J.A. Beltrán, L. Brizuela, J.G. Cobo, H. Cruz, N. Espinoza, D. Molina, M. Peters, T. Reyes, J.A. Sanz, R. Thomas and C.A. Trujillo.

Output 2. Strategies developed to protect and improve soil quality

Activity 2.1 Develop a concept of, and strategies for, the establishment and maintence of an "arable layer"for sustainable production

2.1.1 Measure soil physical conditions under different tillage and management systems to construct an arable layer

Highlight:

- Showed that the decrease in rate of water infiltration and increase in weed infestation could cause a decline in upland rice yields.

Purpose:

To construct an arable layer without any physical, chemical or biological constraints for a more sustainable agriculture.

Rational:

Savanna soils are very susceptible to degradation by use because they have very weak structure, are of low fertility and have very low biological activity. To increase productivity and resilience there is a need to improve soil properties though the rational use of soil and crop management practices.

Materials and Methods:

An experiment to build-up an arable layer (cultural profile) was established in Matazul farm in 1996. Basically the experiment consisted of the construction of a rooting layer without physical, chemical or biological constraints using chisel (for physical amelioration), and crop rotation with early or late residue incorporation. More details of the treatments are presented in tables.

Results and Discussion:

It has been not possible to maintain sustainable yields through time in any of the treatments used which means that some factors or properties have been out of control in the experiment. Table 19 shows the trend of yields. During the first year of establishment yields of rice were higher than 3.0 $t.ha^{-1}$, but they declined as time of use increased irrespectively of the treatment. The rate of yield decline was steeper in the rice-pasture systems. Yields of soybeans also decreased with time. The decline of yields has been associated with an increase in the weed biomass. It had the following trend 35, 320 and 704 $kg.ha^{-1}$ for the years 1996, 97 and 98. Another factor associated to the fall of yields is the weather. In 1997 there was an atypical dry season during grain filling. Uneven nutrient distribution in the rooting soil profile, could be another factor affecting the yields.

A soil physical property that summarized the behavior of most of the physical properties that are related to soil water and nutrient fluxes is rate of waterinfiltration. Table 20 shows the trend of infiltration through time. The tendency of this property was an

Table 19. Changes in rice yields (kg ha^{-1}) as function of time.

Treatment	Rice			Soybean	
	1996A	1997A	1998A	1996B	1997B
Rice-soybean rotation (Dolomite: 1500 kg.ha^{-1})					
1 pass of chisel	3241 b	2760 a	2064 a	1932 a	1330 a
2 passes of chisel	3652 a	2888 a	1720 b	1831 a	1277 a
3 passes of chisel	3309 ab	3079 a	1455 b	1834 a	1258 a
Rice-pastures (Dolomite: 500 kg.ha^{-1})					
Andropogon gayanus	3180 b	1727 c	422 d	-	-
A.g + P.p + D.o	3295 ab	1757 c	724 c	-	-
P.p + D.o	3183 b	2368 b	1511 b	-	-
Signific P<	0.09	0.0001	0.0001	0.47	0.66

A.g = *Andropogon gayanus*
P.p = *Pueraria phaseoloides*
D.o = *Desmodium ovalifolium*

Table 20. Changes in water infiltration rates through time.

Treatment	Infiltration rate (cm/h)		
	1996A	1997A	1997B
Rice-soybean rotation			
1 pass of chisel	5.1 a	33.6 a	2.0 c
2 passes of chisel	3.4 a	18.9 ab	1.6 c
3 passes of chisel	2.3 a	16.2 ab	2.2 c
Rice-pastures			
a) Early incorporation			
Andropogon gayanus	2.6 a	8.4 ab	17.0 a
A.g + P.p + D.o	2.8 a	8.2 ab	8.8 abc
P.p + D.o	3.3 a	10.1 ab	9.7 abc
b) Late incorporation			
Andropogon gayanus	-	21.4 ab	8.5 abc
A.g + P.p + D.o	-	23.1 ab	6.5 bc
P.p + D.o	-	21.3 ab	14.2 ab
Native savanna (Control)	1.3 a	0.8 b	1.7 c
Significance (P<)	0.87	0.4	0.07

increase in 1997 and a decrease in 1998. The fall of yields in 1998 has been associated with the low values of infiltration rate. Explanations for the fall of infiltration could be: (a) the presence of a thin layer of surface sealing that impedes the entry of water into the soil, causing water deficiencies in the rooting zone; (b) a collapse of the tilled soil producing a decrease in macroporosity and an increase in bulk density and (c) occurrence of both phenomena. These changes could be produced because the soils have very weak structure and tillage could overcome the forces that maintain the bulk structure of the soil.

Impact:
This study indicated that the decrease in rate of water infiltration and increase in weed infestation could cause a decline in upland rice yields.

Contributors:
COLCIENCIAS, E. Amézquita, D.L. Molina, P. Hoyos, I.M. Rao, R.J. Thomas and E. Barrios.

2.1.2 Evaluate the physical condition of soils subjected to tillage treatments for building-up an arable layer

Highlight:
- Showed that water infiltration is improved in savanna soils by use of the chisel plow and dolomitic lime at a rate of 3.5 t/ha incorporated by use of the chisel plow is adequate for the first maize crop.

Purpose:
To build-up an arable layer through the combination of different doses of dolomitic lime and tillage (disc harrowing and chisel).

Rationale:
In the challenge for building-up an arable layer for soils of the Llanos to improve agricultural sustainability, the physical, chemical and biological constraints should be overcome through simple, inexpensive and easily adaptable practices.

Materials and Methods:
An experiment combining different doses of amendments (dolomitic lime) and tillage (harrowing and chisel) was established in Matazul to evaluate in the long term effect of this combination on the construction of an arable layer.

Results and Discussion:
The influence of tillage with disc harrow or chisel on the amount of infiltrated water compared to native savanna is shown in Figure 9. It can be seen that after 120 min of infiltration savanna had infiltrated a water layer of 50 mm, while under harrowing and chisel the soil infiltrates 70 and 210 mm respectively. This means that if we are to improve water storage capacity to construct an arable layer, vertical land preparation

should be done. Infiltration increases with tillage in these soils because land preparation destroys the small sealed layer that occurs on top of the soils. However, chisel has the advantage of loosening the soil deeper, developing a better environment for root penetration.

Table 21 shows the distribution of Ca, Mg, Al saturation and Organic Matter content as a function of doses of dolomitic lime, the implement used to incorporate it and the depth of sampling six months after the incorporation. It can be seen that Ca content increased with depth until 20 cm, but especially in the 0-10 cm. The amount of Ca found was a function of the amount applied. The Mg contents increased in all the depths studied from 0 to 45 cm, but especially in the first 0-10 and 10-20 cm.

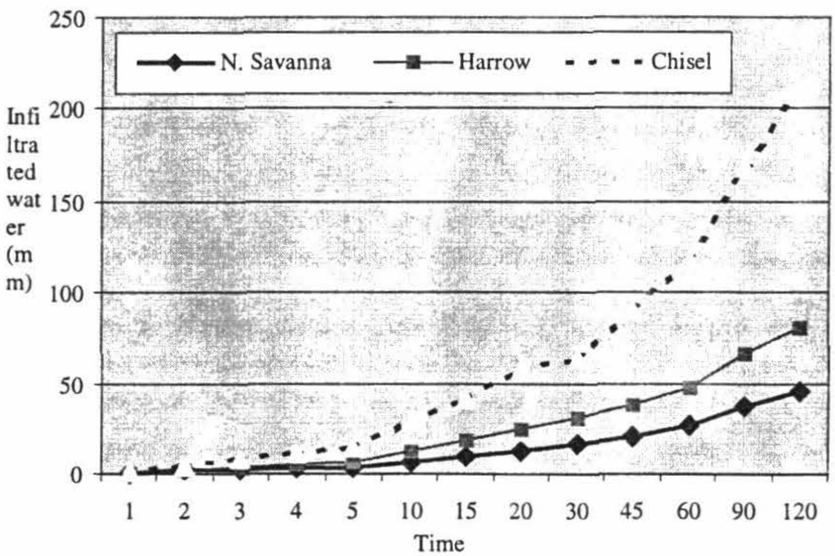

Figure 9. Effect of different tillage systems on rate of water infiltration in savanna soils.

In general, the results obtained suggest that a rate of 3500 kg ha^{-1} of dolomitic lime incorporated with chisel to a depth of 45 cm could be enough to support maize gorwth during the first year. However an additional and more soluble source of Ca should be applied to produce a more uniform control of Al saturation in subsoil . This also will allow to correct the Ca:Mg ratio, which is more critical in subsoil layers.

Table 21. Changes in exchangeable Ca and Mg, Al saturation and organic matter content under different amounts of lime and tillage treatments

Tillage	Lime application (kg/ha)	Soil depth (cm) 0-10	10-20	20-30	30-45
		Ca (meq/100 g soil)			
Chisel	1000	0.82 c	0.175 c	0.087 ab	0.081 a
	3000	1.97 b	0.392 b	0.123 ab	0.097 a
	5000	2.28 ab	0.647 a	0.150 a	0.110 a
Harrow	1000	0.91 c	0.157 c	0.083 b	0.067 a
	3000	2.19 b	0.317 bc	0.107ab	0.073 a
	5000	2.57 a	0.447 b	0.150 a	0.073 a
Native savanna	0	0.12 d	0.108 c	0.100 ab	0.100 a
		Mg (meq/100 g soil)			
Chisel	1000	0.44 c	0.185 b	0.140 b	0.130 a
	3000	0.84 b	0.292 b	0.160 ab	0.143 a
	5000	1.20 a	0.428 a	0.190 a	0.150 a
Harrow	1000	0.47 c	0.188 b	0.150 ab	0.133 a
	3000	1.04 a	0.280 a	0.163 ab	0.143 a
	5000	1.15 a	0.288 b	0.180 ab	0.150 a
Native savanna	0	0.07 d	0.052 c	0.033 c	0.050 a
		Al saturation (%)			
Chisel	1000	53.1 b	79.4 a	85.9 ab	85.6 ab
	3000	7.6 d	64.5 b	80.9 cd	82.5 bc
	5000	5.2 a	52.7 c	80.2 d	82.1 c
Harrow	1000	41.5 c	82.1 a	85.0 bc	86.4 a
	3000	6.0 d	68.8 b	81.6 bcd	83.7 abc
	5000	5.5 d	64.5 b	78.6 d	83.6 abc
Native savanna	0	89.0 a	89.8 a	89.8 a	87.0 a
		Organic Matter (%)			
Chisel	1000	2.79 ab	2.28 a	1.42 ab	0.99 ab
	3000	2.37 cd	1.81 b	1.15 b	0.85 abc
	5000	2.67 bc	2.18 ab	1.57 a	1.10 a
Harrow	1000	3.06 a	2.00 ab	1.40 ab	0.89 abc
	3000	2.64 bc	1.97 ab	1.40 ab	0.88 abc
	5000	2.25 d	1.97 ab	1.30 ab	0.71 bc
Native savanna	0	2.81 ab	1.88 ab	1.15 b	0.63 c

Means followed by the same letter within the column are not significantly different at 0.05 probability level.

Impact:
Results indicated that water infiltration is improved in savanna soils by use of the chisel plow and dolomitic lime at a rate of 3.5 t/ha incorporated by use of the chisel plow is adequate for the first maize crop. The concepts and results obtained, with local modifications due to site specificity, can be applied to the soils of the Altillanura.

Contributors:
PRONATTA; P.Hoyos, E. Amézquita, D.L. Molina, J. Galvis, and L.F. Chávez (CIAT).

Activity 2.2 Develop strategies for nutrient acquisition and replenishment via efficient nutrient cycling and integrated nutrient management

2.2.1 Improved Fallow Systems for recuperation of degraded soils in hillside agroecosystems

Highlight:
- Improved fallow species provided first indications of faster recuperation of soil fertility than natural regeneration.

Purpose:
To provide an alternative for faster recuperation of degraded hillside soils where there is an absence of native fallow management and increased pressure on land.

Rationale:
Fallows with native vegetation are a traditional management practice throughout the tropics for restoration of soil fertility lost during cropping. The successful restoration of soil fertility normally requires a long fallow period for sufficient regeneration of the native vegetation. Increasing population pressure on limited agricultural land, however, requires a reduction in length of fallows or increased use of fertilizers. When purchasing power is low, one alternative to traditional fallows is managed fallows with plants that replenish soil nutrient stocks faster than plants in natural succession. Short-duration fallows with planted trees and shrubs have potential to restore soil fertility in N and/or P limited soils and upon harvest also provide a source of fire-wood.

Materials and Methods:
Two leguminous tree fallows (*Indigofera constricta* and *Calliandra calothyrsus*) and a shrubby fallow (*Tithonia diversifolia*) are being compared with a natural fallow on-farm for their potential to regenerate soil fertility faster than the native flora. Two experiments were established, BM-1 (on-station) at San Isidro Farm and BM-2 (on-farm) at Benicio Velazco Farm. For reasons of space in BM-2 the *Tithonia* treatment is not presented. The experimental design was a RCB with three replicates. Plot size is 18 by 9 m.

Results and Discussion:
The contrasting chemical characteristics of residues (Table 22) generated by the planted fallows facilitates a study of the interactions between residue quality, nutrient availability and residual effect on subsequent crops following the fallows.

Table 22. Chemical characteristics of plant materials used as improved fallows.

Treatment	C	N	P	K	Ca + Mg	Lignin(L)	C/N
	-------	-------	-------	%	-------	-------	
Caliandra	49.4	2.7	0.1	0.9	0.6	14.5	18.6
Indigofera	44.8	3.9	0.2	1.7	2.2	6.9	11.6
Tithonia	38.8	3.9	0.3	3.5	4.2	4.6	9.9

Several parameters related to the growth of improved fallow trees at both experimental locations after one year can be seen in Figure 10. *Indigofera* is faster growing under the hillside conditions in Cauca. Tree height, base and stem diameter were particularly different in San Isidro Farm where overall *Indigofera* was approximately 50% larger than Calliandra while in Benicio Velazco Farm this difference was reduced.

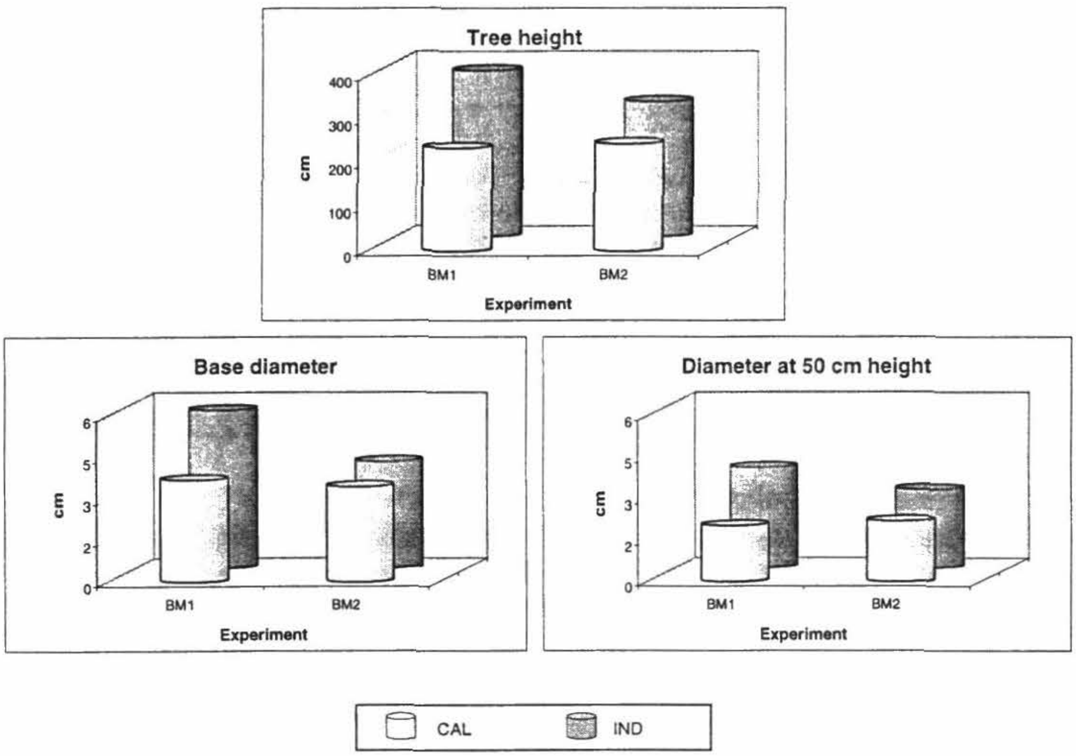

Figure. 10. Productivity measures for arboreal improved fallow species. CAL = *Calliandra calothyrsus*, IND = *Indigofera constricta*. BM-1 = San Isidro Farm, BM-2 = Benicio Velazco Farm.

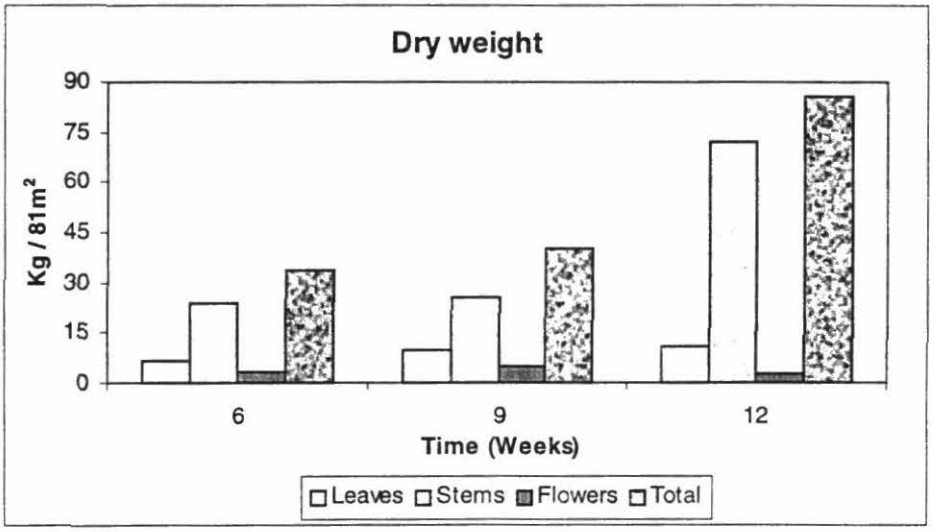

Figure 11. Biomass production of *Tithonia diversifolia* improved fallow at San Isidro Farm.

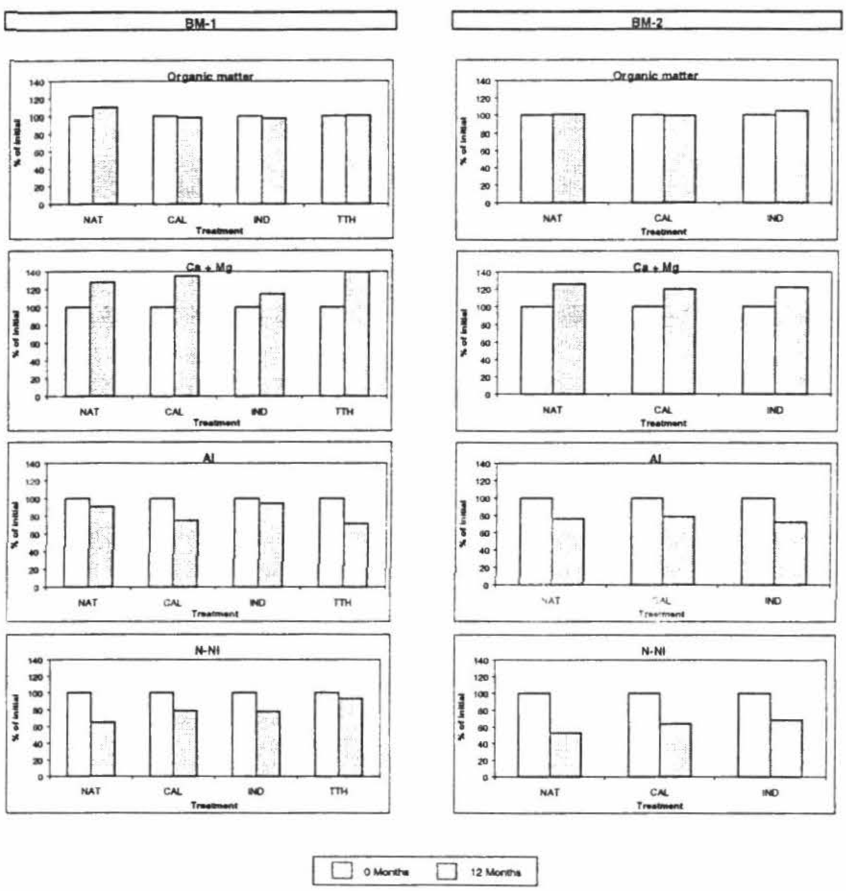

Figure 12. Changes in soil properties (0-20 cm) induced by one year of natural and improved fallows in two Colombian hillside farms (Pescador – Cauca). BM-1 = San Isidro Farm, BM2 = Benicio Velazco Farm.

The biomass production of the *Tithonia* improved fallow can be seen in Figure 11. Harvested biomass was reapplied on the same plot as a mulch for a total of three applications in the first year.

Although results at 12 months did not show much difference among fallow systems some changes are beginning to appear especially in the arable layer (0-20 cm) (Figure 12). Initial weedings and residue removal prior and during establishment of improved fallows possibly influenced the small soil organic matter (SOM) difference observed between natural and improved fallows. Soil Ca+Mg levels were particularly improved by the Tithonia followed by *Calliandra* improved fallow systems. Soil aluminum was also considerably reduced by *Tihonia* and *Calliandra* improved fallows reducing potential Al toxicity problems for crops following the fallow phase. Soil inorganic N was especially reduced in the natural fallow while improved fallows showed less reduction especially in *Tithonia*. These observations are likely a result of the quantity and chemical composition of the recycled fallow residues in the systems compared. These results, however, could be underestimations because 1999 was a particularly rainy year and increased erosion and leaching losses are likely to have taken place thus affecting significant changes in other soil parameters.

Contributors:
E. Barrios, J.G. Cobo, C.A.Trujillo and A. Meléndez

2.2.2 Farm nutrient recycling by strategic combination of double-purpose live barriers in hillside agroecosystems

Highlights:

- Established on-station and on-farm experiments to test the farm nutrient recycling approach by the strategic combination of double-purpose live barriers in a hillside agroecosystem.

Purpose:
To design a hillside farm management approach which is economically attractive and environment friendly.

Rationale:
The use of live barriers to minimize and control soil erosion has commonly been suggested as a suitable land management practice across hillside ecosystems. The adoption of this technology, however, has been slow. Farmers are averse to investing time and effort in protecting the soil while there are more urgent household priorities. One approach which has promoted a limited increase in live barrier on-farm utilization has been the utilization of double purpose live barriers which not only reduce soil erosion but also generate a product of interest to the farmers (i.e. sugar, fodder).

It is proposed that, as a way of increasing live barrier adoption by the farmer community, the concept of farm nutrient recycling must be included as a way of reducing household costs and increasing economic and environmental quality benefits. This notion starts at the farm level with sugar cane live barriers, estimated to produce about 1.5 kg brown sugar (panela) per linear meter of barrier, used as erosion control barriers across the slope (Table 23).

Table 23. Mean agronomic productivity per linear meter of double-purpose sugarcane barriers (var.CC87-45) in a hillside agroecosystem

	CANE PRODUCTION		PANELA* PRODUCTION	
	Number	Weight (kg)	Number	Weight (kg)
Harvest 1 (12/01/98)	21.9	20.6	2.0	1.5
Harvest 2 (12/04/99)	20.2	21.6	2.0	1.5

*Brown sugar bar

Sugar cane live barriers can reduce soil erosion by their physical barrier effect and reduce the movement of nutrients in solution (i.e. nitrates) down the slope. Even in the presence of live barriers, however, a considerable proportion of fertilizer nutrient inputs applied to crops that are grown between live barriers may be lost from the farm and could potentially contribute to water pollution. To minimize these losses, plant components that are efficient in capture of nutrients are needed. The nutrient trap barrier of *Tithonia diversifolia* was strategically located at the lower fringe of each farm (Figure 13).

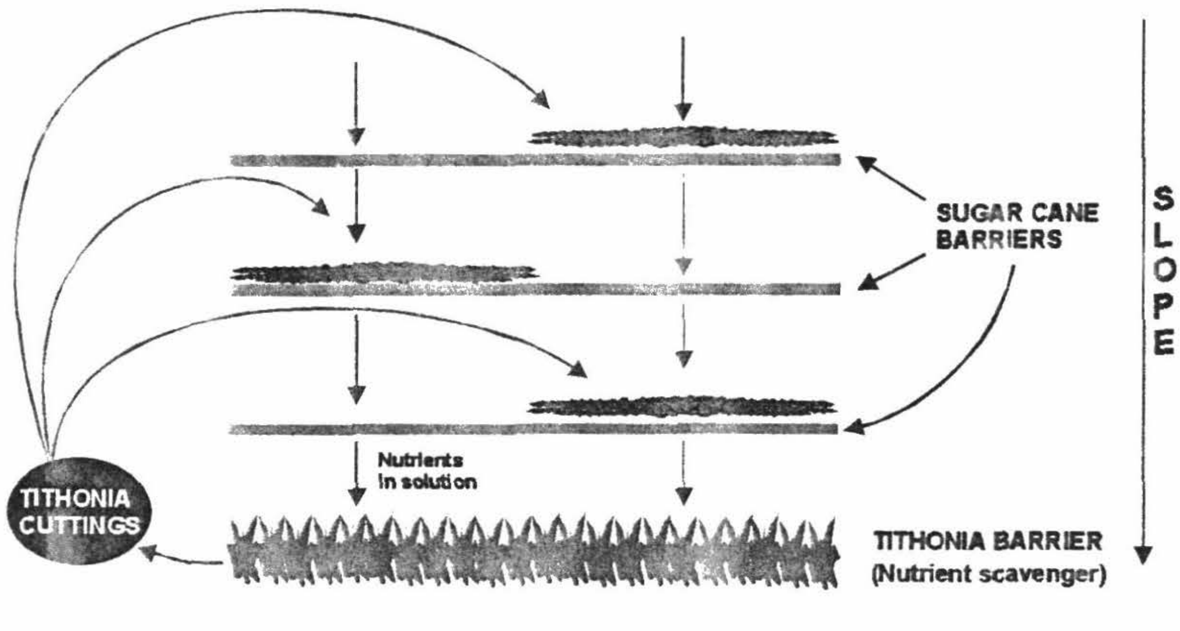

Figure 13. Distribution of Sugarcane and Tithonia live barriers across the slope.

An additional trait of *T. diversifolia* is that it decomposes and releases a large proportion of its nutrients in a short period of time (i.e. two weeks) and thus can be used as a fertilizer (CIAT, 1998, Cobo MSc Thesis). The application of *T. diversifolia* cuttings to the sugar cane barriers, and potentially to other high value crops (i.e. vegetables), would then result in an internal recycling of farm nutrients leading to lower nutrient losses as well as reducing the need for fertilizer inputs and thus higher profitability. Three experiments (2 on-farm, 1 on-station) have been established to test this concept/technology. While the adoption of this approach may be difficult to assess over the short-term the collective effect of this practice can be quite important at the landscape level.

Contributors:
E. Barrios, J.G.Cobo, C.A.Trujillo and A. Meléndez.

2.2.3 Determine the impact of the method of establishment of Tithonia on soil P pools

Highlight:

- Establishment of *Tithonia* by plantlet increased P availability in soil due to increased P cycling via plant residues.

Purpose:
To determine the impact of the method of establishment of *Tithonia* on soil P pools.

Rationale:
In addition to the studies on the impact of the method of establishment of *Tithonia* on biomass production and nutrient acquisition (see 1.5.1 activity), we also evaluated the impact of *Tithonia* establishment method on soil P pools.

Materials and Methods:
The sequential P fractionation of Tiessen and Moir (1993), slightly modified, was carried out on 0.5 g sieved (2 mm) soil samples. The underlying assumption is that readily available soil P in the continuum is removed first with mild extractants, and the plant-unavailable P can only be extracted with strong acids and oxidizers. A sequence of extractants with increasing strength is applied to subdivide soil total P in inorganic (P_i) and organic (P_o) fractions. The following fractions were included: (1) resin P_i, extracted with anion exchange resin membranes, used in bicarbonate form, P_o in the H_2O of the resin extraction step (Oberson et al., 1994); (2) $NaHCO_3$ P_i and P_o, obtained by extraction with 0.5 M $NaHCO_3$; (3) NaOH P_i and P_o, extracted with 0.1 M NaOH; (4) HCl Pi, obtained by extraction with 1.0 M HCI; (5) HCl_{hc}, P_i, and P_o, extracted with hot and concentrated HCI and (6) total residual P, obtained by digestion with $HClO_4$. Total P in the $NaHCO_3$ and NaOH was measured after digestion with potassium persulfate ($K_2S_2O_8$) (Bowman, 1989). Organic P was calculated as the differences between total P and Pi in the $NaHCO_3$ and NaOH extracts, respectively. Total soil P was determined by perchloric acid ($HClO_4$) digestion (Olsen and Sommers, 1982). Inorganic P

concentrations in solution was determined colorimetrically by the molybdate-ascorbic acid method (Murphy and Riley, 1962).

Although separating total P into seven fractions, as described above, helps to elucidate the differences in size of various P fractions, the P fractions are of greater practical value when grouped into fewer functional pools of similar availability with management implications. These pools can then be used to improve soil P management and serve as decision-making aids (Yost et al., 1992). Therefore, in this study we quantified three functional pools: readily available, reversibly available, and sparingly available. The readily available P pool is the first removed by plant roots in the soil P continuum. It comprises primarily P bound to the reactive surfaces that are in direct contact with the aqueous phase (Hingston et al., 1974) or as "more physically adsorbed phosphate" (Sharpley, 1991). This pool represents P that is readily accessible by plant roots. The reversibly available P denotes the soil P reserve that is plant available when converted to readily available P. The sparingly available P is not available on a short time scale such as one or more crop cycles, but a small fraction of this pool may become available during long-term soil P transformations.

The experiment was laid down as RCB design with establishment method as treatment. The experiment was replicated three times. Data from the experiment were subjected to an analysis of variance using the SAS computer program (SAS/STAT, 1990). Least-significant differences were calculated by an F-test. A probability level of 0.05 was considered statistically significant.

Results and Discussion:

Soil P fractionation - Soil P in 'readily available pool' (sum of H_2O, resin, and $NaHCO_3$ extractable P pools) decreased with soil depth and ranged from 56.4 (0-5 cm) to 18.0 µg/g (40-60 cm) which was between 4 to 9% of total P (Table 24; Fig. 14). This pool was less variable and was about the same under the two methods of establishment. The 'reversibly available pool' (NaOH extactable P) was more variable representing 24 to 60% of total P. It was greater under stake establishment throughout the profile. The 'sparingly available pool' (HCl extractable and residual P pools) was less variable, increased slightly with depth, it ranged from 48 to 57 % of total P at 0-5 and 40-60 cm, respectively.

Impact:

Establishment of *Tithonia* by plantlet not only improved shoot biomass yield (see activity 1.5.1) but also increased P availability in soil. This could be due to P cycling in the top soil due to the input of plant residues to soil.

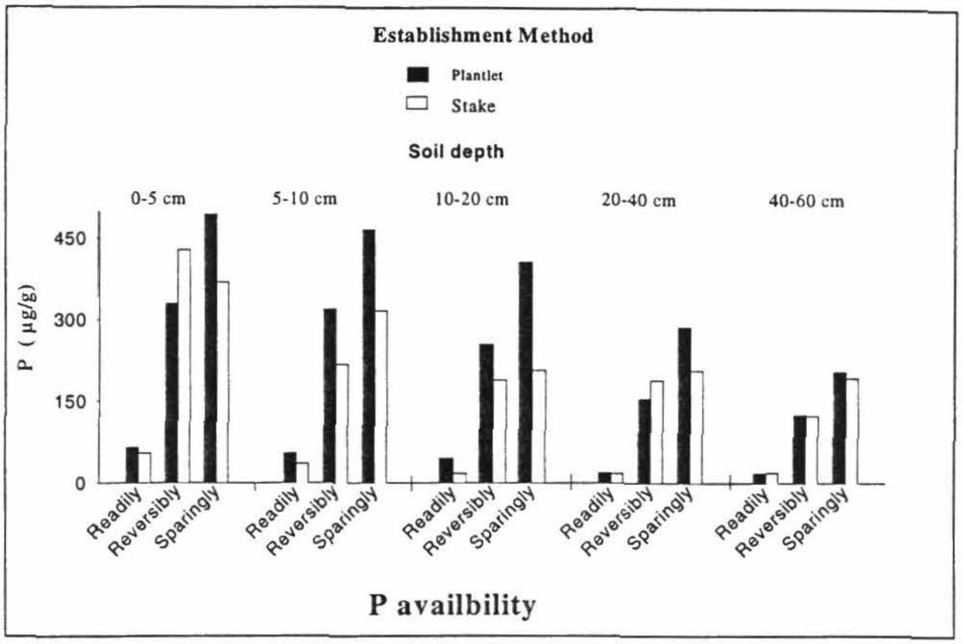

Figure 14. Distribution of three soil P fractions (readily, reversibly and sparingly available P) through 0 to 60 cm soil depth.

Table 24. Distribution of P (µg/g) in various fractions at different soil depth as affected by *Tithonia* establishment.

Depth	Method	H_2O	Resin	Bicarbonate		NaOH		HCl 1M	HCl hc[†]		Residue	Total
		Po	Pi	Pi	Po	Pi	Po	Pi	Pi	Po	Pt	P
		(µg /g)										
0-5 cm	Plantlet	3.35	4.36	21.4	35.5	183	146	15.8	80.6	21.7	375	880
	Stake	2.35	2.55	17.3	32.6	176	252	15.4	37.1	15.0	301	828
		(0.54)[‡]	(1.46)				(51)		(7.0)		(53)	(46)
5-10 cm	Plantlet	2.67	3.26	19.1	29.6	146	172	14.8	67.8	21.6	361	784
	Stake	1.71	1.66	12.8	29.1	155	130	10.0	45.7	10.9	319	717
		(0.53)	(0.92)		(5.2)			(1.8)	(14.6)	(5.8)		
10-20 cm	Plantlet	2.12	2.73	12.2	26.2	160	94.2	11.6	63.0	15.7	315	660
	Stake	1.54	1.34	7.6	25.5	130	88.3	7.6	53.4	17.3	238	603
			(0.5)	(2.3)				(2.6)	(8.3)		(38)	
20-40 cm	Plantlet	1.37	0.44	2.7	14.5	82.6	72	6.1	30.7	12.2	238	420
	Stake	1.36	0.41	2.3	13.1	58.7	130	3.2	29.2	14.0	160	457
						(15.2)						
40-60 cm	Plantlet	1.66	0.30	1.1	15.2	52.5	73	3.2	25.5	16.5	160	336
	Stake	0.83	0.23	2.0	16.2	52.4	72	4.1	26.2	8.9	154	329
										(6.2)		

[†] HCl hc =Hot and concentrated HCl

[‡] Numbers in parentheses are $LSD_{(0.05)}$.

References:

Bowman, R. A. (1989). A sequential extraction procedure with concentrated sulfuric acid and dilute base for soil organic phosphorus. Soil Sci Soc Am J 53, 362-366.

Hingston, F. J., Posner, A. M., and Quirk, J. P. (1974). Anion adsorption by goethite and gibbsite. II. Desorption of anions from hydrous oxide surfaces. J Soil Sci 25, 16-26.

Murphy, J., and Riley, P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27, 31-36.

Oberson, A., Friesen, D. K., Tiessen, H., Moir, J. O., and Borrero, G. (1994). Phosphorus transformation in improved pastures: In Tropical Lowlands. Program. Annual report. Working Document 148, 182-187.

Olsen, S. R., and Sommers, L. E. (1982). Phosphorus. In: Page AL, Miller RH and Keeney DR.

SAS/STAT (1990). SAS/STAT User's Guide. Version 6. Statistical Analysis System Institute, Inc., Cary, NC.

Sharpley, A. N. (1991). Soil phosphorus extracted by iron-aluminum-oxide-impregnated filter paper. Soil Sci. Soc. Am. J. 55, 1038-1041.

Tiessen, H., and Moir, O. (1993). Characterization of available P by sequential extraction. p. 75-86. .

Yost, R. S., Onken, A. B., Cox, F., and Reid, S. (1992). The diagnosis of phosphorus deficiency and predicting phosphorus requirements. In Proceedings of the TropSoils Workshop: Phosphorus Decision Support System. Texas A&M University, College Station, TX, March, 1-20.

Contributors:

S. Phiri, B. R. Singh (AUN, Norway), E. Barrios, G. Borrero, J. Ricaurte and I. M. Rao (CIAT)

2.2.4 Determine the differences in root turnover among native and introduced pastures

Highlight:

- Showed that the contribution of root turnover to nutrient cycling and soil carbon accumulation in introduced pastures, particularly legume-based pastures, could be significantly greater than that of the native savanna pastures.

Purpose:

To determine the differences in root turnover among native and introduced pastures.

Rationale:

Root production, turnover and decomposition are key processes in the carbon and nutrient dynamics in agroecosystems (Aerts et al., 1992; Long et al., 1989; Jackson et al., 1997; Smucker, 1990; Veldkamp, 1993; Vogt et al., 1998). Root production very often exceeds shoot production and thereby determines to a large extent the input (quantitatively and qualitatively) of organic matter and nutrients into the soil. A common approach to measuring root turnover is sequential sampling of root mass and estimating root production by adding increments of standing stocks of living and dead roots(Vogt et al., 1998). Assuming steady state conditions for the living root system, the input of dead roots into soil equals root production. Previous research showed that the average live root biomass of the introduced pastures is significantly greater than that of the native pastures and this markedly superior root production in introduced pastures could result in substantial storage of carbon in soil (Fisher et al., 1994; Rao, 1998). But the extent of root turnover in introduced pastures compared to native pastures is unknown. The aim of this study was twofold: (i) to determine differences in root turnover among native and introduced pastures; and (ii) to assess the impact of root turnover on nutrient cycling, particularly N and P.

Materials and Methods:

The study was carried out at the Carimagua Research Station of CORPOICA-CIAT in the Eastern plains (Llanos) of Colombia. The measurements of root production and turnover were made on two introduced (9-year-old) pastures (grass alone – *Brachiaria dictyoneura* CIAT 6133; and grass + legume pasture – *B. dictyoneura* + *Arachis. Pintoi* CIAT 17434) compared to a native pasture. Both introduced pastures were managed with rotational grazing system (4-paddock system with 7/21 days for both wet and dry seasons). Root sampling involved collection of replicate soil cores of 0 to 80 cm soil depth (Rao, 1998), washing with hydroneumatic elutriation system and sorting of live and dead roots from the soil matrix. Sampling occurred in all three pastures with monthly intervals between May 1995 to May 1996. Root production (P) per sampling interval was calculated depending on the direction of significant change of standing stocks of living (L) and dead (D) roots: a) if $dL > 0$ and $dD > 0$, then $P = dL + dD$; b) if $dL > 0$ and $dD < 0$ then $P = dL$; c) if $dL < 0$ and $dD > 0$ then $P = dL + dD$ or $P = 0$ (in case of a negative P); if $dL < 0$ and $dD < 0$ then $P = 0$ (Aerts et al., 1992). Annual estimates were calculated by summing the estimates within all sampling intervals within the year. Assuming steady state conditions for the root system on an annual basis, root biomass turnover rate (yr^{-1}) was calculated by dividing mean root biomass production by average living root biomass. Root length turnover rate (yr^{-1}) was calculated by dividing mean root length production by average living root length.

Results and Discussion:

Analysis of variance showed significant effects of sampling date ($P < 0.05$) and pasture type (native or introduced) on living root biomass and root length. Significant seasonal fluctuations were observed for both living root biomass and length (Figure 15). The greater amounts of rainfall during June-July and October-November caused significant amounts of root turnover during the rainy season. Annual root production (biomass and length) was significantly greater in the introduced pastures compared with the native pasture (Tables 25 and 26). Root biomass and root length turnover rates were similar among native and introduced pastures. However, the greater amounts of live roots in the introduced pastures could contribute to markedly superior root turnover from the introduced pastures than that of the native pasture (Table 25 and 26).

Table 25. Differences in root biomass production, decomposition and rate of turnover among native and introduced pastures on a clay loam Oxisol at Carimagua.

Pasture	Mean monthly live root biomass	Mean monthly dead root biomass (kg/ha)	Total annual root biomass production (kg/ha)	Total annual root biomass decomposition (kg/ha)	Root biomass turnover (yr^{-1})
Bd	2670	1440	6117	5249	2.29
Bd + Ap	2531	1367	5661	5595	2.23
Savanna	1074	369	2408	1845	2.24
$LSD_{0.05}$	311	201			

Bd = *Brachiaria dictyoneura* CIAT 6133; Ap = *Arachis pintoi* CIAT 17434; Savanna = native savanna.

Table 26. Differences in root length production, decomposition and rate of turnover among native and introduced pastures on a clay loam Oxisol at Carimagua.

Pasture	Mean monthly live root length ($km\ m^{-2}$)	Total annual root length production (km/m^{-2})	Total annual root length decomposition ($km.m^{-2}$)	Root length turnover (yr^{-1})
Bd	15.6	40.7	20.5	2.61
Bd + Ap	13.8	24.8	12.4	1.80
Savanna	7.3	17.5	12.1	2.40
$LSD_{0.05}$	2.3	-	-	-

The processes of production, death, and decomposition of roots are well known to be simultaneous and counteracting (Vogt et al., 1998). Production and turnover, therefore, also occur simultaneously. Observed standing live or dead roots are the end products of these processes. Inferring root production from changes in standing live and dead roots alone does not account for simultaneous and compensating processes of production and turnover. A certain degree of error must therefore be expected with estimations of primary production of roots based on repeated measurements of live and dead roots. Two major factors contribute to this error: (1) dead roots are difficult to sort out from total root sample; and (2) some of the dead material is decomposed between samplings.

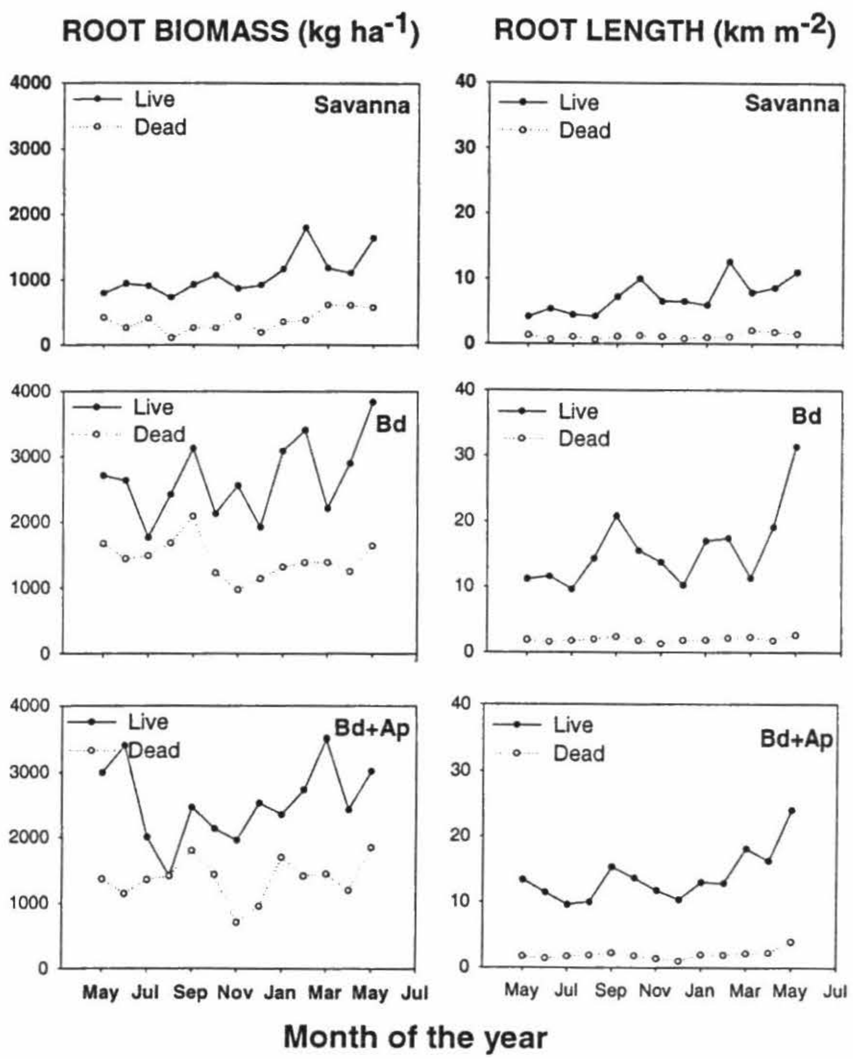

Figure 15. Live and dead root biomass and root length dynamics during the year of three pasture systems (native savanna, grass alone (Bd) and grass + legume (Bd + Ap)).

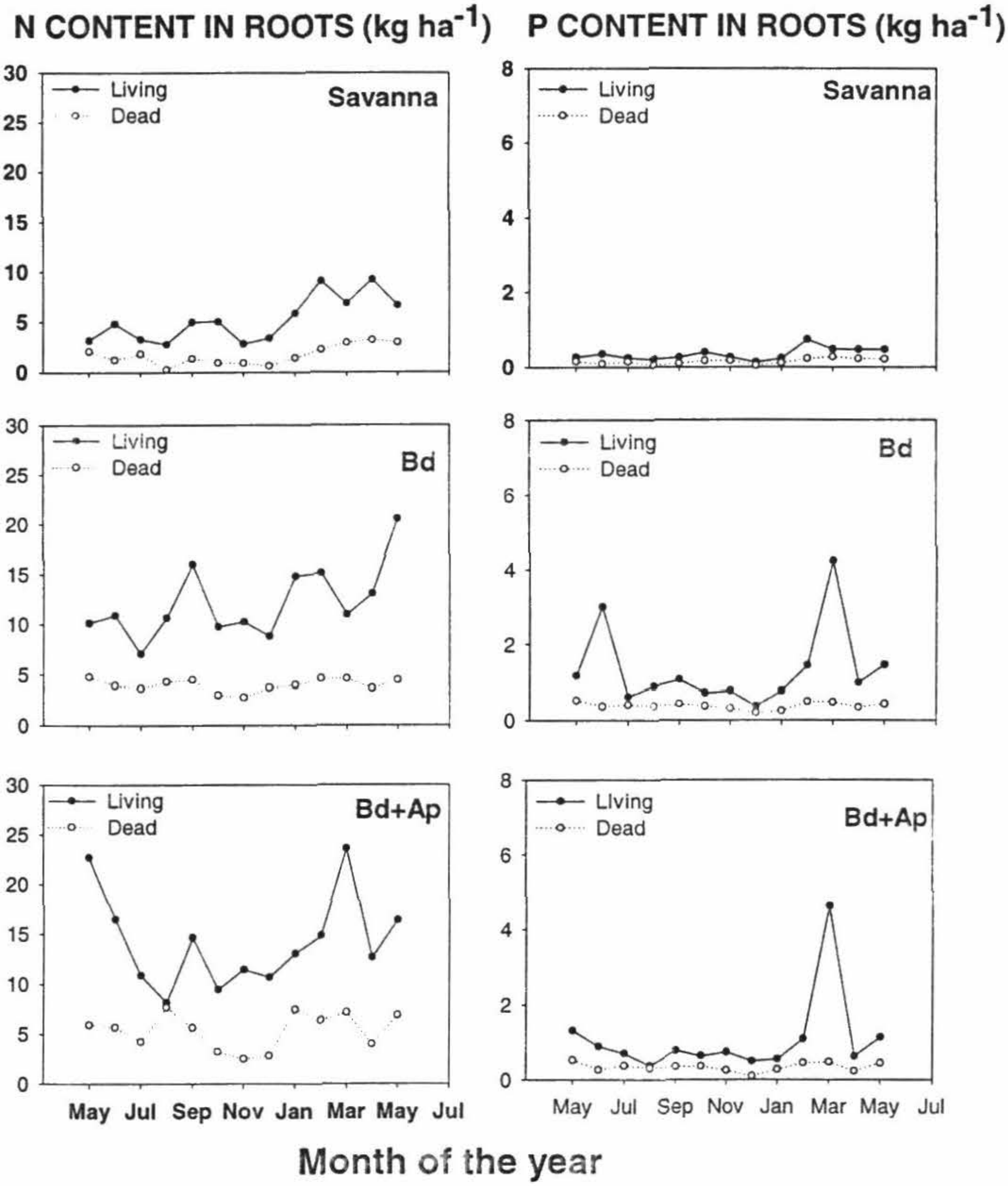

Figure 16. Nitrogen and phosphorus dynamics from live and dead roots during the year of three pasture systems (native savanna, grass alone (Bd) and grass + legume (Bd + Ap)).

Studies on net primary productivity of natural grass ecosystems in the tropics have shown that these ecosystems are far more productive than had previously been estimated (Long et al., 1989). Accounting for the turnover of shoot and root material at only 0-20 cm soil depth resulted in net primary productivity" that were as much as five times higher than those obtained through standard procedure. Below-ground estimations ranged from 610 to 5680 kg/ha. Annual root turnovers, estimated as production divided by mean biomass, were between 1.7 and 4.0. Results from the present work that extended to 0 to 80 cm soil depth indicated that the extent of root turnover could be around 2.3 in natural and introduced tropical pastures while net production of roots may be 2 to 3 times greater in introduced pastures.

The larger amounts of standing live roots of introduced pastures could contribute to greater cycling of nutrients (Figure 16) and sequestration of carbon in soil upon root death and decomposition or because of turnover (Rao, 1998). In contrast, a lower contribution is expected from NS pasture because of its low below-ground root biomass. Changes through time in pool sizes of nutrients in roots and estimation of nutrients cycled through root turnover indicated that the amount of N cycled through roots of introduced legume-based pastures could be as much as 34 kg ha^{-1} y^{-1} compared with grass alone pasture value of 29 kg ha^{-1} y^{-1} and native savanna pasture value of 16 kg ha^{-1} y^{-1} (Figure 16). Cycling of other nutrients such as P via root turnover from introduced pastures could also reach levels that could be five to six times greater than those of native savanna pasture: 7.2, 5.8 and 1.2 kg ha^{-1} y^{-1} from grass alone, grass + legume and native savanna pastures, respectively.

Impact:
This field study indicates the potential contribution of root turnover in introduced pastures to nutrient cycling and soil carbon accumulation. These results have important implications for the management of introduced pastures to improve nutrient cycling and carbon sequestration in soil. Agroecosystems that incorporate the beneficial features of introduced pastures, such as extensive root growth and turnover and permanent above-ground cover, will reduce nutrient losses by storing large quantities of nutrients in the below-ground biomass, augmenting soil organic matter and protecting the soil. Such beneficial features of introduced pastures might usefully be incorporated into the design of agropastoral systems appropriate for the South American savannas, where the potential for nutrient loss rates through leaching and erosion can be significant.

References:

Aerts, R., Bakker, C. and De Caluwe, H. (1992) Root turnover as determinant of the cycling of C, N, and P in a dry heathland ecosystem. *Biogeochemistry* 15, 175-190.

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

Jackson, R. B., Mooney, H. and Schulze, E.-D. (1997) A global budget for fine root biomass, surface area, and nutrient contents. *Proc. Natl. Acad. Sci. USA* 94: 7362-7366.

Long, S.P., Garcia Moya, G., Imbamba, S.K., Kamnalrut, A., Piedade, M.T.F., Scurlock, J.M.O., Shen, Y.K. and Hall, D.O. (1989) Primary productivity of natural grass ecosystems of the tropics: a reappaisal. *Plant and Soil* 115, 155-166.

Rao, I. M. (1998) Root distribution and production in native and introduced pastures in the south American savannas. In: *Root demographics and their efficiencies in* *sustainable agriculture, grasslands and forest ecosystems*. J. E. Box (ed). Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 19-41.

Smucker, A. J. M. (1990) Quantification of root dynamics in agroecological systems. *Remote Sensing Reviews* 5: 237-248.

Veldkamp, E. (1993) *Soil organic carbon dynamics in pastures established after deforestation in the humid tropics of Costa Rica*. Ph.D. dissertation. Wageningen Agricultural University, Wageningen, the Netherlands. 117 p.

Vogt, K. A., Vogt, D. J. and Bloomfield, J. (1998) Analysis of some direct and indirect methods for estimating root biomass and production of forests at an ecosystem level. In: *Root demographics and their efficiencies in sustainable agriculture, grasslands and forest ecosystems*. J. E. Box (ed). Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 687-720.

Contributors:

I.M. Rao, C. Plazas and J. Ricaurte (CIAT)

Activity 2.3 Develop appropriate and diverse strategies for controlling soil erosion

2.3.1 Improving predictability and prevention of soil erosion in hillsides

Highlight:

- Live barriers permit a good control of soil erosion and conservation of water. Crop rotation and minimum tillage are important practices to maintain the productive capacity of the soils.

Purpose:

To compare the efficiency of some erosion control practices using standard USLE plots in Santander de Quilichao and Mondomo.

Rationale:

Hillside farmers need conservation practices to avoid soil losses by erosion and to increase water storage capacity of soils. Under the consortium with the Univ. of Hohenhein, Germany, different soil and crop management systems were established in a formal design to apply the concepts and parameter of the Universal Soil Loss Equation (USLE). The effects of the treatments in soil losses during 1998-99 period are presented here.

Materials and Methods:

The experimental sites are located in Santander de Quilichao (CIAT) and in a farm in Mondomo. In both places, plots description agree with the specifications suggested by Wishmeier and Smith (1978). Last year the accumulated effect of the treatments were tested with maize. The treatments are:

1N. Bare plot (since 1996)
1. Bare plot (since 1992)
2. Crop rotation + (Tillage + Chicken manure)
3. Cassava monoculture + (Tillage + Fertilizer)
4. Crop rotation + (No-tillage + Fertilizer)
5. Crop rotation + (Tillage + Fertilizer)
6. Crop rotation + (Tillage + Chicken manure + Live barrier)
7. Crop rotation + (Tillage + Legumes + Fertilizer)
8. Crop rotation + (Tillage + Pastures + Fertilizer)

Results and Discussion:

Higher soil losses under maize in Santander occurred in the plots under cassava monoculture (Figure 17). They were around 150 $t.ha^{-1}$, a value that was close to that obtained under bare soil, 160 $t.ha^{-1}$. Any other treatment showed half the losses under cassava, but in those including tillage (treatments 2, 7, 8) the losses were higher than in those that included no-tillage, even so, in these treatments there were losses of about 30 $t.ha^{-1}$ which were higher than 12 $t.ha^{-1}$ that usually are claimed as the tolerance limit.

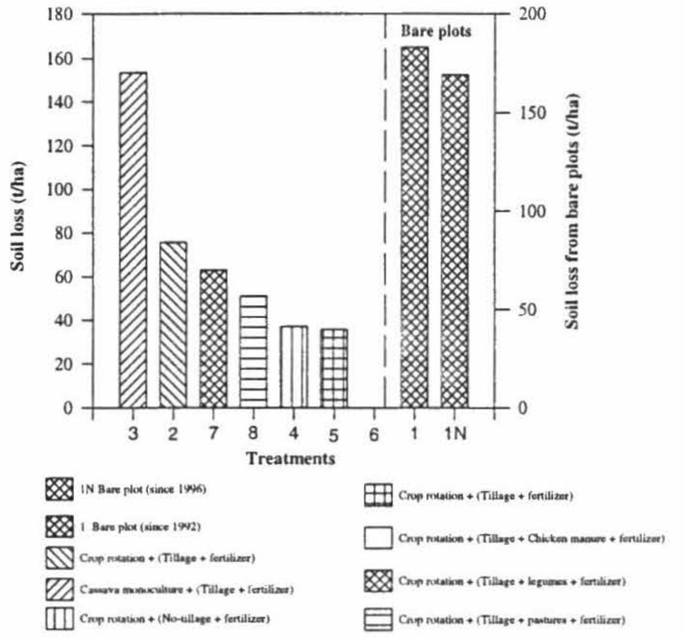

Figure 17. Soil loss under maize in different management tretaments in Santander de Quilichao 1998-1999.

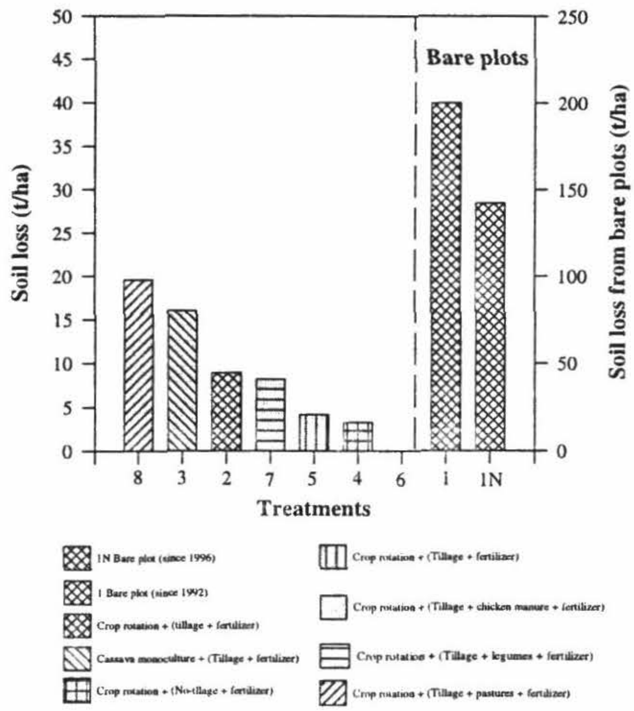

Figure 18. Soil loss under maize in different management tretaments in Mondomo 1998-1999.

In Mondomo (Figure 18), losses in the treatments were lower than those found in the bare plots. Higher losses occurred in treatments 8 and 3, which correspond to tillage + fertilizer after pastures and to cassava monoculture. The other treatments presented losses lower than the tolerance limit.

Impact:
The results showed that it is possible to reduce erosion losses through the use of management systems that minimize erosion.

References:
Wischmeier, W.H. and Smith, D.D. 1978. Predicting rainfall erosion losses - a guide to conservation planning. Agric. Handbook No. 537, USDA, Washington, DC, USA.

Contributors:
J.A. Castillo, E. Amézquita, L.F. Chávez, A. Alvarez, L. Mina, D. Peña, and J.L. Adarve.

Activity 2.4 Develop strategies to maximize C sequestration in soil and minimize emissions of green house gases

Activities on this are pending receipt of two Ph.D. theses currently being prepared in Ohio State and Cornell Universities.
Some activity on C sequestration is reported below and also under activity 2.5.

Contributors:
W. Trujillo, M. Rondón, M. Fisher and R. Thomas

2.4.1 Impact of land use changes on carbon sequestration in the central lowlands of tropical South America

Highlight:
- Developed a case study of land use changes in the central lowlands of tropical South America.

Purpose:
To contribute to case studies for the Inter-Centre Working Group on Climate Change and present a poster on the findings at the international conference of Focus 3 of the Global Change and Terrestrial Ecosystems project.

Rationale:
The lands of tropical South America east of the Andes comprise the central lowlands and cover some 8.2 million km^2. Cochrane et al. (1985) divided the central lowlands into nine physiographic regions (Figure 19), which are overlain by climatic subregions depending on the length of the rainy season, the amount of evapotranspiration and the mean temperature during that rainy season (Table 27). Between them the physiographic regions and the climatic subregions, together with topographic classes that control drainage, broadly determine the natural vegetation classes of the central lowlands (Figure 20).

Only three of the nine physiographic regions, the Orinoco Basin, the Amazon Basin and the Brazilian Shield, will be considered further here as having undergone substantial change in land use in the last 30 yr. Cochrane et al. (1985) classified these lands into land systems, defined as "an area or group of areas throughout which there is a recurring pattern of climate, landscape and soils." Each land system consists of two or three land facets, usually only one of which makes up the major part of the land system. Each land system was given a general classification based on altitude, drainage, slope and vegetation. In Table 28, lands classified as savannas are separated into the physiographic areas in which they are found, and then subdivided on the basis of drainage, altitude and then slope, to give the areas of each. In general, the well-drained savannas of the Amazon Basin occur in scattered small areas, and are of little importance. An exception is the savannas of the Macapá cerrados at the mouth of the Amazon, which have long been used for cattle production (Serrão and Homma, 1993).

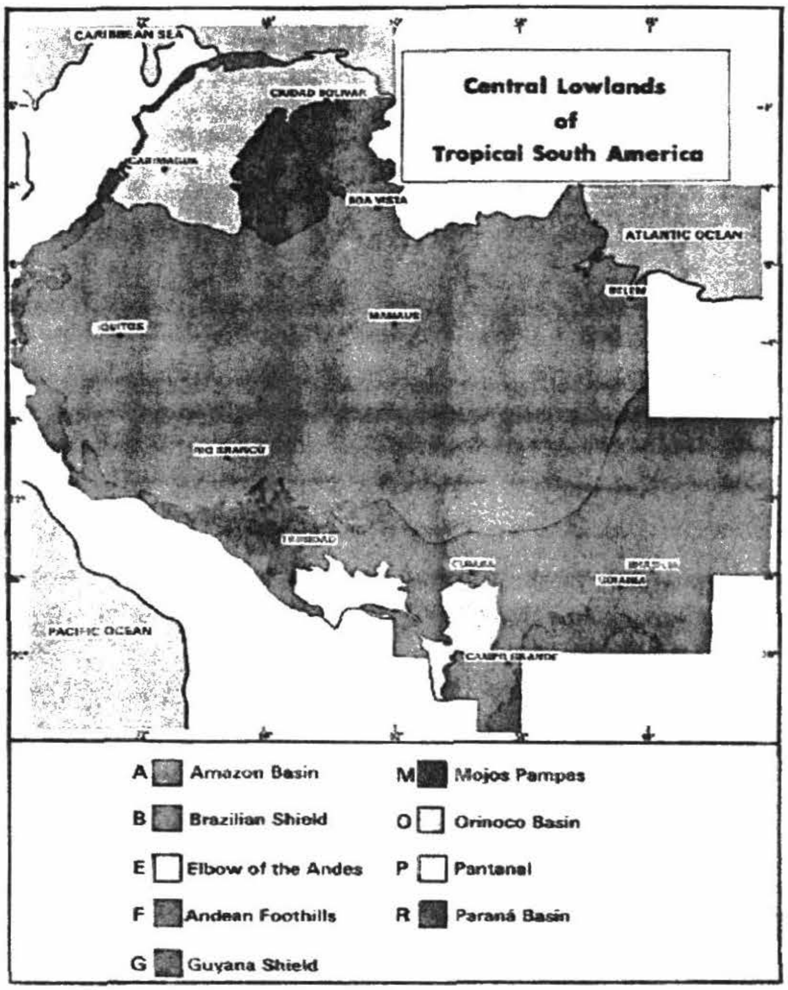

Figure19. Physiographic regions of the central lowlands of tropical South America (from Cochrane et al., 1985).

When considering the effect of changes in land use on C stocks, we can broadly consider the savannas and the tropical forest, estimating the changes in C stocks when each is converted to other uses. Building on this information, we can then attempt to determine over what area is it possible to extrapolate these data. The first exercise is to consider the physiographic regions and vegetation classes and the areas of each. We shall then focus on the savannas, which have the greatest potential to accumulate C. The large amounts of above-ground C lost when the forest is cleared mean that though the soil component may come to a new, even higher, equilibrium than in the uncleared forest, areas of converted forest are net sources of C.

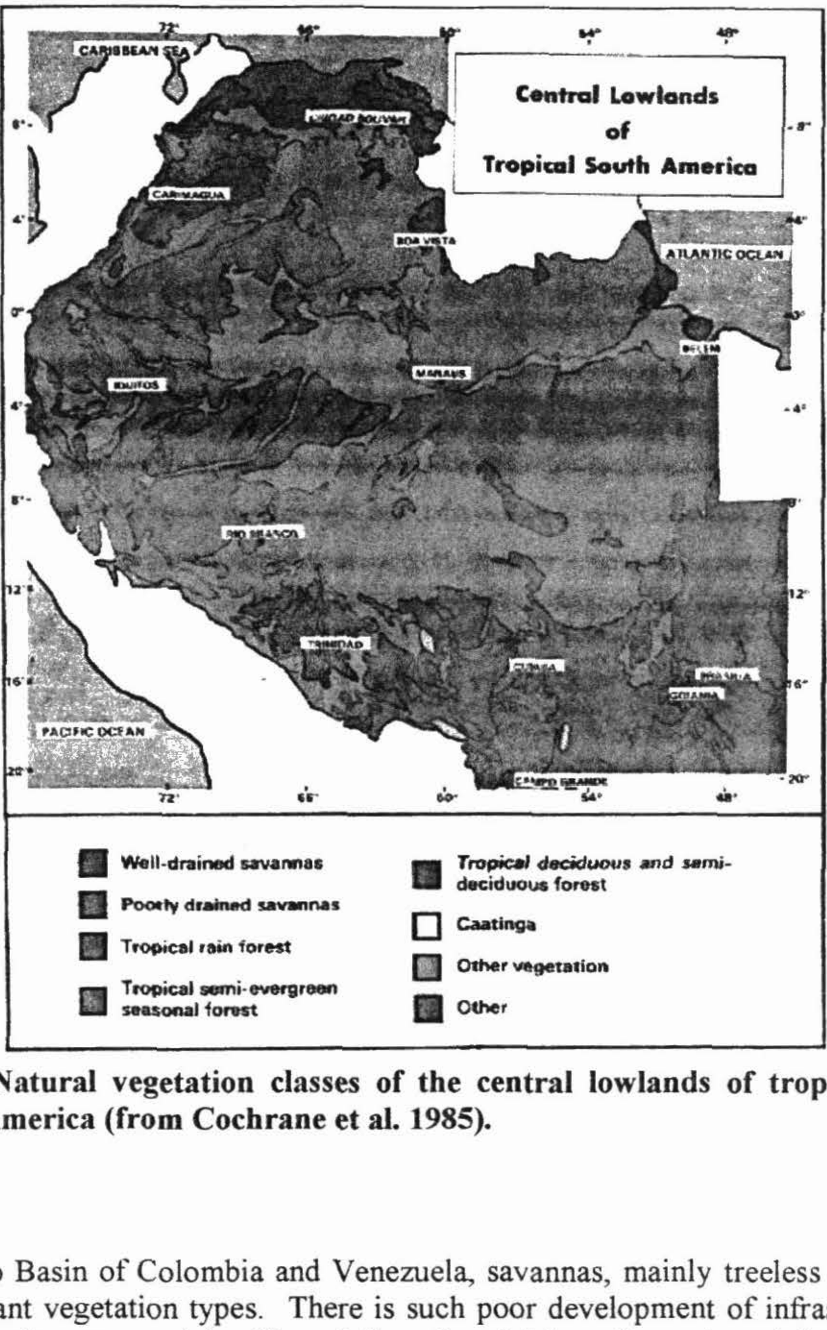

Figure 20. Natural vegetation classes of the central lowlands of tropical South America (from Cochrane et al. 1985).

In the Orinoco Basin of Colombia and Venezuela, savannas, mainly treeless grasslands, are the dominant vegetation types. There is such poor development of infrastructure in the Colombian the eastern plains (llanos) (less than 0.5 km of paved road for each 1000 km^2, Vera and Sere, 1985), coupled with severe security problems that there has been very little agricultural intensification in these lands. In contrast, the savannas of Venezuela have 50 km of paved road for each 1000 km^2, and much of the Venezuelan savannas have been converted to crops and pastures.

Table 27. Physiographic regions and their climatic subregions in the central lowlands of tropical South America (calculated from data for the 481 land systems described by Cochrane et al. 1985, Volume 3.)

Climatic subregions								
WSPE (mm)[1] No of wet months[2] WSMT (°C)[3]	>1300 >9 >23.5 a[4]	1061-1300 8-9 >23.5 b	900-1060 6-8 >23.5 c	900-1060 6-8 <23.5 d	<900 <6 >23.5 e	Sub-tropical f	Other o	Total
Physiographic regions	(km²)	(km²)	(km²)	(km²)	(km²)	(km²)	(km²)	(km²)
Amazon Basin	1,634,573	2,927,221	173,619	-	-	-	-	4,735,412
Brazilian Shield	-	9,768	1,319,603	329,528	692,668	75,604	-	2,427,171
Elbow of the Andes	11,830	32,018	2,288	-	16,169	-	-	62,305
Foothills	104,240	54,761	7,190	-	33,503	-	57,515	257,209
Guyana Shield	86,308	323,342	18,225	-	37,972	-	-	465,846
Mojos Pampas	-	84,919	45,522	-	-	-	-	130,441
Orinoco Basin	29,546	27,201	249,241	-	213,386	-	-	519,374
Pantanal	-	-	-	-	131,942	12,762	-	144,704
Paraná Basin	-	-	57,053	35,429	20,267	31,052	-	143,801
Total	1,866,497	3,459,229	1,872,740	364,957	1,145,907	119,418	57,515	8,886,263

[1] WSPE = Wet season potential evapotranspiration. [2] Number of wet months each year.
[3] WSMT = Wet season mean monthly temperature. [4] The lower-case letter is the climate subregion descriptor used as the second cipher of the land system name.

Table 28. Classification by topographic classes and terrain classes of lands described as savannas in the principal physiographic regions of the central lowlands of tropical South America (from Cochrane et al. 1985).

	Terrain[3]	Amazon Basin	Brazilian Shield	Orinoco Basin	Total
Well drained savannas		(km²)	(km²)	(km²)	(km²)
Lowland[1]	Flat	94,992	1,261,058	167,239	1,523,290
	Hilly		201,982	58,620	370,741
	Total	94,992	1,463,040	225,859	1,894,030
Upland[2]	Flat		57,561		57,561
	Hilly		41,827	9,468	51,295
	Total		99,388	9,468	108,856
Total	Flat	94,992	1,318,619	167,239	1,580,851
	Hilly		243,809	68,088	422,036
	Total	94,992	1,562,428	235,327	2,002,886
Poorly drained savannas					
Lowland	Flat	135,663	81,117	115,096	331,876
	Hilly			2,724	2,724
	Total	135,663	81,117	117,820	334,600
Total savannas					
	Flat	230,655	1,399,736	282,335	1,912,726
	Hilly		243,809	70,812	424,760
	Total	230,655	1,643,545	353,147	2,337,486

[1] Lowland, altitude <900m. [2] Upland, altitude >900m. [3] Terrain: flat, slopes <8%, hilly slopes >8%.

Cochrane et al. (1985) classified 1.7 million km^2 (Mkm^2) of the central lowlands as either isohyperthermic or isothermic savannas (Table 30). Note that subsequent estimates put the area as substantially in excess of this, 2.5 Mkm^2 (Macedo, 1995), because Cochrane et al. did not include the southern parts of Goias and Mato Grosso de Sul nor the northern part of Minas Gerias. Of Cochrane et al.'s 1.7 Mkm^2, 0.68 Mkm^2 were on flat (slope <8%), well-drained lands classified as having soil texture of loamy or heavier and no restriction to root growth in the soil profile (Table 30). It is these soils that are most likely to be similar to the soils in the Colombian llanos where Fisher et al (1994, 1995, 1998) showed accumulation of carbon in the soil under pastures of introduced African grasses (see below). Sandy soils and hilly lands (slopes 8 - 30 %) are included in Table 30, but they need to be treated with caution. Sandy soils are less likely to accumulate arge amount of carbon because of their inherent droughtiness. Although lands with slopes greater than 8% can be managed to avoid erosion, it seems prudent to exclude them and especially those with sandy soils until their sustainable use in commercial practice is more widespread.

Table 29. Classification by land and terrain classes of lands described as savannas in the Orinoco Basin physiographic region of the central lowlands of tropical South America (calculated from Cochrane et al., 1985). Savanna land system Ob639 of the Orinoco delta is excluded.

		Colombia	Venezuela			
		Llanos	Western[1]	Central	Eastern	Total
		(km^2)	(km^2)	(km^2)	(km^2)	(km^2
Well drained	Flat	58,230		57,991	51,018	109,009
	Hilly	47,855		2,619		2,619
	Total	106,085		60,610	51,018	111,628
Poorly drained	Flat	46,421	51,988			51,988
Total		152,506	51,988	60,610	51,018	163,616

[1] The well-drained llanos of western Venezuela were classified by Cochrane et al (1985) as forested lands

Table 30. Extent (10^3 km^2) of fertility capability classification (FCCC) texture classes within the savannas lands of the central lowlands of tropical South America (from Cochrane et al., 1985, Volume 1, Table 6-1).

FCC texture class	Isohyperthermic savanna					Isothermic savanna				
	Flat, poorly drained	Well drained (% slope)			Total	Flat, poorly drained	Well drained (% slope)			Total
		<8	8-30	>30			<8	8-30	>30	
Loamy	46	198	77	60	381	1	57	71	51	180
Loamy over clayey	140	52	14	9	215	6	3	3	2	14
Clayey	80	207	48	11	346	2	158	45	3	208
Sandy	14	152	18	1	185	-	8	3	6	17
Sandy over loamy	14	11	2	-	27	1	1	1	1	4
Loamy over rock	1	04	2	3	10	-	2	2	2	6
Loamy over sandy	1	18	8	3	30	-	-	3	1	4
Sandy over clayey	44	-	-	-	44	-	-	-	-	-
Clayey over rock	-	2	8	20	30	-	-	-	-	0
Clayey over loamy	5		-	-	5	-	-	-	-	0
Total	345	644	177	107	1273	10	229	128	66	433
Heavy textured[1]		457	139				218	119		
All without rock		638	167				227	126		

[1] Heavy textured soils with texture loamy or heavier and with no restriction to root growth at depth. Calculated only for soils on well-drained, flat lands (slope <8%), and for lands with intermediate slopes (8 – 30%).

Areas sown to pasture in the Cerrados of Brazil: Most of the pastures sown in the savannas of Brazil replace the former vegetation types known as *campo limpo*, which has no trees, and *campo sujo*, which has only a few stunted trees and shrubs. Both these occur on infertile, acid soils and together comprise about 24% of the Cerrados or about 500,000 km^2 (50 M ha) (Haridasan, 1992). It is on them that most of the introduced pastures are found largely because the economics of cattle production on pasture cannot support the high costs of mechanical clearing the wooded *campo cerrado* and *cerradão* communities. The area sown to pastures in the Brazilian Cerrados are given in Table 31.

Areas sown to pastures in Amazonia: Using satellite imagery, the Brazilian national space agency, Instituto Nacional de Pesquisa Espaciais INPE, has released figures showing the areas deforested by state in the Legal Amazon from 1978 to 1996 (Tables 32 and 33). Note that the Legal Amazon as defined by the Brazilian government is not the same as the physiographical Amazon Basin of Cochrane et al. (1985), but includes parts of lands that belong to other physiographic regions, most notably parts of the Brazilian Shield. Of the total of 517,000 km^2 deforested to August 1996, 85.7% is in the four states Maranhão, Mato Grosso, Pará and Rondônia, with over 57% in Mato Grosso and Pará. It is also noteworthy that the majority of the deforestation is in the vegetation class classified by Cochrane et al. (1985) as tropical semi-evergreen seasonal forest and not in the tropical rain forest. In Mato Grosso, much of the deforestation in is the vegetation class known as *campo cerradão*, which forms part of the Cerrados of the Brazilian Shield. Although the Cerrados are broadly considered as savannas, the *campo cerradão* contains little or no grass stratum. For this reason it is not strictly a savanna community but forest.

Table 31. Relative approximate distribution of the most commonly cultivated grasses in the Cerrados region of Brazil in 1995 (Zimmer et al., 1999).

Species	Distribution (10^3 km^2)[1]	Relative distribution (%)
Brachiaria decumbens	264.0	55
B. brizantha	96.0	20
B. humidicola	43.2	9
B. ruziziensis, B. dictyoneura	4.8	1
Subtotal	408.0	85
Panicum maximum cv. Colonião comun	38.4	8
P. maximum cv. Tanzânia, Tobiatá, Vencedor	9.6	2
Subtotal	48.0	10
Other genera		
Andropogon, Hyparrhenia, Melinis, Cynodon	24.0	5
Total	480.0	100

[1] The multiplier for the figures of area in table 1 of Zimmer et al. (1999) is 10^3 ha, for a total area of sown pasture of only 48,000 ha. This figure conflicts with the text on page 247, where the total of sown pastures in the Cerrados is "between 45 and 50 million hectares". Other authors have reported figures between 35 and 50 million ha. 10^6 ha is used here, converted to km^2 for internal consistency.

Table 32. Gross area of deforestation (10^3 km^2) in the states of the Legal Amazon of Brazil, 1978-1996 (Source: Instituto Nacional de Pesquisa Espaciais INPE, Brazil, http://www.dpi.inpe.br/amazonia/).

State	Original forest area[1]	Jan-78	Apr-88	Aug-89	Aug-90	Aug-91	Aug-92	Aug-94	Aug-95	Aug-96
Acre	154	2.5	8.9	9.8	10.3	10.7	11.1	12.1	13.3	13.7
Amapá	132	0.2	0.8	1.0	1.3	1.7	1.7	1.7	1.8	1.8
Amazonas	1,561	1.7	19.7	21.7	22.2	23.2	24.0	24.7	26.6	27.4
Maranhão	155	63.9	90.8	92.3	93.4	94.1	95.2	96.0	97.8	99.3
Mato Grosso	585	20.0	71.5	79.6	83.6	86.5	91.2	103.6	112.2	119.1
Pará	1,218	56.4	131.5	139.3	144.2	148.0	151.8	160.4	169.0	176.1
Rondônia	224	4.2	30.0	31.8	33.5	34.6	36.9	42.1	46.2	48.6
Roraima	188	0.1	2.7	3.6	3.8	4.2	4.5	5.0	5.1	5.4
Tocatins	58	3.2	21.6	22.3	22.9	23.4	23.8	24.5	25.1	25.5
Legal Amazon	4,275	152.2	377.5	401.4	415.2	426.4	440.2	470.0	497.1	517.1

[1] Original forest area, from Serrão and Homma (1993)

Table 33. Rate of increase of deforeatation in the states of the Legal Amazon of Brazil, km^2 yr^{-1} (calculated from the data in Table 32.)

State	78/88[1]	88/89	89/90	90/91	91/92	92/94[2]	94/95	95/96	% of the total
Acre	620	540	550	380	400	482	1208	433	2.7
Amapá	60	130	250	410	36	-	9	-	0.3
Amazonas	1510	1180	520	980	799	370	2114	1023	5.3
Maranhão	2450	1420	1100	670	1135	372	1745	1061	19.2
Mato Grosso	5140	5960	4020	2840	4674	6220	10391	6543	23.0
Pará	6990	5750	4890	3780	3787	4284	7845	6135	34.1
Rondônia	2340	1430	1670	1110	2265	2595	4730	2432	9.4
Roraima	290	630	150	420	281	240	220	214	1.0
Tocatins	1650	730	580	440	409	333	797	320	4.9
Legal Amazon	21130	17860	13810	11130	14960	14896	29059	18161	

[1] Mean annual rate for the decade [2] Mean annual rate for the two years.

Of the 377,500 km^2 estimated to have been deforested in the Brazilian Legal Amazon in 1988 (Table 32), approximately 70,000 km^2, or 18.5% were estimated to have been converted to pastures (Serrão and Toledo, 1990). It is not known how reliable this estimate is, nor whether the proportion of pasture has remained constant, increased or decreased in the last decade. If the estimate is valid, and if, conservatively, it has remained constant since then, by 1996 the area converted to pasture was 95,900 km^2. INPE forecast that the rate of clearing would decline in 1997, perhaps as low as 11,000 km^2, but anecdotal reports indicate that far from decreasing the rate increased substantially once more.

Areas sown to pastures in the Orinoco savannas: There are few data for the area of the savannas of Venezuela that have been converted to *Brachiaria* pastures. Pizarro et al. (1996) reported that between 24,000 and 40,000 km^2 were sown to *Brachiaria* species in Venezuela, two-thirds to *B. decumbens*. In Colombia in 1992, only 1,600 km^2 were sown to *Brachiaria* species in the Puerto López - Puerto Gaitán region of the western part of the Colombian llanos (Pizarro et al., 1996).

Variations in soil C under natural vegetation: Cochrane et al. (1985) quote data for spatial variability of soil analytical data for 18 profiles for land facet No. 1 within land system Oc210 on which the CORPOICA-CIAT-Carimagua station is situated on the eastern plains of Colombia. Among the data are soil organic matter (SOM), reported to be calculated from soil organic carbon (SOC) multiplied by 1.7. The methodology used to determine SOC is not given. Nevertheless, mean SOM over the 18 samples for the A horizon is 3.78 with a standard deviation of 0.780. Measured values range from 1.7 to 5.3 percent. For the B horizon, the mean and standard deviation were1.12 and 0.368, with extremes of 0.5 and 2.1. In no case did the sample with the highest or lowest A horizon SOM have the corresponding highest or lowest B horizon SOM. The correlation coefficient between the two data sets was only 0.69. Extrapolation from mean figures, or from data for small areas is therefore subject to considerable uncertainty.

Carbon losses above ground: The amount of standing above-ground biomass in *campo limpo* and *campo sujo* are probably no more than 1-2 t ha^{-1} (Fisher et al., 1991), so that losses of above-ground C when introduced pastures replace the native grasslands are trivial. Indeed, because native savannas are commonly burned as frequently as annually, in contrast with introduced pastures, which are normally only burned by accident, above-ground C may actually increase when the lands are sown to introduced pastures (Long et al., 1992; Greenland, 1995).

In contrast, losses of C above-ground when forest lands of the Amazon are deforested are very large, although the reported data vary widely, and the amounts lost may not be as great as commonly thought. Cerri et al. (1994) quoted estimates of the above-ground biomass of the forest near Manaus ranging from 256 to 353 t ha^{-1} and from 248 t ha^{-1} at Tucurui to 300 t ha^{-1} in Paragominas. They used a mean value of 290 t ha^{-1}, although clearly this mean contains considerable uncertainty. The biomass estimates of Brown and Lugo (1992) of ">290Mg/ha" are consistent with this estimate. Assuming that biomass is 45% C they calculated the above-ground C as 130.5 t ha^{-1}. Of this they estimated that 13.2 t C ha^{-1} was removed as millable timber leaving 117 t C ha^{-1} as felled timber. They estimated that combustion efficiency (amount of C released to the atmosphere when the felled timber was burned) was between 20.0 and 27.6%, leading them to use a mean of 23.8% for a release of 27.9 t C ha^{-1} in the burn. They assumed that the C remaining in the unburned timber decayed over the subsequent 8 yr, releasing C to the atmosphere, apart from a small residue of 1.4 t ha^{-1}, presumably remaining as charcoal from the burning process. The net loss above ground over 8 yr was 115.6 t C ha^{-1}.

C accumulation in the soil under introduced pastures: Data from introduced pastures on land facet number 1 of land system Oc210 (Cochrane et al., 1985) on the eastern plains of Colombia show accumulation of C, much of it at depth in the soil greater than 20 cm (Fisher et al., 1994, 1998) (Tables 34 and 35). The data are for replicated experiments with plots 0.5 to 1 ha. They were grazed at normal stocking rates for introduced pastures. Recent data from a study of the characteristics of the casts of the large aneic earthworm *Martiodrilis caramaguensis* show that the casts account for the accumulation of 8.6 t C ha^{-1} yr^{-1}.

Other data, also for facet number 1 of land system Oc210, show accumulation of C in the soil under introduced pastures. A 17-yr-old pasture of *A. gayanus* subjected to severe mis-management (burning, over- and under-grazing) at least as bad as the worst farmers' fields, accumulated C at the rate of 3 t ha^{-1} yr^{-1} in the soil to a depth of 160 cm over this period. (Fisher et al., 1995). A 50 ha pasture of *B. humidicola*, sown in 1979 with modest amounts of fertilizer but which received no maintenance fertilizer, had by 1997 accumulated C in the soil at the rate 2.9 t ha^{-1} yr^{-1} (W. Trujillo, personal communication). This pasture was managed as a normal farm pasture for 15 yr. Recent unpublished data from a project in Brazil, Colombia and Venezuela, financed by the Department for International Development of the United Kingdom government show broadly similar accumulations.

Table 34. Yield, net gain of C and percentage of the net gain below the plow layer (20 cm) in introduced pastures compared with native savanna on two sites on the eastern plains of Colombia (data from Fisher et al., 1994).

Site	**Matazul Farm**				
Pasture	**Savanna**	***A. gayanus/S. capitata***		***B. dictyoneura/C. acutifolium***	
Depth	C	C	Increase	C	Increase
Cm	kg m^{-2}	kg m^{-2}	kg m^{-2}±SE	kg m^{-2}	kg m^{-2}±SE
0-20	6.4	7.1	0.7±0.20 **	6.5	0.1±0.15 ns
20-100	12.3	16.6	4.4±0.97 ***	15.0	2.7±0.88 **
Total	18.7	23.7	5.1±1.14 ***	21.5	2.8±1.06 *
% deeper than 20 cm			86.0		95.7
Site	Carimagua Research Station				
Pasture	Savanna	*B. humidicola alone*		*B. humidicola/A. pintoi*	
Depth	C	C	Increase	C	Increase
Cm	kg m^{-2}	kg m^{-2}	kg m^{-2}±SE	kg m^{-2}	kg m^{-2}±SE
0-20	7.0	7.6	0.6±0.43 ns	8.8	1.8±0.42 **
20-80	12.6	14.7	2.0±0.70 *	17.9	5.3±1.17 ***
Total	19.7	22.3	2.6±0.77 **	26.7	7.0±1.55 ***
% deeper than 20 cm			78.6		74.7

ns P>0.05, * P<0.05, ** P<0.01, *** P<0.001. SE = standard error of difference between the means (n=14 for Matazul Farm, n=12 for Carimagua).

Neill et al. (1998) measured soil C in a number of chronosequences following forest clearing for pasture in the Rhondônia state of Brazil. They confirmed that pastures are able to contribute to the carbon stocks of the soil (Figure 21). Indeed the C concentration in the surface 10 cm increased from about 1.6 kg m^{-2} under the forest to almost 2.7 kg m^{-2}. The net increase over the layer 0-30 cm was a little over 1.6 kg m^{-2}, equivalent to 16 t ha^{-1}. Obviously these amounts are almost an order of magnitude less than the carbon stocks of the original forest, but the point is that once the forest has been cleared, pastures can increase the amount of C in the soil.

Table 35. Details of the pastures in Table 34

Site	Matazul farm	Carimagua Research Station
Location	Eastern plains (Llanos), Puerto Lopez, Colombia.	Eastern plains (Llanos), 200 km ENE of Puerto Lopez, Colombia.
Latitude, longitude.	4° 9' N, 72° 39' W	4° 37' N, 71° 19' W
Altitude (m)	160	175
Mean annual rainfall (mm)	2,700	2,240
Soil	Oxisol	Oxisol
Texture	Clay loam	Clay loam
pH (1:1 water)	4.4	4.1
P (0-20cm), Bray II (ppm)	1.8	1.5
Land system/facet number (Cochrane et al., 1985)	Oc210/1	Oc210/1
Pasture details	1989. Cropped from savanna with upland rice undersown with either mixed *A.gayanus* cv Carimagua 1 and *S. capitata* cv Capica pasture or mixed *B.dictyoneura* cv Llanero and *C. acutifolium* cv. Vichada. 1989-93. Rotationally grazed with cattle at 2 head ha^{-1}.	1984. Sown to *B. humidicola* cv Humidícola from savanna, with the legume *Desmodium ovalifolium*, which failed. 1987. Resown to *B. humidicola* cv Humidícola alone or with *A. pintoi* cv Mani Forrajero. 1988-93. Rotationally grazed with cattle at 3 head ha^{-1}.
Date soil sampled	December, 1992.	April, 1993.

Cerri et al. (1994) estimated that well-managed pastures sown after forest lose C from the soil in the first few years, but that within 8 years C in the soil has returned to an equilibrium, very close to the original level. Although Cerri et al.'s (1994) estimates from central Amazonas and Neill et al.'s (1998) data from Rhondônia are consistent, they only considered C in the soil to 20 or to 30 cm respectivley. If dynamics of soil C under *Brachiaria* pastures in the forest ecosystem are similar to the data for the Colombian savannas summarized above, both Cerri et al.'s (1994) estimates and Neill et al.'s (1998) measurements could be substantially lower than the actual figures for the whole soil profile.

Mean elapsed time since conversion to introduced pasture: It is uncertain over what time scale any C accumulation in the soil under introduced pastures might have occurred. *B. decumbens* cv. Basilisk is well adapted to the infertile acid soils typical of much of the Cerrados region. Widespread conversion of the Cerrados to pastures was stimulated by its introduction from Australia in the early 1970's (Pizarro et al., 1996). It is not known the rate at which conversion occurred, but it seems likely that a broadly linear progression took place. In this case, a mean age of, say, 14 years would be a reasonable estimate.

The converted area of the Amazonian forest in Brazil grew from 152,000 km^2 in January 1978 to 517,000 km^2 in August, 1996, an increase of 364,000 km^2 in 18-1/2 yr (Tables 32 and 33). Although the rate of conversion fluctuated considerably from year to year

(Table 33), the mean rate is just under 20,000 km^2 yr^{-1}. If as discussed above, the proportion of the converted lands sown to pasture remained constant at the 18.5% estimated from Serrão and Toledo, (1990), the area of pasture in 1996 would be 95,900 km^2. Conservatively ignoring lands sown to pasture prior to 1978, we can estimate the pastures as having a mean age of about 9 years.

There are no data for either Colombia or Venezuela of the rate of conversion to enable an estimate of mean pasture age, but since the technology was largely imported from Brazil, it seems reasonable to allow a decade to pass before conversion started, or a mean age of 9 years.

Pasture degradation Since the source of any C that accumulates in the soil must be net primary productivity (NPP), anything that constrains NPP will inevitably reduce C accumulation. Pasture degradation is one such constraint, although there are few definitive data that document exactly what a degraded pasture is, nor is there a clear consensus what causes degradation (Miles et al., 1996). Compared with productive pastures, degraded pastures sustain lower stocking rate and liveweight gain per animal falls so that liveweight production per unit area is drastically reduced (Kluthcouski et al., 1999). As a pasture degrades, individual plants die so that the sward opens up to bare soil, which either remains without plant cover or is invaded by herbaceous and woody weeds. Termite mounds become prominent and are often used as a simple indicator of failing pasture health (Boddey et al., 1996).

Pastures are thought to degrade due to one or more of N deficiency, P deficiency, over grazing, insect attack (mainly spittlebug, Homoptera:Cercopidae, Valério et al., 1996) and trampling leading to soil compaction. Although there are examples of pure grass pastures 15 to 20 yr old that are not degraded, there is no universal recipe for their success (Fisher and Kerridge, 1996). Nor is there an unequivocally successful treatment to recuperate degraded pastures apart from some form of mechanical intervention, such as the Barrerão System (Kluthcouski et al., 1999) or some other form of integrated crop-pasture system (Sanz et al., 1999; Valencia et al., 1999; Zimmer et al., 1999).

There are no data that show what form the decline in productivity takes, but for the purposes of general representation we may use a declining ramp function (Figure 22). While this model is undoubtedly simplistic, its use may be justified on the grounds that it is probably conservative and it permits the calculation of a mean 'rate of C accumulation' with minimum information, which is the current situation. The underlying assumption in the model is that a measure such as stocking rate is a reasonable indicator of NPP, although other measures such as annual liveweight gain per ha may be more sensitive indicators of degradation.

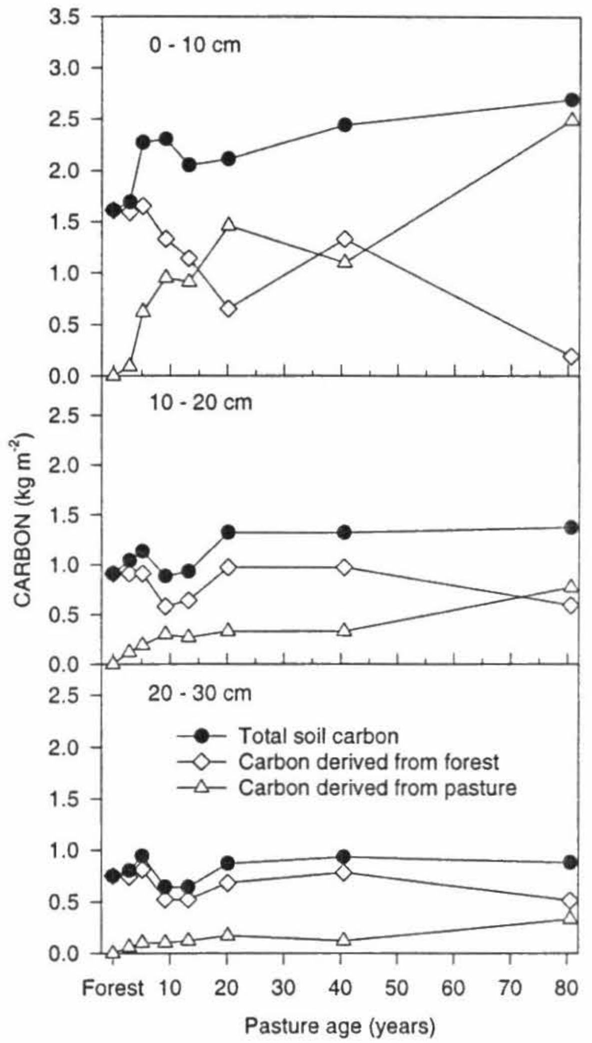

Figure 21. **Changes in total soil C, in C derived from the original forest vegetation and in C derived from the sown pasture after felling of the forest. The data are from a chronosequence on the Fazenda Nova Vida, Rhondônia, Brazil (Neill et al., 1997).**

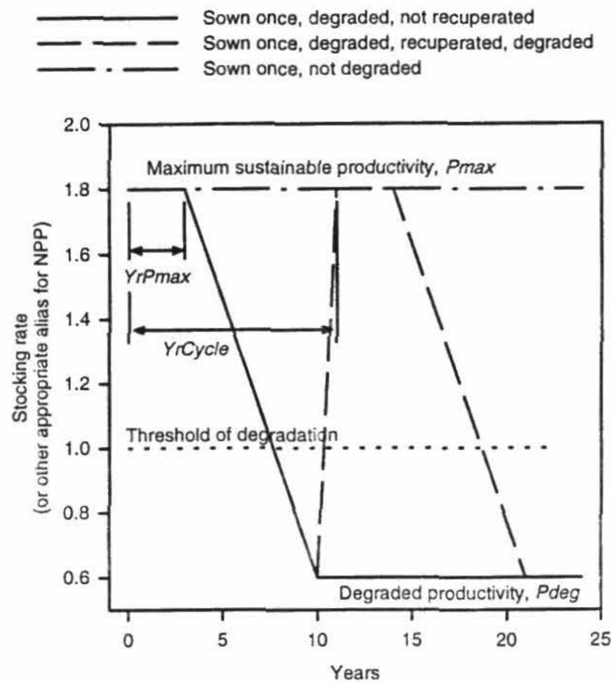

Figure 22. Conceptual model of the degradation process in pastures in terms of stocking rate.

Three parameters describe the degradation relationship, maximum sustainable productivity (*Pmax*, with units of hd ha^{-1}), degraded productivity (*Pdeg*, also hd ha^{-1}) and rate of degradation (*Rdeg*, the slope of the line linking *Pmax* and *Pdeg*, with units of hd ha^{-1} yr^{-1}). The time in yr (*Tdeg*) for a pasture to reach *Pdeg* is given by

$$Tdeg = (Pmax - Pdeg) / Rdeg.$$

Two further parameters give a complete description of a pasture, the duration of the *Pmax* phase (*YrPmax*, with units of yr) and the cycle length between successive renovations (*YrCycle*, also yr). It is assumed that the productivity of a renovated pasture returns to *Pmax*. If these few parameters are known, we can readily calculate a mean degradation index (*Ideg*), which is the weighted mean range of productivity over any renovation cycle compared with the difference between *Pmax* and *Pdeg*.

Because pastures of different species have different nutritional characteristics, the parameters of the functional relationship for stocking rate and especially for liveweight gain, will almost certainly be species specific. There will probably be a considerable amount of site specificity as well. However, we are attempting to use some alias for NPP, itself an alias for C accumulation in the soil, but none of these relations have yet been established. Given these uncertainties, it may be possible to apply a set of parameters to one group of lands with the same generalized classification within one particular climate subregion. The extent to which this is possible in practice is a clear area for research.

We calculated the influence of an arbitrary selection of scenarios for pasture degradation on the degradation index compared with a well-managed pasture, that is a pasture that does not degrade (Table 36). The main feature is that pastures that are recuperated not long after they have reached complete degradation (the 8-yr and 12-yr scenarios) probably accumulate as much as 50% the C in the soil compared with well-managed pastures. It requires quite draconian mismanagement of rapid degradation and long-delayed renovation for the amount of soil C accumulated to fall below 30% of a well-managed pasture.

Table 36. The influence of a range of arbitrarily-chosen scenarios on the degradation index, described in the text above, compared with well-managed pasture.

Description	Symbol	Units	Scenario				
			WM[1]	8 yr	12 yr	15 yr	20 yr
Maximum sustainable productivity	*Pmax*	hd ha^{-1}	1.8	1.8	1.8	1.8	1.8
Degraded productivity	*Pdeg*	hd ha^{-1}	0.6	0.6	0.6	0.6	0.6
Rate of degradation	*Rdeg*	hd ha^{-1} yr^{-1}	na	0.2	0.15	0.25	0.25
Time to degrade	*Tdeg*	yr	na	6	8	4	4
Time at maximum productivity	*YrPmax*	yr	X	1	2	2	2
Time between renovation events	*YrCycle*	yr	X	8	12	15	20
Accumulated production:							
During maximum productivity	Maximum	hd ha^{-1} yr	1.8*X	1.8	3.6	3.6	3.6
While degrading	Degrading	hd ha^{-1} yr	0	7.2	9.6	4.8	4.8
When completely degraded	Degraded	hd ha^{-1} yr	0	0.6	1.2	5.4	8.4
Weighted mean productivity	*AvProd*	hd ha^{-1}	1.8	1.2	1.2	0.92	0.84
Degradation index	*Idag*	%	100.0	50.0	50.0	26.7	20.0

[1] WM, well-managed pasture.

Fifty percent of the grass pastures of the Cerrados are said to show some degradation (Macedo, 1995). Kluthcouski et al. (1999) put the amount of pastures degraded or in the process of degradation as high as 80%. Pastures are reported to be vigorous and productive their first years, but to decline drastically in productivity after 4 to 10 years of use (Lopez et al., 1999). However, Gomide (1999) reported that the area of degraded pastures recuperated with the Barreirão System in 1993/94 was 4,000 km^2, or a little under 10% of the area sown to introduced pasture *in just one year*. This confirms that there are substantial areas recuperated, else, based on the scenarios in Table 36, the percentage of degrading and degraded pastures would be higher than even Kuthcouski et al.'s (1999) estimate.

Conclusions:

There are a number of data for well-managed pastures of introduced grasses of African origin that show accumulation of C in the soil at rates close to 3 t ha^{-1} yr^{-1}. Even mismanaged *A. gayanus* accumulated C in the soil at this same rate. These data can be extrapolated to the 1,600 km^2 sown to *Brachiaria* species in the Puerto López - Puerto Gaitán region of the western part of the Colombian llanos with some confidence. However, it is unclear the extent to which they might be extrapolated either to the 408,000 km^2 of *Brachiaria* pastures in the Brazilian Cerrados or with greater uncertainty to the 100,000 km^2 of pastures in the Amazon, largely *Brachiaria* spp.

All the data come from land facet number 1 of land system Oc210 (Cochrane et al., 1985), described as well drained, flat, lowland savannas in climate subregion 'c'. Climate subregion 'c', the third data column of Table 27, has wet season potential evapotrans-piration 900-1060 mm, 6-8 months growing season and wet season mean temperature >23.5°C. Reference to Table 1 will show that of a total of 2.43 million km^2 (Mkm^2) in the Brazilian Shield physiographic region, 1.32 Mkm^2 or 54% have the same climate descriptor. Well-drained, flat lowland savannas on the Brazilian Shield occupy 1.26 Mkm^2 or 52% of the total area. It is not possible to say with certainty that the 0.41 Mkm^2 of *Brachiaria* pastures in the Cerrados all lie in climate subregion 'c', or are on lands that are well drained, flat lowland savannas, but on balance it is likely that most of them do. Because of this, while extrapolation to them is not without risk, it does not seem unduly heroic.

Most of the lands converted from forest in Amazonia are in the tropical semi-evergreen seasonal forest and semi-deciduous seasonal forest vegetation classes (Figure 20) in eastern, central and southwestern Amazonia. These areas lie mainly in climate subregion 'b' (Table 28), which has a wetter and longer growing season than subregion 'c', in which the data of C accumulation in the soil under introduced pastures were measured. It does not seem unreasonable to suggest that the net primary productivity (NPP) of well-managed introduced pastures in subregion 'b' should be higher than the NPP of similar pastures in the drier subregion 'c' with a shorter growing season. Since the source of any C that accumulates in the soil must be NPP, it is conservative to assume that subregion 'b' accumulates C in the soil at the same rate as in the drier subregion 'c'.

We can now summarize the main areas converted to pastures in the central lowlands of tropical South America and their possible accumulation in the soil (Tables 37 and 38). The data indicate that the lands sown to pastures in the savannas are strong sinks for C, potentially accumulating as much as 1800 million t (Mt) C. Even discounting this by 50% to account for pasture degradation still gives an accumulation of 900 Mt C. In contrast to use-conversion in the savannas, the forest areas sown to pasture, which account for less than 20% of the total forest area converted, have been a powerful source of atmospheric C, as much as 980 Mt assuming a 50% discount for degradation. At the level of 50% discount for degradation in both the forest and the savannas converted to pasture, the net scenario is a source of about 80 Mt C.

Table 37. Estimates of possible C accumulation in soils under pastures in the central lowlands of tropical South America without considering degradation.

	Total area (see Tables 2 and 3)	Area of *Brachiaria* pasture	Mean time since conversion	Area yr	Degradation discount	Potential accumulation [2]
Savannas	(10^3 km^2)	(10^3 km^2)	(yr)	(10^3 km^2 yr)	(%)	(10^6 t C)
Brazilian Shield	1,261.1	408.0	14	5712	0	1713
Orinoco Basin	167.2					
Colombia	58.2	1.6	9	14	0	4
Venezuela	109.0	24.0 - 40.0	9	288	0	86
	Total cleared area	Area of *Brachiaria* pasture			Amount	
Forest	10^3 km^2	10^3 km^2	Yr	10^3 km^2 yr	t ha^{-1}	10^6 t C
Clearing losses		95.9		96	115.6	-1109
Pasture gains		95.9	9	863	0%	259
Balance						-850

[1] Flat (slopes <8%), well-drained, lowland savannas.
[2] Assuming a mean rate of C accumulation in the soil of 3 t ha^{-1} yr^{-1}.

Table 38. Estimates of possible C accumulation in soils under pastures in the central lowlands of tropical South America allowing 50% discount due to degradation.

	Total area (see Tables 2 and 3)	Area of *Brachiaria* pasture	Mean time since conversion	Area yr	Degradation discount	Potential accumulation [2]
Savannas	(10^3 km^2)	(10^3 km^2)	(yr)	(10^3 km^2 yr)	(%)	(10^6 t C)
Brazilian Shield	1,261.1	408.0	14	5712	50	857
Orinoco Basin	167.2					
Colombia	58.2	1.6	9	14	50	2
Venezuela	109.0	24.0 - 40.0	9	288	50	43
	Total cleared area	Area of *Brachiaria* pasture			Amount	
Forest	(10^3 km^2)	(10^3 km^2)	(yr)	(10^3 km^2 yr)	(t ha^{-1}	(10^6 t C)
Clearing losses		95.9		96	115.6	-1109
Pasture gains		95.9	9	863	50%	130
Balance						-979

[1] Flat (slopes <8%), well-drained, lowland savannas
[2] Assuming a mean rate of C accumulation in the soil of 3 t ha^{-1} yr^{-1}.

Of course there are uncertainties in these figures, which we have been at pains to identify in the foregoing text. In all cases we have tried to make our estimates conservative. Clearly there are pressing needs for better data as well as further research to enable more confident estimates. We have attempted to identify these needs below.

Research and data needs:

- There is a need to extend Cochrane et al.'s (1985) land system classification to include the whole of the Brazilian Cerrados.
- There are a number of errors in the land system and land facet descriptions of Cochrane et al. (1985) that require at least the publication of an erratum document.
- The distribution of pastures by land system, preferably including pasture species and some estimate of pasture condition would enable extrapolation from point sources of data to broader areas with greater confidence.
- Could well-designed rural censuses provide some improvement?
- Can the latest remote sensing technologies provide these data? For example, can pastures be identified compared with crops? If so, can pastures be identified by species? Then by level of productivity?
- If the area of sown pasture can by established, can data of animal turnoff by municipality be sufficiently sensitive to act as a proxy for NPP and hence C accumulation in the soil?
- What are the characteristics of degradation in more precise terms than are currently available? What is the form of functional relations of pasture degradation in terms of NPP? Animal performance? Stocking rate?
- To what extent and with what degree of certainty can land systems with similar general descriptions within the same climatic subregion be treated as the same for the purposes of extrapolation?

References:

Boddey, R.M., B.J.R. Alves and S. Urquiaga (1996). Nitrogen cycling and sustainability of improved pastures in the Brazilian Cerrados. In: *8o. Simposio sobre o Cerrado. 1st International Symposium on tropical Savannas.* (R.C. Pereira and L.C. Nasser, eds.). EMBRAPA-CPAC, Brasilia, D.F. Pp33-38.

Brown, S. and A.E. Lugo (1992). Above-ground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia* **17**:8-18.

Cerri, C.C., M. Bernoux and G.J. Blair (1994). Carbon pools and fluxes in Brazilian natural and agricultural systems and the implications for the global CO2 balance. Transactions of the 15th World Congress of Soil Science, Acapulco, Mexico, 10-16 July, 1994. Volume 5a. Pp. 309-406.

Cochrane,T.T, L.G. Sánchez, L.G. de Azevedo, J.A. Porras and C.L. Carver (1985). *Land in Tropical America.* Centro Internacional de Agricultura Tropical, Cali, Colombia and Empresa Brasilera de Pesquisa Agropcuária, Centro de Pesquisa Agropecuária dos Cerrados, Planaltina, Brazil. Three volumes.

Fisher, M.J., C.E. Lascano, R.R. Vera and G. Rippstein (1992). Integrating the native savanna resource with improved pastures. In: *Pastures for the Tropical Lowlands: CIAT's contribution.* CIAT, Cali, Colombia, pp. 75-99.

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

Fisher, M.J., I.M. Rao, C.E. Lascano, J.I. Sanz, R.J. Thomas, R.R. Vera, and M.A. Ayarza (1995). Pasture soils as carbon sink. *Nature (Lond.)* **376:** 472-473.

Fisher, M.J. and P.C. Kerridge (1996). The agronomy and physiology of *Brachiaria* species. In: Brachiaria*: Biology, Agronomy, and Improvement.* (J.W. Miles, B.L. Maass and C.B. do Valle. Eds.). Centro Internacional de Agricultura Tropical, Cali, Colombia and Empresa Brasileira de Pesquisa Agropecuária/Centro Nacionalde Pesquisa de Gado de Corte, Campo Grande, Brazil. Pp. 43-52.

Fisher, M.J., R.J. Thomas and I.M. Rao (1998). Management of tropical pastures in acid-soil savannas of South America for carbon sequestration in the soil. In: *Management of Carbon Sequestration in Soil.* (R. Lal, J.M. Kimble, R.F. Follett and B.A. Stewart, eds.). *Advances in Soil Science Series.* CRC Press, Boca Raton, Florida. Pp. 405-420.

Gomide, J.de C. (1999). Transferencia de tecnolgía: el caso del Sistema Barreirão en Goiás, Brasil. In: *Sistemas Agropastoriles en Sabanas Tropicales de América Latina.* (E.P. Guimarães, J.I. Sanz, I.M. Rao, M.C. Amézquita, and E. Amézquita, eds.). CIAT, Cali, Colombia and EMBRAPA, Brasilia, Brazil. Pp. 107-114.

Greenland D.J. 1995. Land use and soil carbon in different agroecological zones. In: *Soil management and greenhouse effect.* (R. Lal, J. Kimble, E. Levine and B.A. Stewart, eds.). *Advances in Soil Science Series.* CRC Press, Boca Raton, Florida. Pp. 9-24.

Haridasan, M. (1992). In: *Nature and Dynamics of Forest-Savanna Boundaries* (P.A. Furley, J. Proctor and J. Ratter, eds.). Chapman and Hall, London. Pp. 171-184.

Kluthcouski, J., I.P. de Oliviera, L.P. Yokoyama, L.G. Dutra, T.de A. Portes, A.E. da Silva, B.da S. Pinheiro, E. Ferreira, E.da M. de Castro, C.M. Guimarães, J.de C. Gomide and L.C. Balbino (1999). Sistema Barreirão: recuperación/renovación de pasturas degradas utilizando cultivos anuales. In: *Sistemas Agropastoriles en Sabanas Tropicales de América Latina.* (E.P. Guimarães, J.I. Sanz, I.M. Rao, M.C. Amézquita, and E. Amézquita, eds.). CIAT, Cali, Colombia and EMBRAPA, Brasilia, Brazil. Pp. 195-231.

Long S.P., M.B. Jones, and M.J. Roberts. 1992. *Primary Productivity of Grass Ecosystems of the Tropics and Sub-tropics.* Chapman and Hall, New York.

Macedo, J. (1995). *Prospectives for the Rational Use of the Brazilian Cerrados for Food Production.* EMBRAPA/CPAC, Brasilia.

Miles, J.W., B.L. Maass and C.B. do Valle (1996). Report of working groups. In: Brachiaria*: Biology, Agronomy, and Improvement.* (J.W. Miles, B.L. Maass and C.B. do Valle. Eds.). Centro Internacional de Agricultura Tropical, Cali, Colombia and Empresa Brasileira de Pesquisa Agropecuária/Centro Nacionalde Pesquisa de Gado de Corte, Campo Grande, Brazil. Pp. 272-277.

Neill, C., C. Cerri, J.M. Melillo, B.J. Feigl, P.A. Steudler, J.F.L. Moraes, and M.C. Piccolo (1998). Stocks and dynamics of soil carbon following deforestation for pasture in Rondonia. In: *Soil Processes and the Carbon Cycle.* (R. Lal, J.M. Kimble, R.F. Follett and B.A. Stewart, eds.). *Advances in Soil Science Series.* CRC Press, Boca Raton, Florida. Pp. 9-28.

Pizarro, E.A., C.B. do Valle, G. Keller-Grein, R. Schultze-Kraft and A.H. Zimmer (1996). Regional experience with *Brachiaria*: tropical America - savannas. . In: Brachiaria*: Biology, Agronomy, and Improvement.* (J.W. Miles, B.L. Maass and C.B. do Valle. Eds.). Centro Internacional de Agricultura Tropical, Cali, Colombia and Empresa Brasileira de Pesquisa Agropecuária/Centro Nacionalde Pesquisa de Gado de Corte, Campo Grande, Brazil. Pp. 225-246.

Sanz, J.I., R.S. Zeigler, S. Sarkarung, D.L. Molina and M. Rivera (1999). Sistemas mejoradas arroz-pasturas para sabana nativa y pasturas degradadas en suelos acidos de América Sur. In: *Sistemas Agropastoriles en Sabanas Tropicales de América Latina.* (E.P. Guimarães, J.I. Sanz, I.M. Rao, M.C. Amézquita, and E. Amézquita, eds.). CIAT, Cali, Colombia and EMBRAPA, Brasilia, Brazil. Pp. 232-244.

Serrão, E.A.S. and A.K.O. Homma (1993). Brazil. In: *Sustainable Agriculture and the Environment in the Humid Tropics.* National Research Council, National Academy Press, Washington DC. Pp. 265-351.

Valencia R., R.Q., C.R. Salamanca, G.E. Navas R., J.E. Baquero P., A. Rincón and H. Delgado (1999). Evaluación de sistemas agropastoriles en la altillanura de la Orinoquia Colombiana. In: *Sistemas Agropastoriles en Sabanas Tropicales de América Latina.* (E.P. Guimarães, J.I. Sanz, I.M. Rao, M.C. Amézquita, and E. Amézquita, eds.). CIAT, Cali, Colombia and EMBRAPA, Brasilia, Brazil. Pp. 284-300.

Valério, J.R., S.L. Lapointe, S. Kelemu, C.D. Fernandes and F.J. Morales (1996). Pests and diseases of *Brachiaria* species. In: Brachiaria*: Biology, Agronomy, and Improvement.* (J.W. Miles, B.L. Maass and C.B. do Valle. Eds.). Centro Internacional de Agricultura Tropical, Cali, Colombia and Empresa Brasileira de Pesquisa Agropecuária/Centro Nacionalde Pesquisa de Gado de Corte, Campo Grande, Brazil. Pp. 87-105.

Vera,R. and C. Sere (1985). Los sistemas de producción pecuaria extensiva del trópico sudamericano; análisis comparativo. In: *Sistmeas de Producción Pecuaria Extensiva, Brasil, Colombia y Venezuela* (R. Vera and C. Sere, eds.). (Proyecto ETES, TUB, GTZ y CIAT). Centro Internacional de Agricultura Tropical, Cali, Colombia. Pp431-439.

Zimmer, A.H., M.C.M. Macedo, A.N. Kichel, and V.P.B. Euclides. (1999). Sistemas integrados de producción agropastoril. In: *Sistemas Agropastoriles en Sabanas Tropicales de América Latina.* (E.P. Guimarães, J.I. Sanz, I.M. Rao, M.C. Amézquita, and E. Amézquita, eds.). CIAT, Cali, Colombia and EMBRAPA, Brasilia, Brazil. Pp. 245-283.

Contributors:
Myles J. Fisher and Richard J. Thomas

Activity 2.5 Characterize soil biodiversity and develop strategies to manage beneficial soil biological processes

2.5.1 Carbon and nitrogen dynamics in in-situ ageing earthworm casts in grasslands of the Eastern Plains of Colombia.

Highlight:

- Showed that soil in earthworm casts are enriched in carbon by 1.5 to 1.9 times that of the surrounding bulk soil and are enriched in nitrogen by 1.4 to 1.6 times. Carbon contents of casts increased significantly over time resulting in a build up of active but physically protected C pools. When total casting activity per ha is taken into account we estimate that up to 8.6 tons C/ha/yr may accumulate in casts on improved grass/legume pastures compared with 0.6 t C/ha/yr on native savanna.

Purpose:
To describe short- and long-term dynamics of carbon and nitrogen in earthworm casts and in the surrounding surface soil.

Rationale:
Tropical savannas represent 43% of the overall plains of Latin America, and cover an area of 243 million hectares. They are traditionally used for extensive cattle ranching of low productivity. The expanse of land used for intensive agricultural production, however, has been increasing during the past 20 years. Common agroecosystems range from pure grass or grass/legume improved pastures, to high input annual crops. Such an evolution involves a high economic cost, but environmental impacts are little known.

Large invertebrate species, mostly earthworms, termites and ants, have been defined as "ecosystem engineers". In the humid tropics, where neither climatic conditions nor clay minerals can efficiently regulate mineralisation, regulation of soil processes operated by these organisms may become predominant. Ecosystem engineers actively regulate the activity of soil microorganisms in the organo-mineral structures that they produce (e.g. earthworm casts, termite mounds or ant nests) and therefore have important effects on soil aggregation and the regulation of organic matter dynamics.

Earthworm effects on soil organic matter dynamics vary with the space and time scale considered. On a short time scale, microbial activity is enhanced in the earthworm digestive tract, leading to an increased mineralization of organic matter and an important release of assimilable nutrients in fresh casts. On a larger time scale, ageing casts protect organic matter from further mineralisation processes as long as they retain their physical properties. Finally, earthworms seem to generally promote a rapid turnover of organic matter in the soil profile. More information however is still needed, since very few tropical species (mostly peregrine endogeic species) have been intensively studied so far in relation to soil processes.

The aim of the present study was to describe short- and long-term dynamics of carbon and nitrogen in earthworm casts and in the surrounding surface soil. Special attention was given to *in-situ* effects of *Martiodrilus carimaguensis* Jiménez and Moreno (Oligochaeta, Megascolecidae), which is the dominant surface casting earthworm present at the study site. Experiments were conducted in a native tropical savanna and an improved pasture derived from savanna. Root biomass was measured to assess plant response to cast deposition.

Materials and methods:
The study was carried out at the CIAT-CORPOICA research station of Carimagua (4°37' N, 71°19'W), located in the phytogeographic unit of the well-drained isohyperthermic savannas of the Eastern Plains of Colombia. The climate is subhumid tropical with an annual mean temperature and rainfall of 26°C and 2300 mm respectively, and a pronounced dry season from November to March. Native vegetation is determined by

topography: open savannas in the uplands ("altos" and "planos"), and gallery forests or flooding savannas in the low-lying areas ("bajos"). Soils are Oxisols (Tropeptic Haplustox Isohyperthermic) in the uplands and Ultisols (Ultic Aeric Plintaquox) in the low-lying areas. Both are characterized by favorable physical properties (aggregation, porosity, water retention), high acidity (pH (H_2O) < 5) and very low chemical fertility (Al saturation > 80%, CEC < 5 meq. $100g^{-1}$).

The experiment was carried out in two different management systems on a well drained upland Oxisol:

(1) A *Trachypogon vestitus* native savanna, protected from grazing for four years and managed traditionally by burning every year during the dry season.

(2) A 3 year-old pasture of *Brachiaria humidicola*, *Arachis pintoi*, *Stylosanthes capitata* and *Centrosema acutifolium*, grazed by cattle with an average stocking rate of 2.0 animals units. ha^{-1}.

Among the 11 species recorded at the study site, *Martiodrilus carimaguensis* Jiménez and Moreno was chosen because it is the only one that has a significant casting activity at the soil surface. In addition, it adapts very well to some agroecosystems, and therefore can be considered as a potential species for the management of soil fertility via earthworms.

Casts of *M. carimaguensis* were marked in the field at the beginning of the rainy season (May 1996), during the peak of earthworm activity. In both systems, 80 casts were marked using small metal plates, left *in-situ* and divided in 4 groups of 20 contiguous casts. During this operation, special attention was paid to choose casts in early process of deposition, i.e. fresh and small feces. That is, we ensure the presence of earthworms in each of the marked galleries, while avoiding any cumulative effects that might have resulted from their prolonged presence before the beginning of the experiment. In the pasture, each group of casts was protected from animal trampling by a 2 x 2 meters metallic cage.

Casts and soil were sampled 0, 7, 14 days and 1, 2, 3.5, 5, 6.5, 8, 9.5, 11 months respectively after deposition of the cast. At each date, a sample was randomly taken from each group of 20 casts. Each sample consisted of three subsamples: (i) the cast, (ii) the underlying soil (located directly below the cast) and (iii) the adjacent soil (located 20 cm apart from the cast) (Fig. 23). The soil was sampled using a 5 cm diameter and 5 cm deep aluminum cylinder and kept at 4°C.

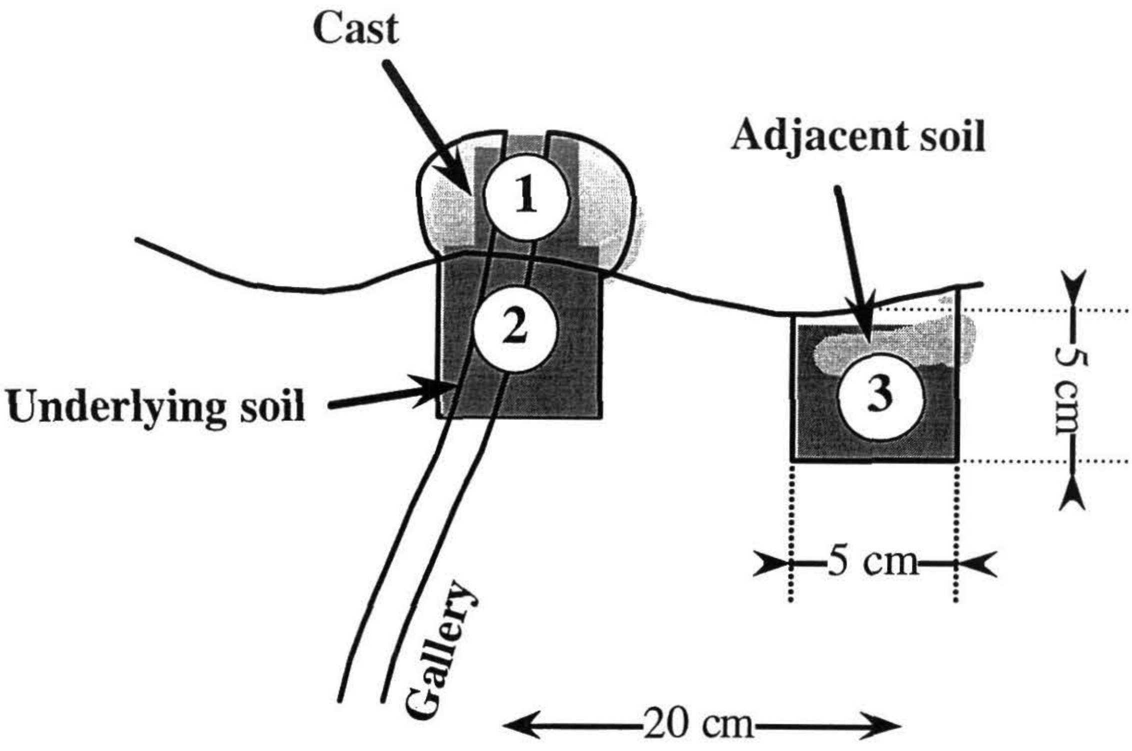

Figure 23. Description of the sampling procedure. Each sample is divided in three subsamples: (1) the cast, (2) the underlying soil and (3) the adjacent soil.

Chemical analysis of C and N were performed at CIAT). Beforehand, four grams of each fresh sample had been shaken for 30 minutes with 40 ml of a KCl 1M solution. The suspensions were filtered and the filtrates kept at -15°C before analysis. Colorimetric methods were used to determine ammonium and nitrates concentrations.

Total carbon and nitrogen were analyzed on subsamples previously sieved at 2 mm. We used a colorimetric method after acid digestion to measure total C and the standard Kjeldahl digestion to measure total N contents.

Roots were sampled in soil located in an area free of casts, below fresh casts and below dry casts respectively. For each location, 8 samples were taken using a 10 cm diameter and 10 cm deep aluminium cylinder. The soil was washed and sieved though a 0.053 mm sieve. Living roots were manually separated from dead roots and organic matter fragments, and oven-dried at 75 °C during 48 h.

Roots and macrofauna were sampled in casts simultaneously with soil organic matter coarse fraction. Living roots and macroinvertebrates where collected from the 0.250 mm sieve after washing and sieving of the cast samples. Invertebrates were killed in 70% alcohol. Roots and invertebrates were dried at 75 °C during 48 h and weight.

Data were transformed before analysis to reduce the asymmetry of the frequency distribution. The normalization of data were obtained using the Box-Cox transformation which is: $y = (x^{\delta} - 1)/\delta$. The δ parameters were estimated using the program VerNorm 3.0 from the "R package.

Three-way analyses of variance (ANOVA) were performed with system, sample origin (i.e., casts, underlying soil and adjacent soil) and cast ageing as the fixed main effects. These analyses were performed for NH_4^+, NO_3^- and inorganic N concentrations (in µg. g of dry soil^{-1}), total C and N concentration (in % of dry soil), C:N ratio and moisture contents (%). Seven analyses were performed and each analysis involved seven tests (three main effects and four interaction). The Bonferroni procedure for nested tests was used to ensure against statistical error: the adjusted 0.05, 0.01 and 0.001 significant levels were 0.001 [= 0.05 / (7 x 7)], 0.0002 [= 0.01 / (7 x 7)] and 0.00002 [= 0.001 / (7 x 7)] respectively.

Two-way analyses of variance were performed for the root and macroinvertebrate biomass in casts (in g of dry matter. g dry cast^{-1}). The fixed main effects were system and cast ageing. The Bonferroni procedure for nested tests was used and the adjusted 0.05, 0.01 and 0.001 significant levels were 0.0125 [= 0.05 / (2 x 2)], 0.003 [= 0.01 / (2 x 2)] and 0.0003 [= 0.001 / (2 x 3)]. Additional comparisons of average data values were performed by using a t-test.

Results and Discussion:

Earthworm behavior: Most of the earthworms were active in the same galleries during the first week following the onset of cast production. This confirms previous ecological studies of M. carimaguensis, which concluded that this species had a semi-sedentary behavior. As a result, in the two systems, casts were partially fresh during all this period, and had higher moisture contents than the adjacent soil (Fig. 24). Afterwards, water content of casts sharply decreased between 7 and 30 days of ageing. Then, when compared to the soil, casts constantly had lower humidity and higher variation amplitudes. On the other hand, moisture contents were generally higher in the pasture than in the savanna. The decrease in water content observed about 8 months after the beginning of the experiment corresponded to the middle of the dry season.

Nitrogen dynamics as affected by earthworm activity: The general scheme of inorganic N dynamic in the casts of M. carimaguensis supports the actual knowledge of how earthworms affect organic matter dynamics. A succession of processes must be considered, that may have antagonistic impacts on soil organic matter depending on the time-scale considered.

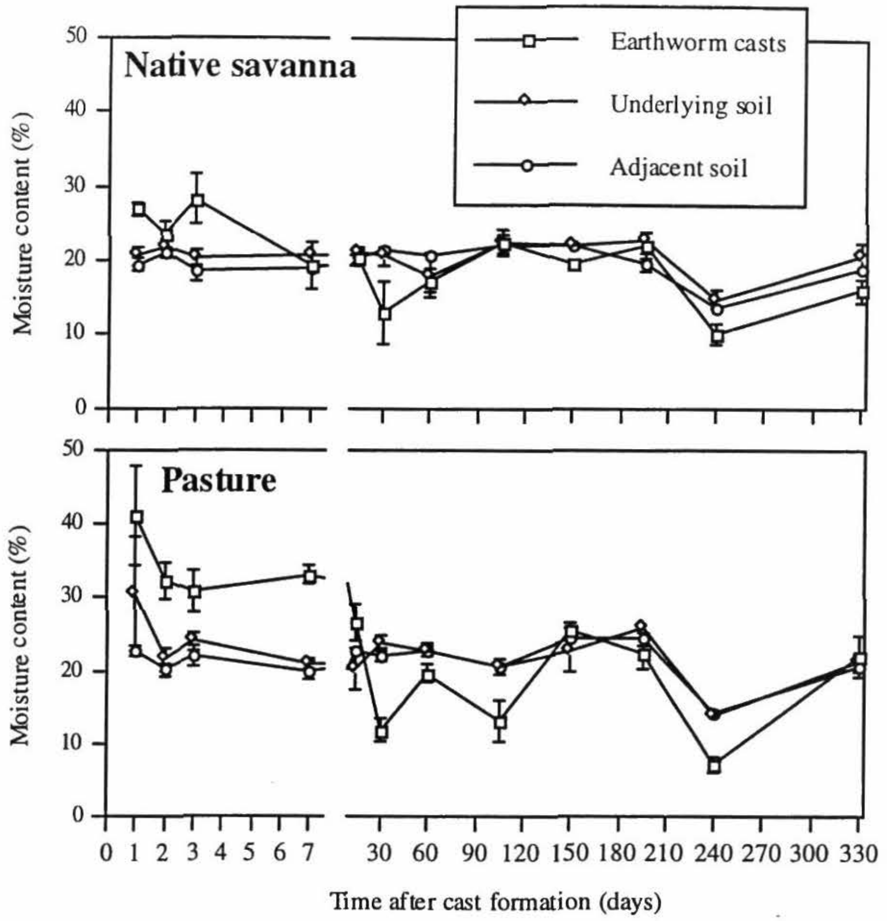

Figure 24. Evolution over time of the moisture content in the soil and the casts of the two studied systems.

Earthworms generally assimilate a relatively low proportion of organic matter contained in the soil that they ingest. In the anterior part of their gut, they mix the ingested food substrate (i.e. soil and/or litter) with water and mucus, a readily assimilable source of C for microflora. Consequently, microbial activities and mineralisation are greatly enhanced during the gut transit and in fresh casts. This process, plus the addition of urine in the posterior part of the digestive tract, may explain the high NH_4^+ levels observed in the casts of *M. carimaguensis* during the first month of cast ageing (5 and 15 times higher than in the bulk soil in 1-day-old casts, respectively in the savanna and the pasture) (Fig. 25a and 25b). This result is consistent with others referring to inorganic N release in fresh casts of different tropical species.

During the first 2 weeks after cast deposition high concentrations of NH_4^+ were maintained by the continuous excretion of new depositions on the same casts. After 30 days, however, as earthworms abandoned their burrows, concentration decreased to a minimum and constant value similar to the one observed in soil (Fig. 25a and 25b). This

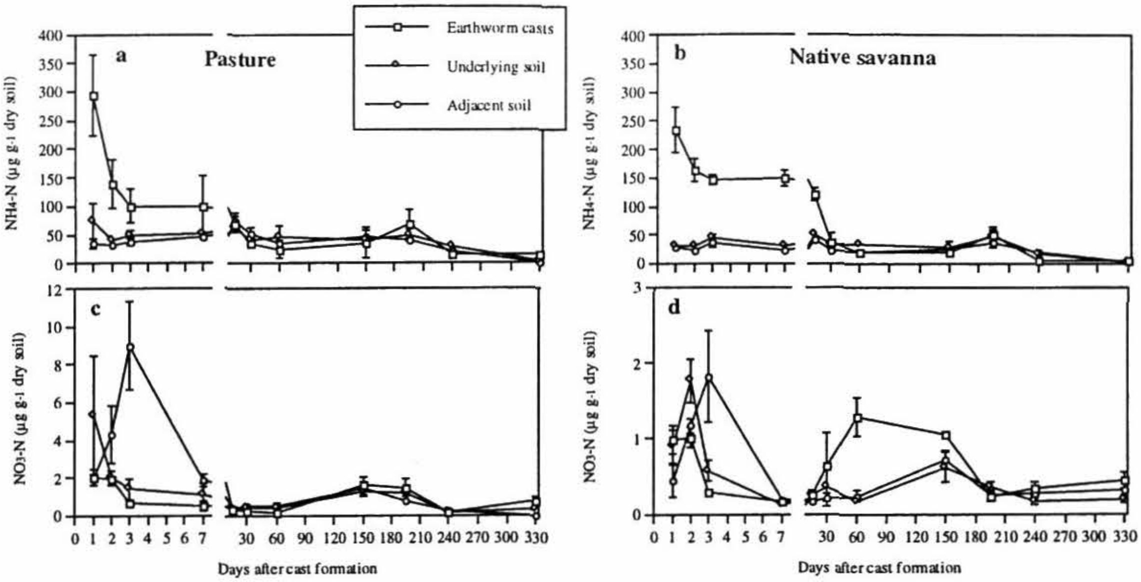

Figure 25. Evolution over time of NH_4^+ and NO_3^- contents in the soil and the casts of the *Brachiaria humidicola* / *Arachis pintoi* pasture (a-c) and the native savanna (b-d).

decrease can be largely attributed to the production of NO_3^- in fresh casts via nitrification processes. Then a rapid diffusion to the soil would explain why no accumulation of NO_3^- was observed in casts. Three significant and transient peaks of NO_3^- were successively observed in the casts, the cast-underlying and the adjacent soil (Fig. 25c and 25d). They may be interpreted as the results of: (i) a fast production of NO_3^- in the casts, (ii) a rapid diffusion of this NO_3^- with the water flowing through the gallery, (iii) a slower lateral diffusion with the water running of on the cast and soil surface (Fig. 26). Finally, inorganic N excesses largely disappeared from the casts and the surrounding soil, certainly as the result of root uptake, denitrification processes, reorganization in soil microbial biomass or losses by leaching.

After this initial period, casts rapidly dried at the soil surface (Fig. 24). Dry earthworm casts are known to be stable aggregates, rather compact and impermeable, which efficiently protect the organic matter they contain from decomposition processes. In our experiment, however, slight increases in NH_4^+ and NO_3^- concentrations were observed between 30 and 195 days after the beginning of the experiment, simultaneously in the casts and soil of the two systems (Fig. 25). They took place during the "veranillo" (i.e. a short dry event in the middle of the wet season) and can be attributed to variations in water contents. These fluctuations of dry and wet conditions are likely to favor successively NH_4^+ and NO_3^- production in soil. As superficial casts were exposed to higher moisture fluctuations, they showed higher amplitudes of inorganic N production.

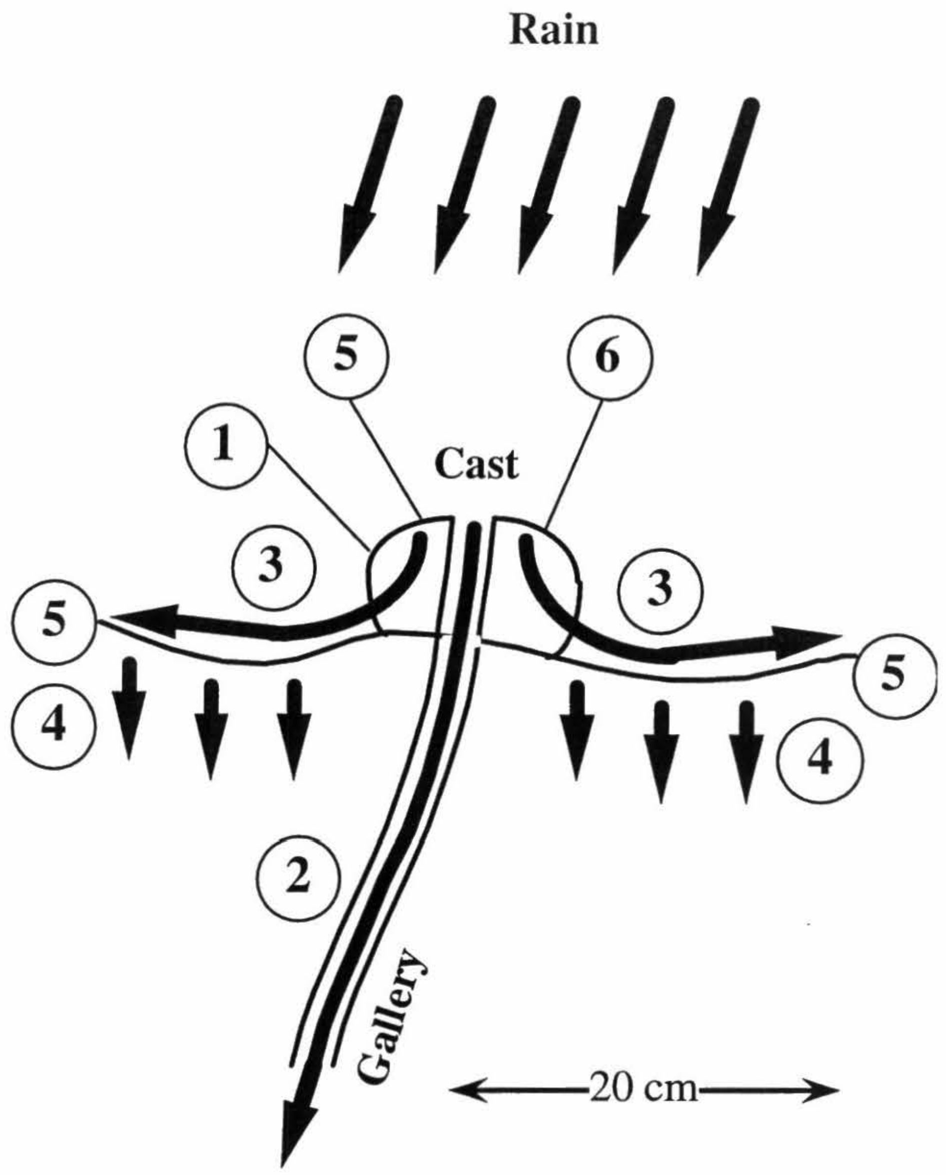

Figure 26. Nitrogen dynamics in earthworm casts and the nearby soil (→ = water floods; numbers refer to a chronological order). (1) High NH_4^+ release in fresh casts + NO_3^- production. (2) Vertical drainage in the gallery. (3) Lateral runoff on the cast and the soil surface. (4) Vertical leaching in the soil profile. (5) Denitrification + root and microbial uptake. (6) Locking of mineralisation in dry casts.

In the two systems, average values of inorganic N (i.e., $NH_4^+ + NO_3^-$) were significantly higher in the casts than in soil, while no significant differences were observed between the underlying and the adjacent soil (Fig. 27). Thus, casts may be considered as microsites of nutrient availability for plants. During the study period, surface cast production by *M. carimaguensis* at the study site ranged from 9.4 to 53.8 tons. ha^{-1}. $year^{-1}$, respectively in the savanna and in the pasture (based on a density of 0.3 ind. m^{-2} in the savanna and 1.6 ind. m^{-2} in the pasture, Decaëns unpublished data).

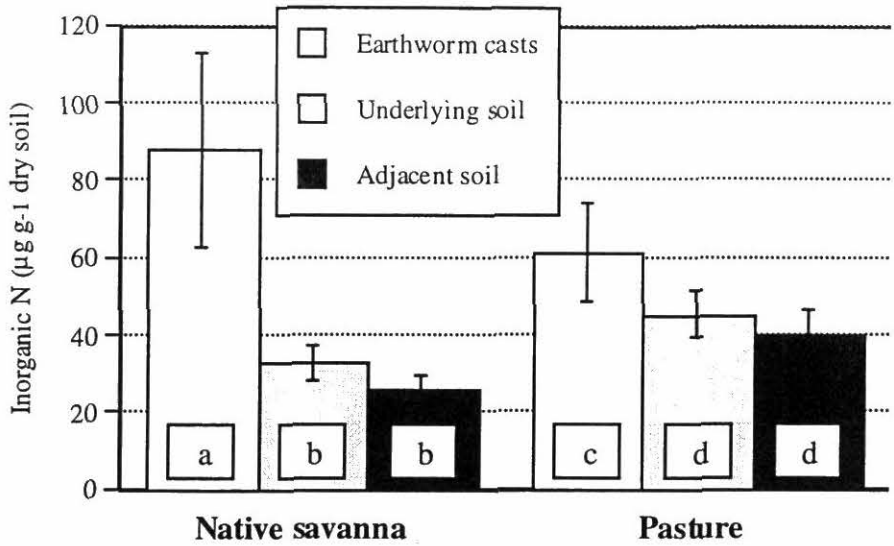

Figure 27. Average values of inorganic N in the soil and the casts of the two studied systems (letters mean significant differences at $p < 0.05$).

This species also produce underground casts, and the overall production of casts (surface + bellow ground) has been estimated at 14.2 tons dry casts. ha^{-1}. $year^{-1}$ in the savanna and 114.3 tons. ha^{-1}. $year^{-1}$ in the pasture. Thus, from 1.2 to 7.0 Kg of inorganic N may be released per ha and per year in casts of *M. carimaguensis*, respectively in the savanna and the pasture. This represent a significant contribution to the overall N budget of agroecosystems. For example, in the case of the pasture, inorganic N release from casts is equivalent to *ca.* 4.5% of the total annual N uptake by grasses. This is also equivalent to *ca* 10% of the total N inputs generally used in upland rice monocrops. These results are consistent with other estimations of earthworm impact on N mineralisation. The overall contribution of earthworms to N availability for plants may be even higher, due to the presence of significant populations of other species, and to the production of mineral N through other processes such as urine and cutaneous mucus release, and dead bodies decomposition.

Carbon accumulation in earthworm structures: In the soil that had not been recently in contact with earthworms, total C content was significantly higher in the pasture than in the savanna, while no significant differences were recorded in the total N contents and the C:N ratio (Fig. 28). This is consistent with other studies showing that grass/legume pasture, when sowed on savanna, generally increases to a large extent the contents of the soil organic C, while organic N remains the same. The regular increase of C content and C:N ratio observed in the pasture soil (Fig. 29a and 29e) is probably due to the presence of the cages used to avoid grazing pressure on the vegetation, that may have promoted leaf litter production and the accumulation of fresh organic matter in the soil.

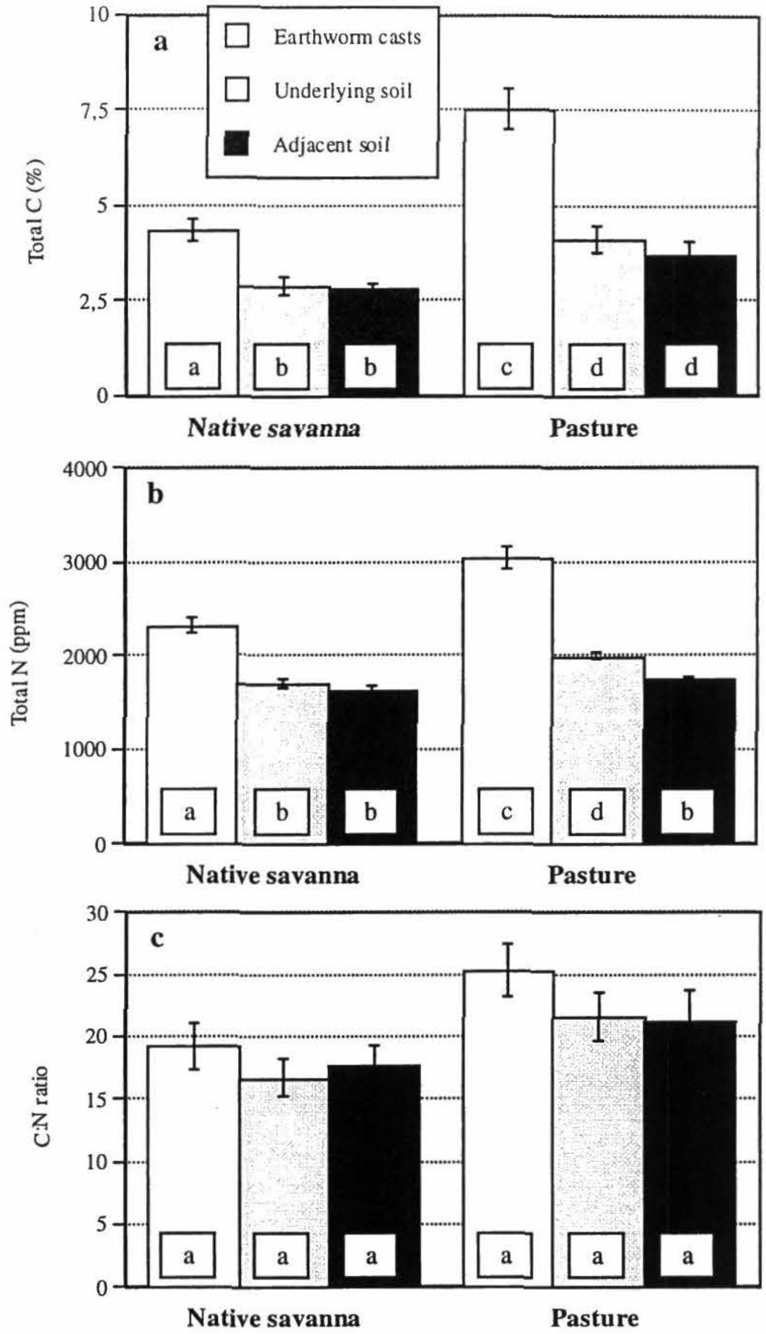

Figure 28. Average values of total C (a), total N (b) and C:N ratio in the soil and the casts of the two studied systems (letters mean significant differences at $p < 0.05$).

Compared to the bulk soil, the casts produced in the two systems had significantly higher contents of total C (1.5 to 1.9 times higher) and total N (1.4 to 1.6 times higher) (Fig. 28). Similar results have been reported in other studies, and can be explained by the capacity of *M. carimaguensis* to select a food substrate with high organic contents. We also observed the presence of significant quantities of recognizable plant debris, ranging from 1.04 to 2.88% of the total dry weight of the casts on average, respectively in the savanna and the pasture (data not presented). This result confirms the ability of *M. carimaguensis* to ingest both soil and fresh litter, and the fact that this species truly belongs to the anecic ecological category. This can explain why the casts produced in the pasture, with a high availability of palatable litter, had significantly higher levels of total C and N, when compared to those of the savanna where plant debris were scarce.

The concentrations of total N were rather constant during all the maturation process of casts (Fig. 29c and 29d), indicating an efficient conservation of the organic matter that they contain. More surprising was the continuous and significant increase of C observed in casts during their ageing (Fig 29a and 29b). This increase was highly significant in both systems (+ 100%), and may be explained by a combination of several factors, (i) fixation of atmospheric CO_2 by autotrophic microorganisms (e.g. algae or nitrification germs) may have been enhanced in casts, at least when moisture conditions were suitable for their activity, (ii) Roots never reached high biomass in casts (Fig 30a), but adverse humidity and temperature variations may have resulted in a rapid root turnover and a storage of dead roots in the ageing feces. (iii) Cast-dwelling macroinvertebrate were present from the first month of the experiment (Fig 30b) and may have contributed to the C concentration by bringing organic material and/or producing carbon-rich fecal pellets (5.23 to 10.17% of C, Decaëns unpublished data).

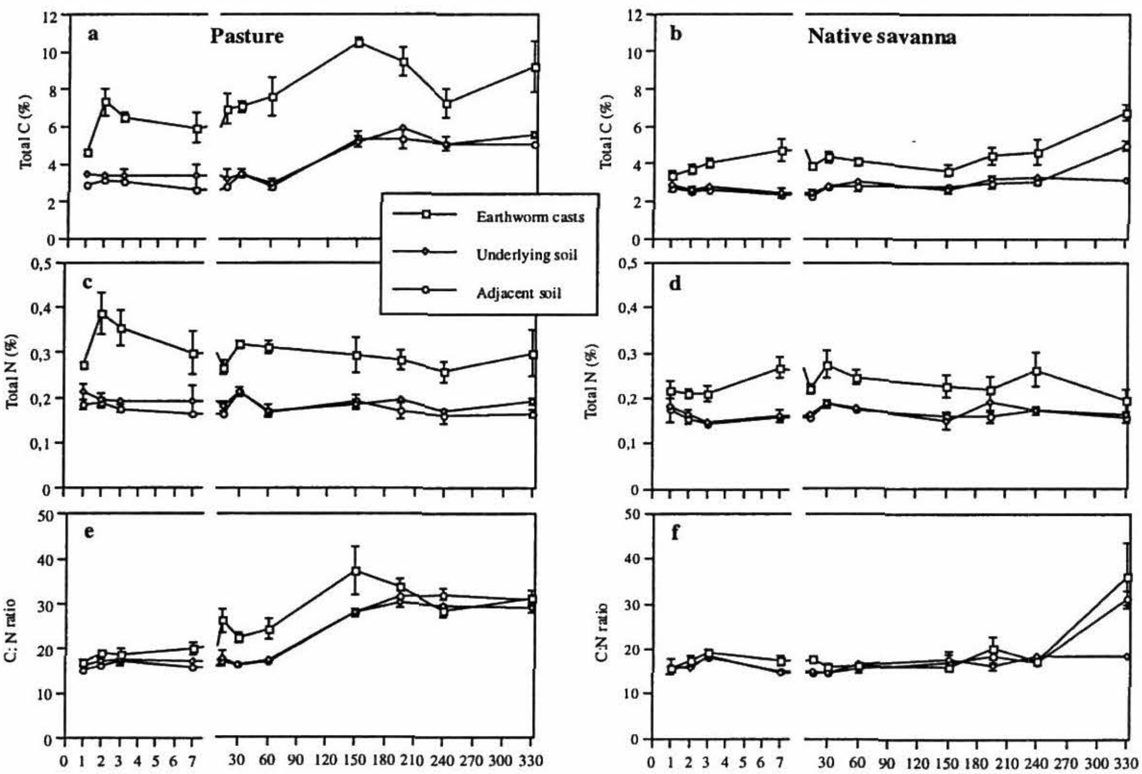

Figure 29. Evolution over time of the total C (a-b) and N contents (c-d), and the C:N ratio (e-f) in the soil and the casts of the *Brachiaria humidicola* / *Arachis pintoi* pasture (a-c-e) and the native savanna (b-d-f).

A possible effect of the concentration of organic C in the casts and burrows of *M. carimaguensis* is the build-up of a rather active but physically protected C pool which is probably released concurrently with the disintegration of the casts. Due to the very high quantity of soil excreted by earthworms in the form of casts, the earthworm-induced C accumulation in stable aggregates may be considerable. We estimate this quantity at 0.6 tons. ha^{-1}. $year^{-1}$ in the savanna and 8.6 tons. ha^{-1}. $year^{-1}$ in the pasture. A part of this C (83% and 62% in the savanna and the pasture, respectively) may be due to the selective ingestion by earthworms of organic-rich food substrates, while the remaining is due to the increases in C concentration that occur after the casts have been produced. This quantity of C concentrated in casts of *M. carimaguensis* represents 2.3 and 30.6% of the total soil C in the top 10 cm (based on a bulk density of 1.0 g. cm^{-3}), respectively in the savanna and the pasture.

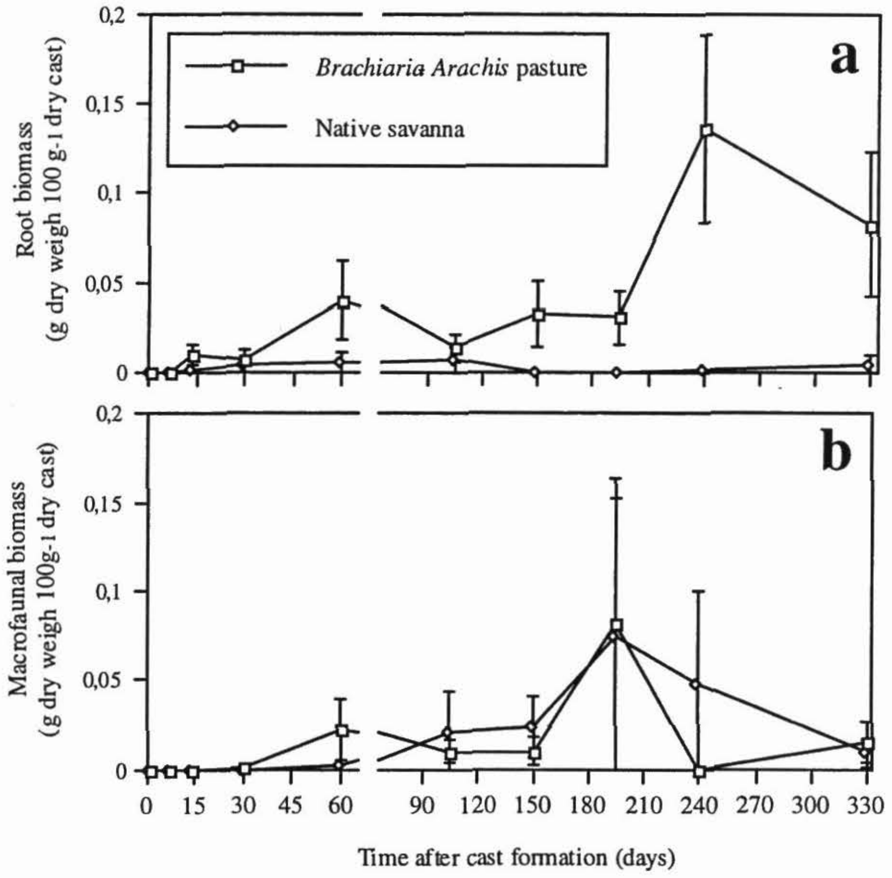

Figure 30. Evolution over time of root (a) and macrofauna biomass (b) in the casts of the two studied systems.

Effect of casting activity on surface root growth: Though roots were not found in significant quantities inside casts, root biomass in the superficial soil layer of the pasture significantly responded to cast presence at the soil surface (Fig. 31). Compared with a control soil without casts, it increased by a factor of 2 below a recent cast and 5 when located under an old cast. In the savanna, the same trend was observed, although it was not supported by statistics.

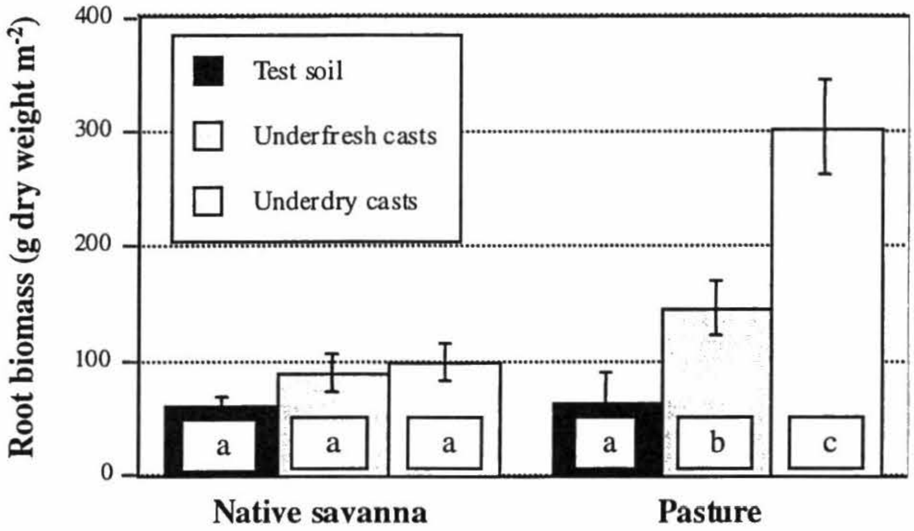

Figure 31. Average root biomass in the 0-15 cm superficial soil layer as affected by the presence of fresh and dry casts on the surface (letters mean significant differences at $p < 0.05$).

Positive effects of earthworms on plant growth have been largely documented, especially in short-term experimental pots. They are the result of many mechanisms, some of them supported by the present study. Casting activity by *M. carimaguensis* first enhances the mobilization of nutrients (e.g., of NH_4^+ and NO_3^- in our study) that are not generally available in the soil. Moreover, as this species is mostly active at the beginning of the wet season, the timing of earthworm-induced mineralisation may coincide with high nutrient requirements of plants.

Beside the effect of nutrient availability previously mentioned, other factors may contribute to this increase in root biomass, for example: (i) the physical effects of earthworm burrowing, (ii) the favorable changes in water and oxygen supply or (iii) the "hormone-like" effect of earthworms.

Impact:
The present study confirms the hypothesis of antagonistic effects of earthworms activities on soil organic matter, according to the time-scale considered. Casts of *M. carimaguensis* may be considered as microsites of short-term mineral N production and long-term soil organic matter concentration. Inorganic N production occurs during the period of cast

production, and there is evidence of a rapid diffusion of the produced NO_3^- to the surrounding soil. Carbon concentration occurs gradually during cast ageing, maybe under the influence of other organisms such as autotrophic microorganisms, small invertebrates and roots.

The modification in the location and dynamics of organic resources through the production of earthworm casts may be considered as an example of engineering activity. In the light of the high quantities of soil processed in some ecosystems by the overall earthworm population (e.g. in some pastures of Carimagua, the biomass of *M. carimaguensis* was up to 2 times higher than in the pasture of this study, the global effects on soil fertility and plant production must be extensive. This may have great relevance in the context of soil organic matter management, which is a fundamental step to improve agroecosystem sustainability and decrease CO_2 emission in the atmosphere.

Earthworms, and in a general way soil macroinvertebrates, may be considered as a natural resource that is highly sensitive to agricultural practices. At Carimagua for example, native species are greatly enhanced in improved pasture or, on the contrary, dramatically decreased in annual crops. Attention should be now paid to the general effect of such changes on the functioning of ecosystems. This will imply studies of the impact of other soil organisms (e.g. other earthworm species, termites and ants) that produce other kinds of structures and may have different effects on soil processes. More research is also needed to identify practices that efficiently maintain native communities in highly productive systems, or successfully introduce adapted exotic species where the soil fauna has been eliminated by human activities.

Contributors:
Thibaud Decaëns (ORSTOM), Andres F. Rangel, Neuza Asakawa, and Richard J. Thomas (CIAT).

Output 3. Improved decision making for combating soil degradation and improved agricultural production

Activity 3.1 Identify dynamic soil properties and test their suitability as soil quality indicators.

3.1.1. Soil macroorganic matter and N mineralization in crop-rotations and ley farming systems for acid-soil savannas of Colombia

Highlight:

- Showed the value of a soil organic matter fraction related to soil nutrient availability that is able to detect soil quality changes not captured by conventional measures like total soil C and N.

Purpose:

To identify a soil organic matter fraction that is related to soil nutrient availability

Rationale:

Many models have been constructed to describe the dynamics of soil organic matter (SOM) and generally two major pools are distinguished, a small pool with a high turnover rate and a larger pool with a slower turnover. The SOM fractions with high turnover and mineralization rates have been found to be more sensitive to management (i.e. residue additions) than total organic C and N.

Materials and Methods:

In this study we attempted to separate this SOM fraction using a size-density fractionation methodology known as the Ludox Method (Meijboom et al., 1995) which generates three SOM size-density fractions: LL (>150 m, <1.13 g.cm^{-3}), LM (>150 m, 1.13-1.37 g.cm^{-3}) and LH (>150 m, >1.37 g.cm^{-3}). We studied the arable layer (0-20 cm) from long-term experiment soils after five years of rice and maize systems. Soil potential N mineralization was also determined using the anaerobic incubation procedure (Anderson and Ingram, 1993).

Studies were carried out at the Carimagua Experimental Station. Soils are well-drained clay-loams classified as oxisols (Tropeptic haplustox, isohyperthermic). Rice systems included the following treatments: rice monoculture, rice/cowpea rotation, rice/cowpea as a green manure, rice agropastoral (*Brachiaria humidicola* + Legume cocktail: *Centrosema acutifolium, Stylosanthes capitata, Arachis pintoi*) and the native savanna as a control. Maize systems included the following treatments: maize monoculture, maize/soybean rotation, maize/soybean as a green manure, maize agropastoral (Panicum maximum + Legume cocktail: *Glycine wightii, Arachis pintoi*) and the native savanna as a control.

Results and Discussion:

In general, no significant differences (P<0.05) among treatments were found using conventional measures like total soil C or N. Significant differences, however, were found for rice and maize systems when using the LL dry weight, C and N contents (Figures 32 and 33). The relative differences among treatments are similar for LL dry weight and amount of C in LL are maintained suggesting that LL dry weight could serve as a sensitive indicator of SOM differences. This coincides with results from Barrios et al. (1996, 1997) where LL was identified as a sensitive SOM fraction that is able to detect differences resulting from soil and crop management that are not detected with measurements of total soil C or N.

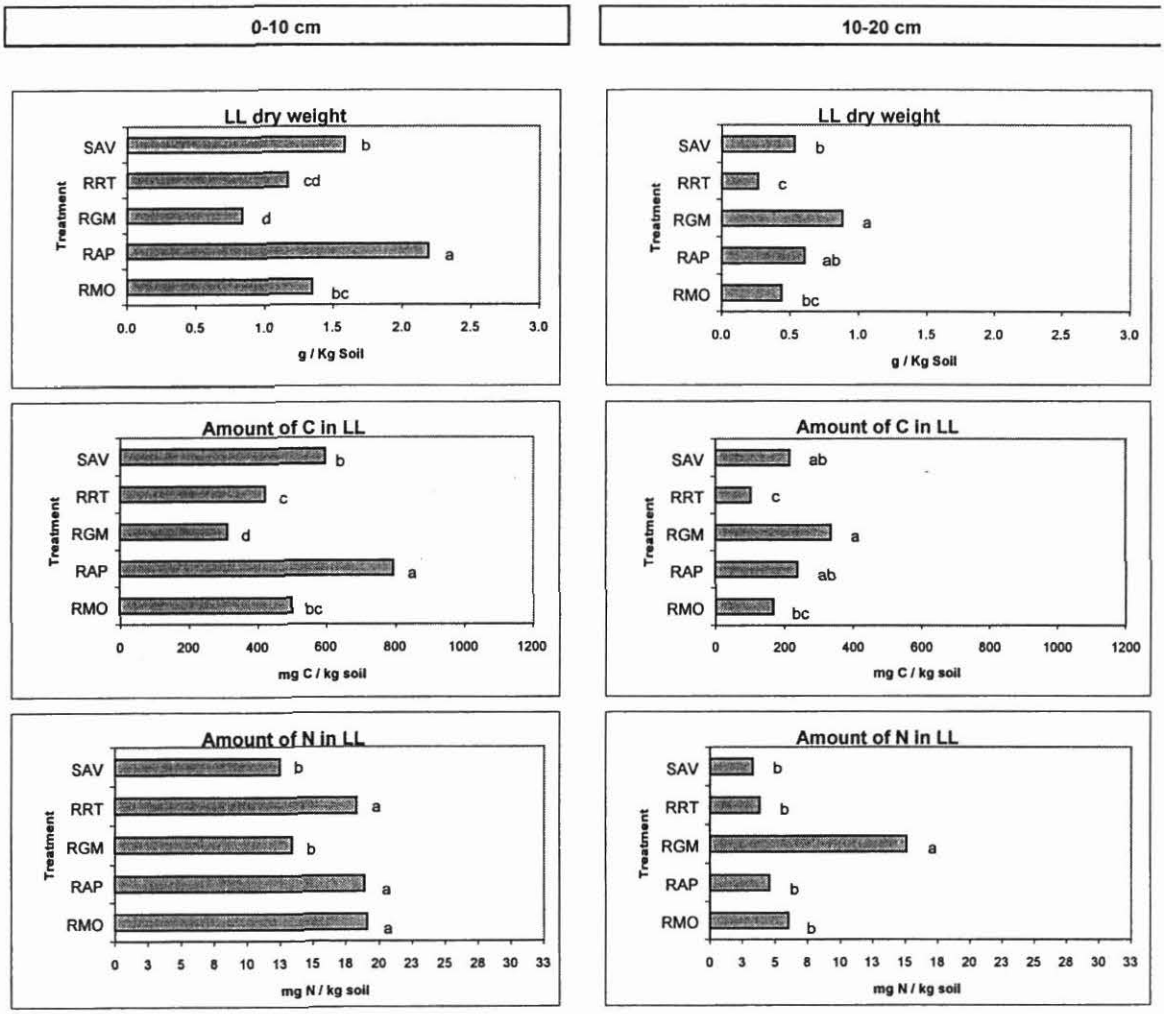

Figure 32. Light fraction SOM dry weight, amount of C and amount of N in soils under rice systems from the Culticore Experiment. SAV = Native savanna, RRT = rice/cowpea rotation, RGM = rice/cowpea as green manure, RAP = rice agropastoral (Brachiaria humidicola + Legume cocktail), RMO = rice monoculture.

Topsoil LL measures (0-10 cm) were usually higher than those of the following soil depth (10-20 cm) studied. Agropastoral systems generally presented the highest topsoil values for LL dry weight and C in rice systems and for all LL measures in maize systems. The lower values for LL dry weight and C were usually found in the green manure, rotations and monocrops treatments. Lower amount of N in LL was generally associated with the native savanna. Green manure treatments presented the highest LL values for all measures at 10-20 cm depth because organic residues had been incorporated to the soil especially in LL-N. It can be concluded that based on LL as a soil quality indicator the agropastoral systems showed a better C and N status than the native savanna while other treatments generally showed poorer status than the native savanna.

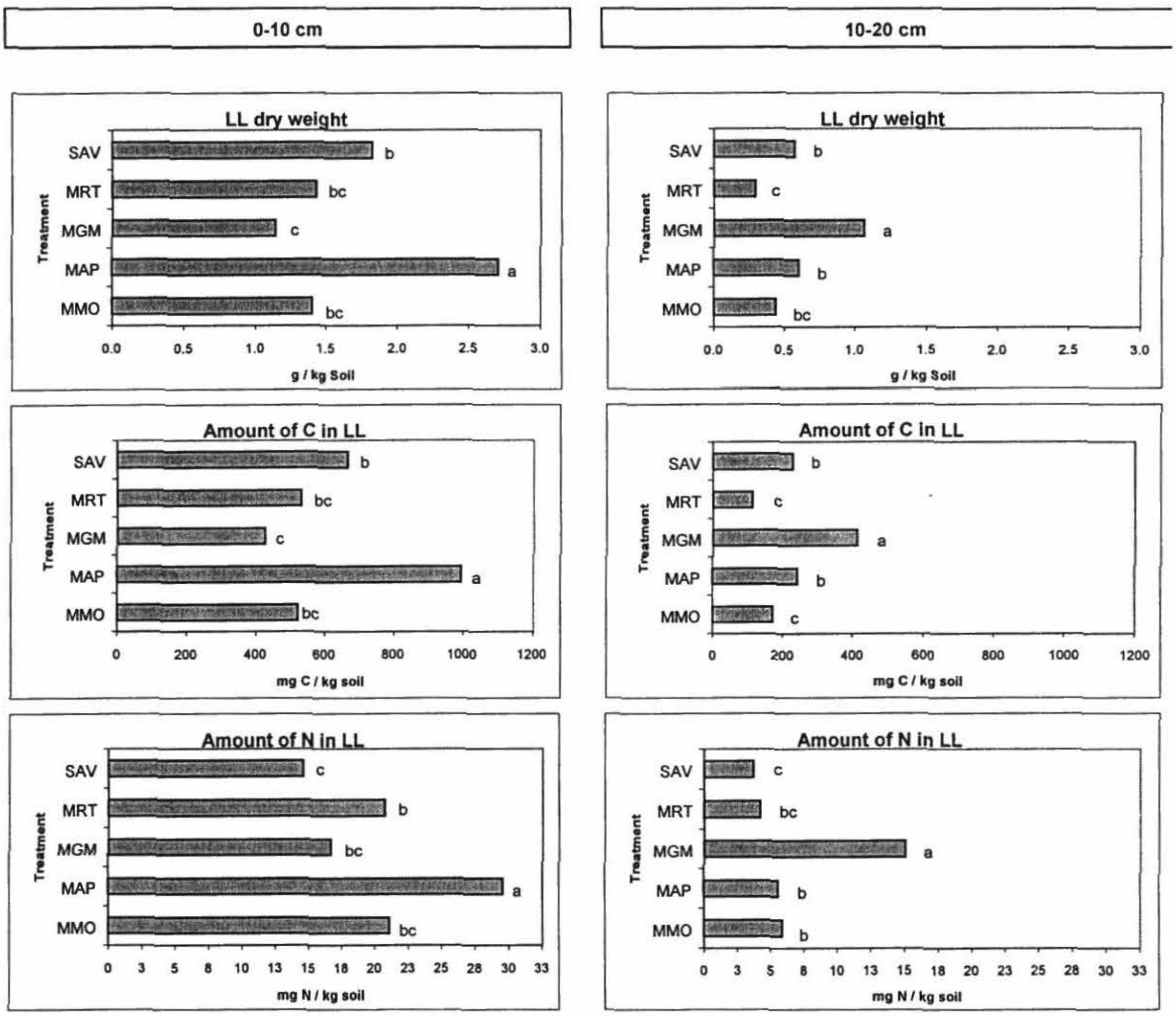

Figure 33. Light fraction SOM dry weight, amount of C and amount of N in soils under maize systems from the Culticore Experiment. SAV = Native savanna, MRT = maize/soybean rotation, MGM = rice/soybean as green manure, MAP = rice agropastoral (Panicum maximum + Legume cocktail), MMO = maize monoculture.

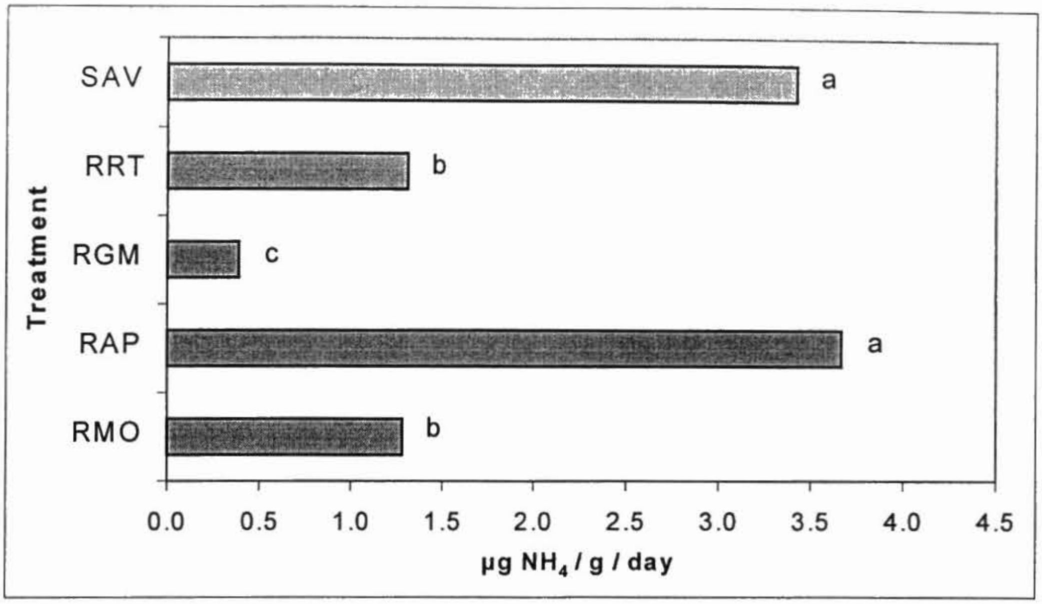

Figure 34 Potential N mineralization in soils under rice systems from the Culticore Experiment (0-5 cm). SAV = Native savanna, RRT = rice/cowpea rotation, RGM = rice/cowpea as green manure, RAP = rice agropastoral (*Brachiaria humidicola* + Legume cocktail), RMO = rice monoculture.

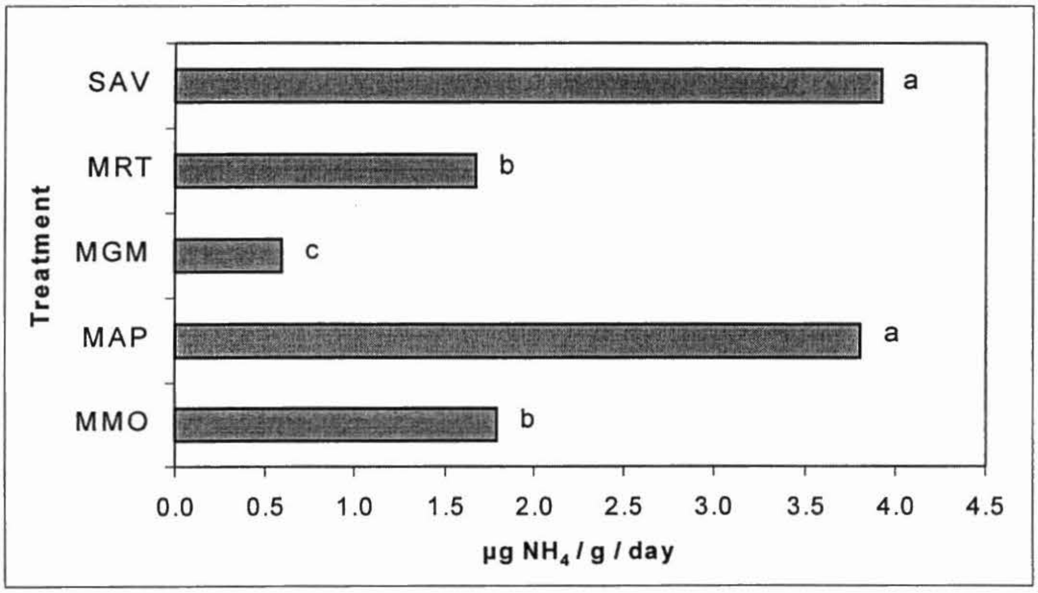

Figure 35. Potential N mineralization in soils under maize systems from the Culticore Experiment (0-5 cm). SAV = Native savanna, MRT = maize/soybean rotation, MGM = maize/soybean as green manure, MAP = rice agropastoral (Panicum maximum + Legume cocktail), MMO = maize monoculture.

Measurements of potential N mineralization in soil showed considerable differences among treatments (Figure 34 and 35.). The savanna and agropastoral systems showed the highest values across systems, the rotation and monocropping intermediate values and the green manures the lowest values. While soil N availability was maintained by the agropastoral systems, soils under rotations, monocrops and green manures showed a reduced capacity for N supply. Lowest values in green manures were probably related to the rapid mineralization of labile organic N (i.e. LL-N) after incorporation of legume residues into the soil. This observation is supported by the finding of nitrate accumulation near 50 cm soil depth presumably caused by nitrate leaching in the green manure treatments (CIAT, 1998).

References:

Anderson J.M. and Ingram J.S.I. (1993) Tropical Soil Biology and Fertility: A Handbook of Methods. Second Edition. CAB International, Wallingford, U.K.

Barrios E., Buresh R.J. and Sprent J.I. (1996) Organic matter in soil particle size and density fractions from maize and legume cropping systems. *Soil Biology & Biochemistry* 28(2): 185-193.

Barrios E., Kwesiga F., Buresh R.J. and Sprent J.I. (1997) Light fraction soil organic matter and available nitrogen following trees and maize. *Soil Science Society of America Journal* 61(3): 826-831.

CIAT (1998) PE-2 Project: Overcomimg Soil Degradation Annual Report

Contributors:

E. Barrios, I.I.Corrales, N. Asakawa, J.G.Cobo, R.Thomas and D.Friesen (CIMMYT-IFDC)

3.1.2 Test the suitability of different methods to assess soil P availability as a soil quality indicator

Highlight:

- Showed that water soluble P fertilizers have a high residual value and Bray-II could be a useful method to estimate P availability in Colombian savanna Oxisols.

Purpose:

To test the suitability of different methods to assess soil P availability.

Rationale:

The high oxide contents of highly weathered acid Oxisols and Ultisols present surfaces that strongly sorb phosphates, giving rise to what is commonly referred to as a 'high P fixation capacity'. However, several researchers have found very substantial residual effects of applied P on the so-called high P-fixing soils (Wolf et al., 1987). To maximize P fertilizer use efficiency, it is necessary to be able to quantify the residual value of previous P fertilizer applications. For this purpose, in a field study over four-year period, annual P applications were compared with single residual P applications. The main objective of the study was to determine optimal P levels and application modes for soluble P fertilizers. Different soil P extractants were tested to quantify available soil P and are related to grain yield and P uptake by the maize crop.

Materials and Methods:

The residual effect of a soluble P fertilizer (triple super phosphate) was evaluated in a field experiment carried out at CORPOICA-CIAT research station at Carimagua. The soil is a well drained Oxisol (tropeptic haplustox, isohyperthermic). The study was carried out in a maize (first semester)-soybean (second semester) rotational crop system established in 1993. Treatments of P application and P rates were: residual P treatment with initial P application rates of 80, 120, and 200 kg P ha^{-1} (one time initial applications at the establishment of the field experiment); and annual P treatment with applications of 0, 20, 30, and 50 kg P ha^{-1} resulting in a total of 7 treatments. The system was evaluated for five years (1993 - 1997), with no P fertilizer application in 1997. To estimate available inorganic P, soils were extracted using:

1) Bray-II (0.1 *M* HCl and 0.03 *M* NH_4F) (Bray and Kurtz, 1945);
2) FeO impregnated filter papers (Menon et al., 1990);
3) Resin strips: anion exchange membranes cut into strips, converted to bicarbonate form (Tiessen and Moir, 1993).

Results and Discussion:

Application of P fertilizer greatly improved maize yields and the amount of P transported to grains when compared to the non-fertilized plot (Figs. 36 and 37). However, improvement in grain yield was not marked with applications greater than 30 kg P ha^{-1} yr^{-1}. Grain yields resulting from annual applications were greater than those from the corresponding single equivalent residual applications towards the end of the evaluation time (1996 and 1997). However, P transported to maize grains was similar among annual and residual applications, especially with high doses (50 kg P ha^{-1} and 200 kg P ha^{-1}, respectively) over the four-year period. As expected, greater values of P transport to maize grains were obtained with increasing levels of P application. A simulation model that had been verified on Brazilian Oxisols (Wolf et al., 1987) underestimated the maize yield for the four-year period, thus indicating that the residual P fertilizer value, on this site, is greater than that of the other Oxisol sites. The model, however, predicted reasonably well the evolution of grain yield as a function of time. The effects of P fertilizer treatments on soil inorganic P availability, as determined by three different methods (Figure 38), were similar to that of the amount of P transported to maize grains (Figure 37). Bray-II and Resin extraction methods were more effective than the FeO impregnated filter paper in detecting the differences among the fertilization treatments.

Figure 39 shows the relationships (Mitscherlich equation) between yield and soil P availability; and P transported to maize grains and soil P availability. Available soil P was estimated by using Bray-II, FeO impregnated filter papers or resin strips as soil P extractants. Only residual P fertilizer treatments were included in the relationships.

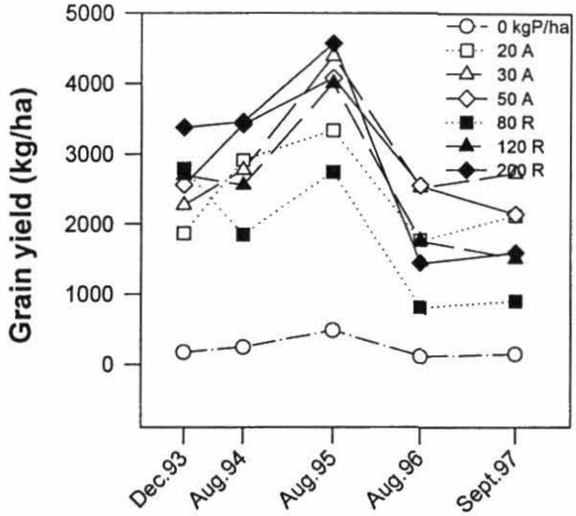

Figure 36. Effect of annual (A) or *single residual* (R) applications of P fertilizer on maize grain yield.

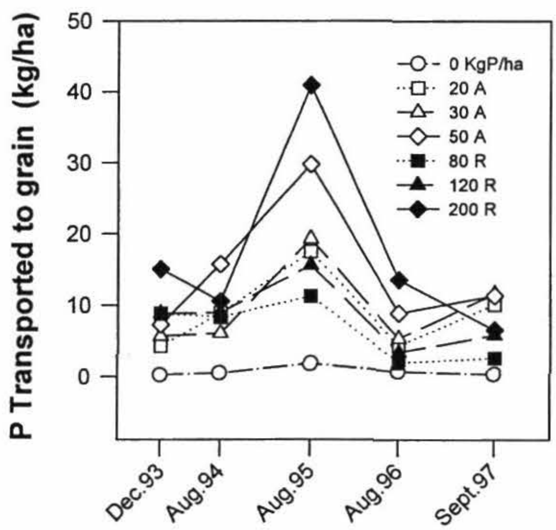

Figure 37. Effect of annual (A) or single residual (R) applications of P fertilizer on P transported to grain of maize.

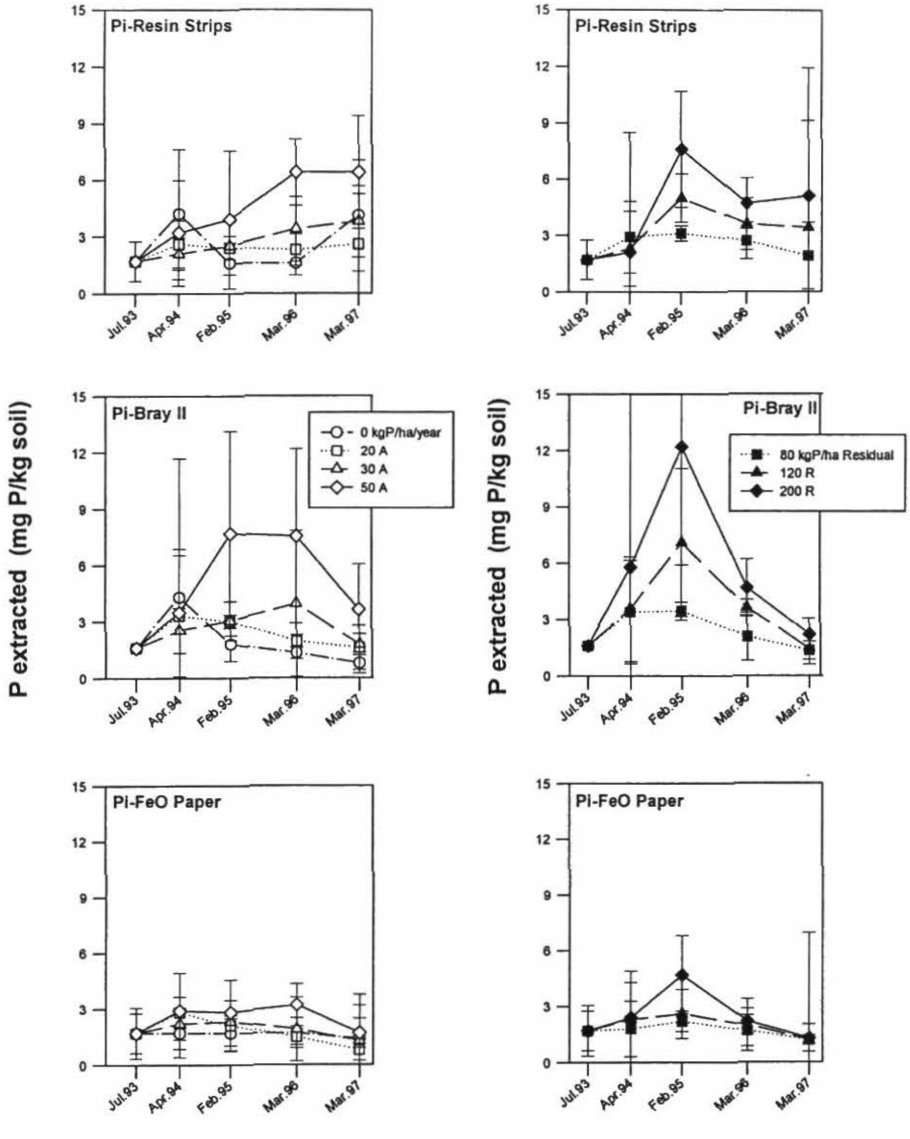

Figure 38. Phosphorus extracted using FeO paper, Bray II and Resin strip methods. Levels of annual (A) and single residual (R) applications of P were included.

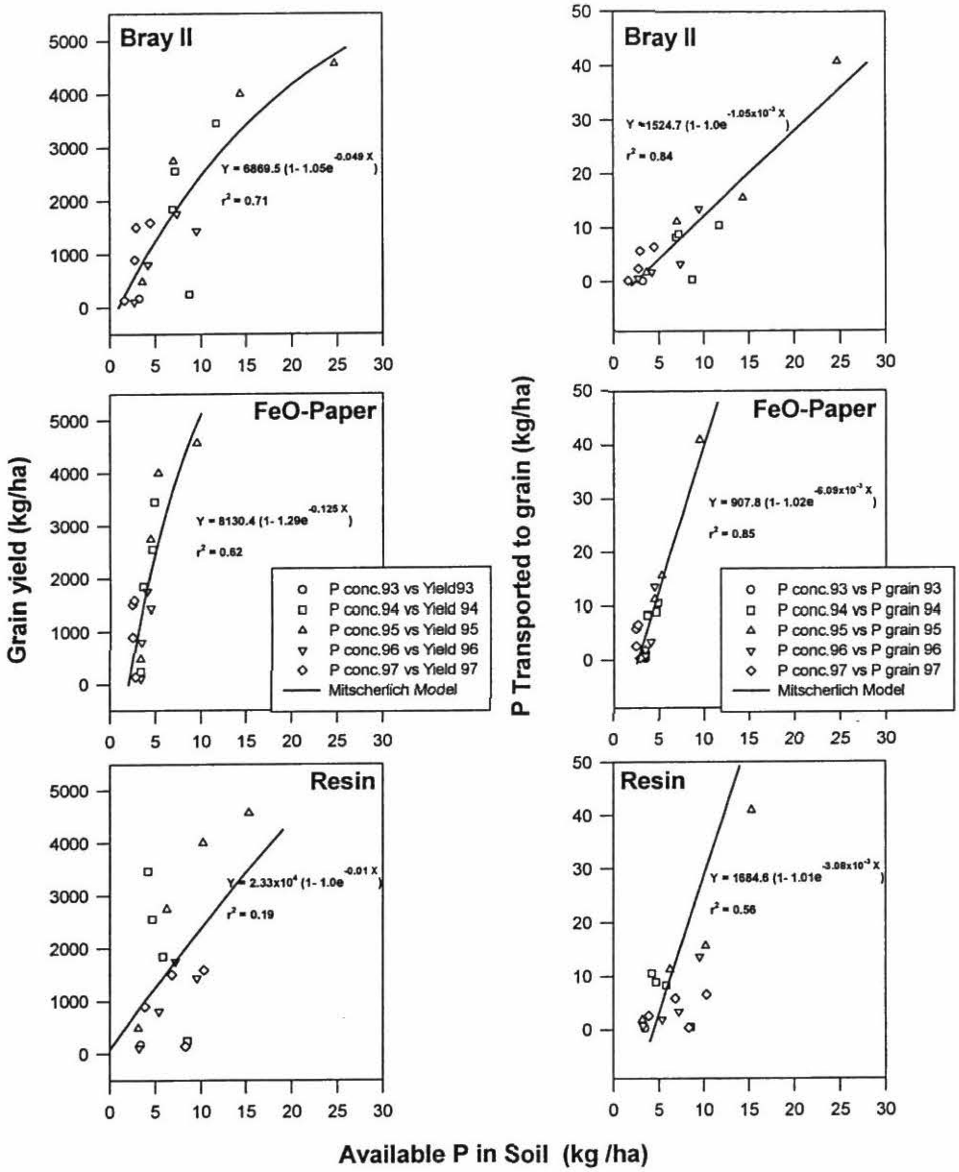

Figure 39. Relationships (Mitscherlich equation) between yield and P availability; and P transported to maize grains and soil P availability. Only the three residual P treatments were included to generate the relationships.

Soil P availability determined by FeO impregnated filter paper and Bray-II was better related to grain yield and P transport to grains than that of the P extracted using resin strips (Figure 39). These results indicate that these methods are useful to detect differences among P fertilizer treatments as revealed by their closer association with grain yield and also P transport to grain. While the physico-chemical basis of P extraction using Fe impregnated filter papers is clearer, Bray-II is more rapid and less labor intensive. Thus Bray-II is the most suitable of the three methods tested to predict available P in Oxisols.

Impact:

The Bray-II extractant currently used to estimate available P in Oxisols was found to be well correlated to grain yield and P transport to maize grains. This method could also detect differences in soil P availability in Oxisols that have received different levels of either annual or single residual P applications. Over the four years of field experimentation, single residual P applications maintained a good amount of available soil P in comparison with annual applications.

References:

Bray, R.H., Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus in soil. Soil Sci., 59:39-45.

Menon, R.G., Chien, S.H., Hammond, L.L. (1990). Development and evaluation of the Pi soil test for plant-available phosphorus. Commun. Soil Sci. Plant Anal. 21:1131-1150.

Tiessen, H. and Moir, J.O. (1993). Characterization of available P by sequential extraction. In: M.R. Carter (ed.) Soil sampling and methods of analysis. CRC Press Inc. Boca Raton Florida USA, pp. 75-86.

Wolf, J., Janssen, H. and Lathwell, D. (1987). Modelling long-term crop response to fertilizer phosphorus. I. The model. Agron. Journal, 79:445-451.

Contributors:

G. Borrero (CIAT), D. Friesen (IFDC-CIMMYT), A. Oberson (ETH, Switzerland), and I. M. Rao (CIAT)

3.1.3 Test the suitability of microbially bound phosphorus as an indicator of soil biological fertility and of land use sustainability

Highlight:

- Showed that microbially-bound phosphorus could be an indicator of changes in soil fertility with respect to phosphorus.

Purpose:

To test the suitability of microbially bound phosphorus as a soil quality indicator

Rationale:
The objective was to evaluate the role of the soil microbial biomass in the cycling of the scarce P resources in contrasting agricultural systems on low P tropical soils by:
(1) devising methodology to measure the uptake of soil solution PO_4 by the soil microbial biomass;
(2) assessing the size of microbially bound P (P_{mic}) and the uptake of soil solution PO_4 by microorganisms in different agricultural systems; and
(3) relating the size and the uptake of soil solution PO_4 to other soil chemical and biological parameters, soil P status, P balance and system productivity to test the value of P_{mic} as an indicator of the overall soil fertility and system sustainability.

Materials and Methods:
Soil samples were taken in the Culticore field experiment started in 1993 at the CIAT-CORPOICA experiment station in Carimagua (4°30'N, 71°19' W and 150 m.a.s.l) on the eastern plains of Colombia (Friesen et al., 1997). The soils are well-drained, silty clay Oxisols (tropeptic haplustox, isohyperthermic (U.S. taxonomy)). The following contrasting treatments were included:

- Continuous Rice (CR): since 1993 continuous rice *Oryza sativa* cv Oryzica Sabana 6, cv Oryzica Sabana 10 since 1996, fallow during dry season;
- Native savanna (SAV): burned once per year in February; not grazed;
- Rice-Grass-Legume pasture (RGL): rice in 1993, with under sown pasture, since then grass-legume pasture association with *Brachiaria humidicola* CIAT 679, *Arachis pintoi* CIAT 17434, *Stylosantes capitata* CIAT 10280 and *Centrosema acutifolium* CIAT 5277; renovated in June 1996 with legumes (the same *Arachis pintoi*, additionally *Centrosema acutifolium* cv Vichada CIAT 5277 and *Stylosanthes guianensis* CIAT 11833, and *Desmodium ovalifolium* CIAT 13089).

Rice was fertilized each year with 60 kg P ha^{-1} y^{-1}. The pasture received an additional 20 kg P ha^{-1} when it was renovated while native savanna was never fertilized. The systems additionally differ in soil cultivation and in the application of herbicides (frequent, rare or no application of herbicides for CR, RGL and SAV treatments, respectively). Basic soil characteristics are indicated in Table 39. Soils of all treatments have a high P sorption capacity (see 1.4.2 activity in this report). The experiment is a split-plot design with four replicates. Sampling was carried out at a depth of 0-10 cm in September 1998 during the rainy season.

Table 39. Soil chemical characteristics of the three contrasting land use systems from the Culticore experiment.

Treatment	pH	Al saturation (%)	Total C (mg kg^{-1})	Total N (mg kg^{-1})	Bray-II P (mg kg^{-1})
SAV	4.9	86	26	1676	1.4
RGL	4.8	67	28	1800	3.4
CR	4.7	69	25	1669	16

SAV = native savanna; RGL = rice-grass-legumes; CR = continuous rice

Soil measurements included:

(i) Organic and inorganic P fractions using sequential P fractionation (Tiessen and Moir, 1993; Oberson et al., 1999) and particulate organic matter (Cambardella and Elliott, 1992).

(ii) Biological and biochemical soil analysis (determination of microbial C, N (Vance et al., 1987; Joergensen, 1996; Joergensen and Mueller, 1996) and P (Oberson et al., 1997); soil respiration including calculation of C mineralization (Gijsman et al., 1997); acid phosphatase activity (Tabatabai, 1982); and isotopic composition of chloroform released P in an incubation experiment using $^{33}PO_4$ labelled soils) (McLaughlin et al., 1986; Oberson et al, in prep.).

Results and Discussion:

Based on yield and P content data, an input-output balance was estimated for the selected treatments (Table 40). In agreement with the positive P balance, total and available P have clearly increased in the continuous rice treatment (Tables 39 and 41). Resin, $NaHCO_3$ (0.5 M) and NaOH (0.1 M) extractable P_i were greater in CR than in RGL treatments, both in absolute and relative terms (Table 41). NaOH-P_i is the main sink for applied P. Organic P fractions were not affected in CR, but increased in RGL soils where especially NaOH-P_o acted as a sink, too. Analysis of changes in fractions was carried out using the following formula:

Increase (%) = (size of fraction in fertilized treatment - size of fraction in SAV) / (Sum-P_t fertilized treatment – Sum-P_t SAV) * 100

Results showed that more than 30% of the increase over SAV could be accounted from organic fractions in RGL while the corresponding portion was less than 11% in CR soils (Table 41). Differences in the partitioning of P in the fertilized treatments indicated that P transformation processes in CR differ from RGL soils.

The size of the microbial biomass, and consequently its significance as N and P compartment, was affected by the land use systems in the order of RGL > SAV > CR (Fig. 40). The fraction of microbially bound P measured after chloroform fumigation (P_{chl}) was lowest in CR despite the fact that this treatment showed the highest content in Bray-II extractable P (Table 39). Consequently, the size of the microbial P is determined by factors other than that of available P.

Table 40. Total P input by fertilizers, total P export by harvested products (rice grains, beef) and input-export balance of selected treatments from the Culticore experiment, 1993-1997.

Treatment	P Input	Total P export	P balance
	(kg P/ha)		
CR*	300	23	+ 277
SAV	0	0	0
RGL	80	10	+ 70

*at the time of sampling had a positive balance of + 60 kg P ha^{-1} of fertilizer in the system. CR = continuous rice; SAV = native savanna; RGL = rice-grass-legumes.

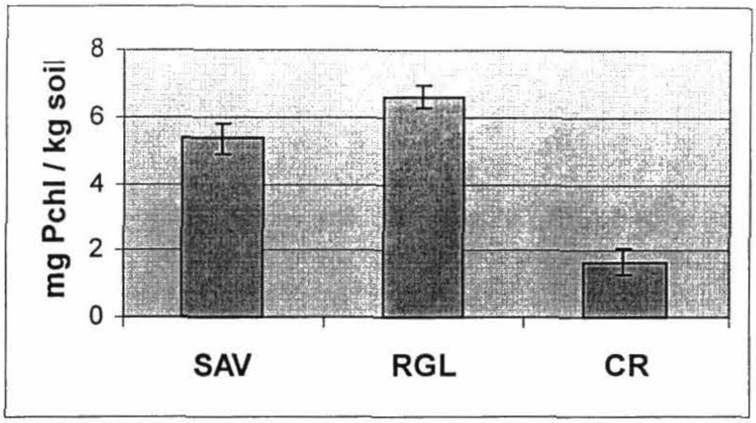

Figure 40. Effect of contrasting production systems on phosphorus held in the soil microbial biomass (Pchl). SAV = native savanna, RGL = rice-grass-legumes, CR = continuous rice.

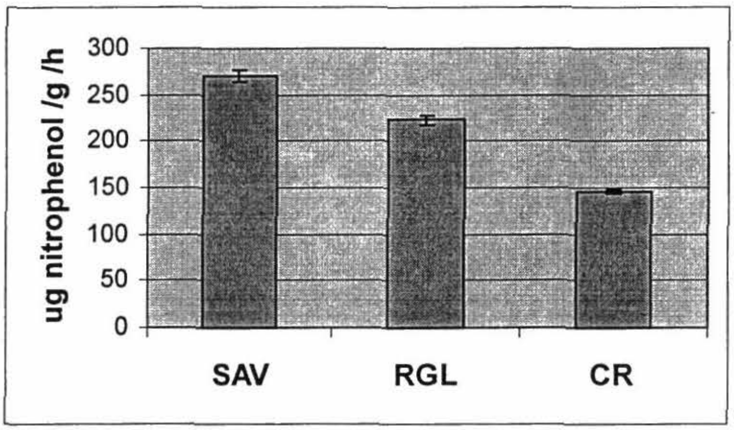

Figure 41. Effect of contrasting production systems on soil phosphatase activity. SAV = native savanna, RGL = rice-grass-legumes, CR = continuous rice.

Table 41. Inorganic and organic P fractions in an Oxisol under three contrasting production systems of the Culticore experiment.

Treatment	Resin-P_i	Bic-P_i	Bic-P_o	NaOH-P_i	NaOH-P_o	HClhc-P_i	HClhc-P_o	Resid-P_t	Sum-P_t	Sum-P_o
Continuous Rice										
Mean (mg/kg)	14.3	20.2	17.1	111.0	42.7	54.3	36.2	65.6	363	98.0
SD (mg/kg)	2.0	2.0	3.0	11.6	10.0	5.1	10.3	3.8	24	22.6
% of Sum-Pt#	3.9	5.6	4.7	30.5	11.7	14.9	10.0	18.0	100	27.0
% Increase□	7.7	10.7	3.8	55.0	-1.7	12.3	8.1	3.3	100	10.6
Savanna										
Mean (mg/kg)	2.6	3.9	11.3	27.4	45.3	35.6	23.9	60.6	212	81.9
SD (mg/kg)	0.2	0.3	2.4	3.4	7.8	5.1	6.0	4.7	18	12.3
% of Sum-Pt#	1.2	1.8	5.3	12.9	21.3	16.8	11.3	28.6	100	38.7
Rice-Grass-Legume										
Mean (mg/kg)	4.8	6.7	14.6	45.5	51.0	46.5	30.3	62.2	263	97.8
SD (mg/kg)	0.6	0.6	1.8	5.3	2.3	8.8	13.1	1.6	8	11.7
% of Sum-Pt#	1.8	2.5	5.5	17.3	19.4	17.6	11.5	23.6	100	37.1
% Increase□	4.3	5.4	6.5	35.5	11.3	21.4	12.6	3.2	101	31.1

Mean and standard deviations: of four replicates
Sum-P_t calculated as sum of extracted fractions agreed well with total P determined using perchloric acid digestion.
□ Calculated as (size of fraction in treatment - size of fraction in savanna) / (Sum-P_t treatment – Sum-P_t savanna) * 100

The measurement of particulate organic matter C and N showed treatment differences in the same order, and it is the presence of this easily decomposable organic material that may also explain why the cumulative carbon mineralization measured during a 63 days incubation experiment was greatest in RGL and lowest in CR soils. Under grass-legumes pasture, the constant input of relatively high-quality plant residues may have resulted in the highest microbiological activity of the three tested systems. Additionally, no pesticides were applied in RGL since 1993, and only minimum soil cultivation in strips was carried out during pasture renovation in 1996. Phosphatase activity, however, was greatest in the savanna soil, suggesting that the amount of this exoenzymes may be determined by P deficiency as well as overall biological activity in the soil (Fig. 37). The results of the labelling experiment show that the microbial biomass rapidly incorporates $^{33}PO_4$ from the soil solution after labelling isotopically exchangeable P of the soil. An incorporation of 9 to 25% of applied tracer during the first two days of incubation demonstrates that microorganisms are highly competitive and reactive.

In summary, these results emphasize the importance of microorganisms in highly P sorbing, low P acid soils. The immobilization of P_i by microbes and its gradual release by microbial turnover may protect P from sorption reactions on soil particles if this release is synchronized with the demand of growing plants and/or of a next generation of microorganisms. Higher C mineralization and increased phosphatase activity suggest a higher potential of biological and biochemical P mineralization in delivering plant available P_i to the soil solution of RGL than CR soils. The relationship of P_{chl} with biological and chemical soil properties confirms that higher P_{chl} is an indicator of improved soil fertility (Oberson et al., 1999). However, further research work is needed to determine the importance of soil microorganisms to improve P efficiency in agricultural production systems that are established on low P acid soils. This requires soils from long-term field experiments differing in their biological activity, and the application of P isotopes to assess P fluxes through microorganisms and into the growing plants.

Impact:

Microorganisms are a significant nutrient compartment and play an important role in soil P dynamics of low P acid soils. Size and activity of the microbial biomass and consequently its role in soil P transformations are affected by the production system. The rice-grass-legumes system had the most favorable effect among the three contrasting land use systems tested. The higher amount of P held in the microbial biomass may be used as an indicator of improved soil fertility of low P acid soils.

References:

Cambardella, C.A. and Elliott, E.T. (1992). Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 56:777-783.

Friesen D.K., Rao, I.M., Thomas, R.J., Oberson, A. and Sanz, J.I. (1997). Phosphorus acquisition and cycling in crop and pasture systems in low fertility tropical soils. Plant and Soil 196:289-294.

Gijsman A.J., Oberson, A., Friesen, D.K., Sanz, J.I., and Thomas, R.T. (1997). Nutrient cycling through microbial biomass under rice-pasture rotations replacing native savanna. Soil Biol. Biochem. 29: 1433-1441.

Joergensen, R.G. (1996). The fumigation-extraction method to estimate soil microbial biomass: calibration of the kec value. Soil Biol. Biochem. 28:25-31.

Joergensen, R.G. and Mueller, T. (1996). The fumigation-extraction method to estimate soil microbial biomass: calibration of the keN value. Soil Biol. Biochem. 28:33-37.

McLaughlin, M. J., Alston, A.M and Martin, J.K. (1986). Phosphorus cycling in wheat-pasture rotations II. The role of the microbial biomass in phosphorus cycling. Aust. J. Soil Res. 26:333-342.

Oberson, A., Friesen, D.K., Morel, C. and Tiessen, H. (1997). Determination of phosphorus released by chloroform fumigation from microbial biomass in high P sorbing tropical soils. Soil Biol. Biochem. 29:1579-1583.

Oberson, A., Friesen, D.K., Tiessen, H., Morel, C. and Stahel, W. (1999). Phosphorus status and cycling in native savanna and improved pastures on an acid low-P Colombian Oxisol. Nutrient Cycling in Agroecosystems (in press).

Tabatabai, M.A. 1982. Soil enzymes. p. 903-947. In A.L. Page, R.H. Miller and D.R. Keeney (eds.) Methods of soil analysis, Part 2. Chemical and microbiological properties. ASA, and SSSA, Madison WI.

Tiessen, H. and Moir, J.O. (1993). Characterization of available P by sequential extraction. In: M.R. Carter (ed.) Soil sampling and methods of analysis. CRC Press Inc. Boca Raton Florida USA, pp. 75-86.

Vance, E.D., Brookes, P.C. and Jenkinson, D.S. (1987). An extraction method for measuring soil microbial biomass C. Soil Biol. Biochem. 19:703-707.

Contributors: A. Oberson, E. Frossard (ETH, Switzerland), G. Borrero (CIAT), D. Friesen (IFDC-CIMMYT) and I. M. Rao (CIAT).

3.1.4 Changes in pore size distribution as the intensity of tillage increase

Highlight:

- Tillage of savanna soils improved the relative distribution of pore sizes compared with native savanna soil. Macroporosity of soil could be used as an indicator of soil quality.

Purpose:

To evaluate the impact of tillage on the pore size distribution at different depths and intensities of disc harrowing.

Rationale:
Tillage has been used traditionally as a way to reduce soil hardness and to control weeds. Each type of soil requires a special kind of tillage, according to the constraints it presents for root growth. Excessive tillage however can cause soil degradation.

Materials and Methods:
In plots that are receiving different number of harrowing passes each year, an evaluation of pore size distribution in the upper 20 cm was made. Undisturbed soil samples were taken at different depths: 0-5, 5-10 and 10-20 cm using cylinders (50 × 50 mm). Four replicates were taken by depth in each treatment. They were saturated and then equilibrated to different suctions from 25 cm to 1.5 MPa to apply La Place equation for the calculation of pore diameter.

Results and Discussion:
Pore size distribution is the more sensitive physical property to evaluate the influence of tillage on the remaining soil physical condition, because it regulates the rate of water entering into the soil and the fluxes that occur into it, which are related to plant nutrition. Table 42 shows the changes in pore size distribution that occur when increasing intensities of tillage (harrowing passes) are applied to the soil.

In the first 0-5 cm, it can be seen that macroporosity increases from 7.8% under native savanna to values of about 20% when any number (6, 12, 24) of harrowing passes were applied. Mesoporosity also increased from 12.7% to around 16% and microporosity decreased as a result of intensity of tillage.

In the second depth, 5-10 cm, there was an increase in macroporosity but it was smaller than in the first layer and was a function of number of passes. Mesopores volume increased with tillage, while micropores diminished from 28.9% in native savanna to about 20% in the plot that received tillage.

In the third layer, 10-20 cm, there was a negative effect of harrowing in the volume of macropores. They diminished from 16% in native savanna to about 10% in the tilled plots. This shows clearly that tillage is causing compaction at 10-20 cm depth. The volume of mesopores increased and that of micropores decreased a little, as the intensity of tillage was higher. Total porosity increased in the first two layers in comparison with native savanna, but decreased in the third layer due to the compacting effects of harrowing. This finding suggests that the real rooting depth promoted by tillage was only up to 10 cm.

The tendency of the changes in pore size distribution between treatments is shown in Figure 42 at different depths. There is a dominance of micropores in all treatments, which made these soils dry to plants. A key point in managing these soils is to increase macro and mesopores and reduce micropores. This could be achieved through good tillage (constructive tillage) and through the stimulation of root growth, so that roots can contribute to better soil conditions.

Table 42. Changes in pore size distribution under different intensities of soil tillage and depth at Matazul, Puerto López, Colombia.

No. of passes	Pore Size	Soil depth (cm) 0 – 5	5 – 10	10- 20
		% of volume		
Native Savanna	Macro	7.8 B	11.0 AB	16.0 A
	Meso	12.7 A	9.1 A	8.8 A
	Micro	26.6 A	28.9 A	26.0 A
	T. Porosity	47.2 A	49.1 A	50.8 A
6	Macro	20.0 A	10.4 B	10.3 B
	Meso	17.6 A	16.5 A	11.5 B
	Micro	17.6 B	21.6 B	26.7 A
	T. Porosity	55.2 A	48.5 B	48.6 B
12	Macro	21.2 A	13.3 A	6.9 B
	Meso	14.1 A	16.2 A	15.1 A
	Micro	18.0 B	18.8 B	23.8 A
	T. Porosity	53.3 A	51.4 A	45.8 B
24	Macro	21.1 A	16.0 AB	10.1 B
	Meso	17.9 A	16.3 A	16.0 A
	Micro	16.3 B	19.9 A	22.1 A
	T. Porosity	55.2 A	52.3 AB	48.1 B

Similar letters in the same column for each pore size class, represent no significant difference ($P<0.05$) by Duncan.

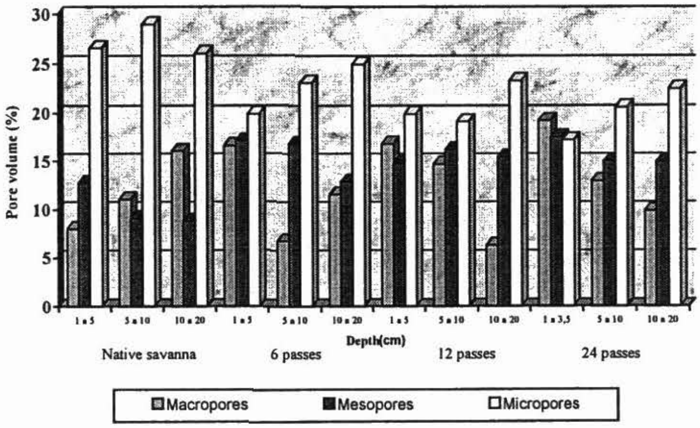

Figure 42. Pore size distribution under different soil tillage treatments.

Impact:

This study indicates that tillage of savanna soils could improve the relative distribution of pore sizes compared with native savanna soil. The findings are applicable to all the conditions of tillage in the Altillanura. Macroporosity.of soil could be used as an indicator of soil quality.

Contributors:

COLCIENCIAS, I. Valenzuela and G. Perea (Universidad de Los Llanos); P.Hoyos, D.L. Molina, L.F. Chávez, J. Galvis and A. Alvarez.

Activity 3.2 Develop and test a soil quality monitoring system (including indigenous knowledge) for use by farmers and extensionists in hillsides and savannas.

3.2.1 Production of a training guide titled: "Participatory Methods for the Identification and Classification of Local Indicators of Soil Quality at the Watershed Scale".

Highlight:

- Produced a training guide on "Participatory Methods for the Identification and Classification of Local Indicators of Soil Quality at the Watershed Scale".

Purpose:

To prepare guidelines for a participatory methodology for the identification and classification of local indicators of soil quality.

Contributors:

M.T.Trejo, E.Barrios, M.Ayarza and R.Thomas

Activity 3.3 Compile data bases to feed into simulation models and decision support systems

The activity with Michigan State University on developing a modified sub-routine for soil phosphorus continues and a workshop will be held on this topic in October 1999 with TSBF in Nairobi, Kenya as part of the SWNM (SW-2) project.

Data from the Culticore are currently being used to develop socio-economic models of savanna production systems with Michigan State University and CIAT project BP-1.

Activity 3.4 Develop decision support tools for improved soil, water and crop management

See project SW-2 for progress on the organic matter decision tree (with TSBF).

3.4.1 Develop decision support system for land management in the Llanos

Highlight:

- Developed a preliminary decision support tool using the MapMaker GIS software and a spreadsheet to evaluate land suitability for crop-livestock systems in the Llanos of Colombia.

A prototype decision tree for the use of the Colombia llanos is being developed with PE-4 and is reported on there.

Activity 3.5 Develop and test DSS for organic materials

Progress report on this activity in collaboration with TSBF is pending from Dr. Robert Delve.

Activity 3.6 Development of erosion risk maps for the Rio Cabuyal watershed

3.6.1 Develop erosion risk maps for the Rio Cabuyal watershed

Highlight:

- Produced erosion risk maps for the Rio Cabuyal watershed in Cauca, Colombia.

Purpose:
To develop erosion risk maps for the Rio Cabuyal watershed

Rationale:
As part of the work to develop decision support tools for better soil management we have developed maps of erosion risk based on the physical data available. We aimed to develop an index of erosion that adequately represents areas under highest risk of erosion but one that does not require a large amount of parameters or time consuming field work. Thus we used a model based on the analysis of topography.in the form of a digital elevation model. The concept is that spatial analysis of the elevation data can yield a wide range of topographic attributes to describe the land form and these can also be used as surrogates for complex hydrological and geomorphological purposes. The indices thus serve as descriptive models that tells us something about the propensity of the land surface to erode. The indices used were wetness index, unit stream power and sediment transport index.

Materials and Methods:
A series of analyses that included maps of wetness index, sediment transport index (topographic potential for erosion), degradation index (potential of sediment to be removed), stream power index (erosive power of overland flow) and gully formation index (propensity for gully/rill erosion) were used to develop on overall erosion risk map (Figure 43).

Results and Discussion:

The Erosion risk Maps where classified into high and low risk areas. From these maps, watersheds with apparently grave soil erosion problems can be identified (Figure 43).
These spatial attributes were then combined with the land use map and the areas ranked according to management priority (Figure 44). A 4 tier hierarchy of priority was identified, 1 being areas for immediate attention.(Table 43)

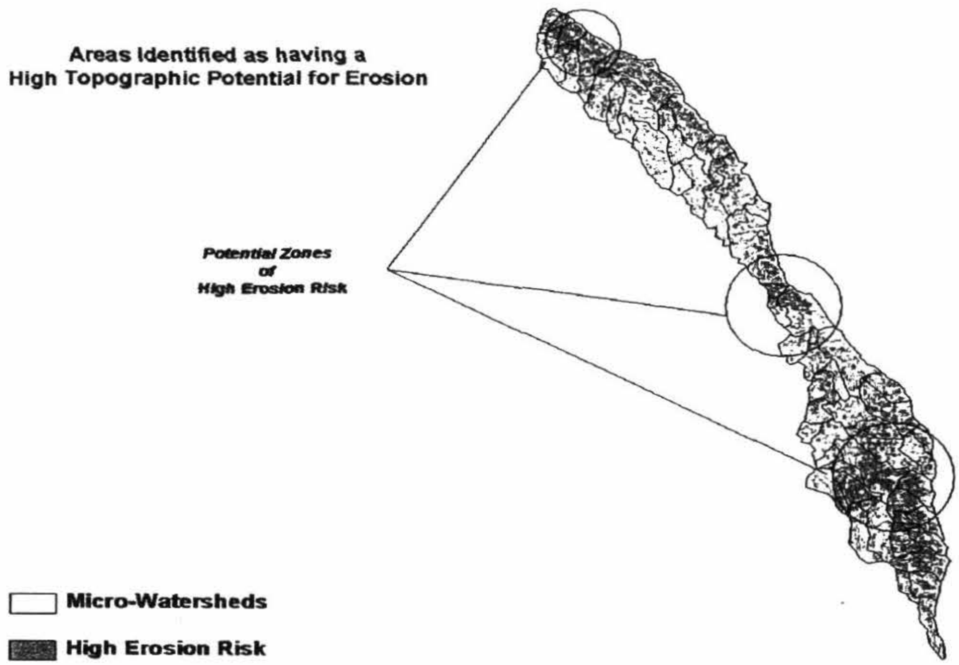

Figure 43 . Areas with high erosion risk in the Rio Cabuyal Watershed.

Impact:

Areas cropped with annual crops where considered as important as bare areas, because depending on the time of year, land cover of these areas is variable. These areas are also likely to be the areas currently with soil erosion problems. Forested areas found in areas depicted as having a high potential for erosion were considered areas that should be protected from future deforestation. High risk areas with pasture are considered possible erosion risk areas if the land cover was to change, therefore these areas should be promoted for permanent cover crop cultivation or with the implementation of management practices.

This information needs to be verified on the ground with potential to be used in any future planning activities that the local communities and authorities may initiate as part of a local watershed management plan.

Table 43. Ranking of land use according to management priority.

Rating	Land Use	Erosion Risk	*Management Actions*
1	Bare/Fallow	High	Requiring immediate implementation of soil conservation practices
1	Annual Crops	High	Requiring immediate implementation of soil conservation practices
2	Permanent Crops	High	Implementation of soil conservation in the near future
3	Pasture	High	Areas to maintain under permanent cover. Potential areas of agriculture with soil conservation methods
4	Forests	High	Protected zones. No Deforestation of these areas.

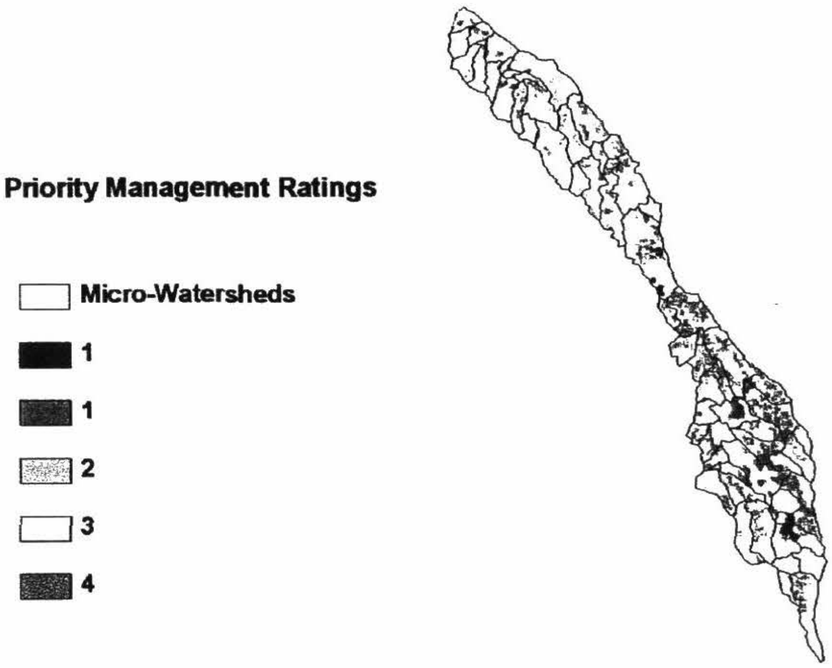

Figure 44. High risk areas identified by combining erosion risk with land management

Contributors

K. Pallaris (King's College London & CIAT), R. Thomas, E. Amézquita and G. Hyman (CIAT).

3.6.2 Mapping of soil restrictions as part of a land use planning tool

Highlight:

- A GIS application has been developed to map soil constraints and land use restrictions from the IGAC soil studies in Colombia in an automated way. This application is part of a land use planning tool developed in CIAT and which is being used by the Puerto López municipality in its land use planning process.
- A guidebook has been written to enable other municipalities to build their own system from IGAC's soil studies (where available), the MapMaker GIS software and the Microsoft Excel Spreadsheet.

Purpose:

To allow municipalities to easily plan general land use strategies that consider soil constraints derived from semi-detailed soil studies developed by IGAC.

Rationale:

Municipalities need low cost and easy-to-use tools to allow them to synthesize information and take decisions. We found there needed to be more intuitive and more accessible tools than the ones available at the moment. We were confronted with these concerns while supporting the Municipality of Puerto López (CIAT's municipal-level savannah benchmark site) in the Land Use Planning process, or *ordenamiento territorial*, that is required from Colombian municipalities in 1999.

Materials and methods:

A preliminary version of a land use planning tool was elaborated by the Land Use and Soils projects with the municipality of Puerto López (PE-4 annual report, 1999). This tool is composed of a GIS (MapMaker Popular) linked to a spreadsheet program (Mircrosoft Excel) and to a series of guidebooks in Adobe Acrobat (PDF) format. A series of menus guides the user through the planning process.

One of the steps of this process is to determine the level of land suitability for the land uses contemplated by the stakeholders. For the municipality of Puerto López, for the moment, this suitability has been determined on the basis of soil characteristics only. Other factors such as climate, accessibility to markets, availability of labour, input costs and potential sales prices will have to be taken into account in order to determine if a given portion of land is suitable or not for a given land use or crop. These factors can vary in time, especially the socio-economic ones. When considering only certain factors, it is more accurate to refer to restrictions rather than suitability. In the following paragraphs, we describe the component of this land use planning tool which determines the restrictions imposed by soils.

In the GIS component of this tool, the management units are represented as polygons. The GIS coverage of land management units is related to a database where the characteristics of each polygon is given in a series of fields. The restriction level is evaluated by confronting these characteristics with the conditions corresponding to different levels through a simple logical formula. But the application of these conditions to soil units represented in the soil map is not straightforward. Soil maps generally represent complex soil associations. Each polygon can contain more than one soil type with potentially different land use restrictions. The level of restriction must then be evaluated for each of the soils and then the proportions corresponding to each of these levels must be calculated for each of the units. The units can then be classified into categories as a function of these different proportions. There are usually a limited number of land unit types that are repeated throughout the map in a much larger amount of polygons. When this is the case, the characterisation is achieved for these land unit types, and the polygons are subsequently linked to this smaller database as a function of the land unit type they represent.

A guidebook has been written to enable municipalities to build their own system from IGAC's soil studies (where available), the MapMaker GIS software and Microsoft Excel (Rodriguez *et al.*, (1999)). The same approach can be used with any other GIS or spreadsheet packages. The guidebook describes the steps to prepare the spreadsheet from the data relative to the land units, how to evaluate the level of restriction for each soil type as a function of crop requirements, and how to classify the land units as a function of the proportions occupied by soils of different restriction levels. The guidebook also presents the requirements for a number of crops of interest for the Colombian *llanos* in terms of precipitation and soil characteristics.

We applied this approach to the municipality of Puerto López using the MapMaker GIS software and the Microsoft Excel spreadsheet. A comprehensive database was derived from the semi-detailed soil study that IGAC has conducted in the area (IGAC, 1978), from which the 1:100 000 soil maps had previously been digitized by CIAT's Land Use project. Among others, the following parameters were determined for each soil type found in each of the soil units: soil effective depth, texture, land slope range, pH range, drainage, moisture regime, percentage of the surface covered by rock fragments and percentage of the profile volume occupied by rocks, cation exchange capacity, organic carbon, total bases, base saturation, aluminium saturation, total nitrogen and phosphorus. When expressed qualitatively or as a range of values, these parameters were then numerically coded following, in some cases, the criteria proposed by IGAC (1996). We have composed a set of restriction formulas from requirement values found in literature, mostly from studies conducted in the region. The user can modify these formulas depending on the requirements of specific varieties, or can create new formulas for additional crops to be considered.

Results and discussion:

Figure 45 shows the screen with which the user displays the map resulting from this process, and accesses the spreadsheet containing the data and criteria formulas. The map presents the results of a general land use restrictions evaluation for use in the Puerto López land use planning process. The areas shown in red correspond to river banks on which it is required, by law, to preserve the gallery forest. The ones shown in pink correspond to areas where more than 60% of the area was characterised as having high slopes (more than 12%). In the colombian llanos slopes are not caused by mountains but by erosion, and these areas correspond to excessively fragile soils. The areas shown in yellowish olive green are ones where more than 60% was characterised as having intermediate slopes (higher than 7%), with a gravely texture or with very superficial soils. These are not suitable for mechanisation except in the valleys, between the hills, where accessibility to machinery is often a problem. These areas are suitable for livestock on native pastures or for tree plantations on relatively flat terrain. Areas shown in dark blue are frequently flooded, and would be best used for the conservation of the gallery forest. Areas in olive green have more than 60% characterised as slightly undulated, and thus have slight mechanisation limitations. They can be used in agropastoril systems involving crops and improved pastures, as long as the mechanisation is not frequent (for example, every two or three years). The areas shown in light green have more than 60% without significant restrictions to mechanisation, so can be used for annual crops such as rice.

In the dissected part of the high plains, at this scale of study, slope can greatly vary within a single map unit. The different soils often correspond to different geomorphological positions that cannot be mapped at this scale, especially since slope varies continuously in the dissected portions of the municipality. For example, in the dissected high plains landscapes, the soils are much deeper, more fertile and richer in organic matter at the bottom of hills and in valleys than on the slopes and the top of hills. The top of hills, sometimes present as relatively wide and flat plateaus, have a limitation in soil depth, because of the presence of plinthite. For planning at the municipal level, it is not necessary to explicitly display this variability. A map with a great number of small polygons can even be confusing. We have found that the general classes that are displayed on figure 45 correspond to the general landscape types for which the restrictions are understood by the local population. An approach based on geomorphological landscapes derived from satellite images could be used for land use planning in municipalities or departments where soil data is not available. These considerations lead to the geomorphological approach described in 3.6.2. However, for planning on a more detailed basis, we feel that the variability within soil units is a great obstacle to accurate statements about the areas available for a given land use. The analysis presented in this section could be refined by using a raster-based Digital Elevation Model, and calculating the restrictions for each pixel, considering local slope. The potential erosion risk could also be used as an input to this mapping of restrictions. In section 3.6.3, we describe an effort to evaluate the erosion risk over the municipality of Puerto López, using a raster approach.

Impact:

The municipality of Puerto López is using the tool in its land use process. The zonification shown in figure 45 corresponds quite well with the actual land use. The environment of the municipality has been relatively well protected because population pressure is not high in the areas, and there are no important agro-industries. However, in its land use planning process, the municipality has expressed its desire to intensify areas that are more resilient and to conserve the most fragile areas. For example, the dissected portion of the municipality is regularly being burnt for an extensive cattle ranching that

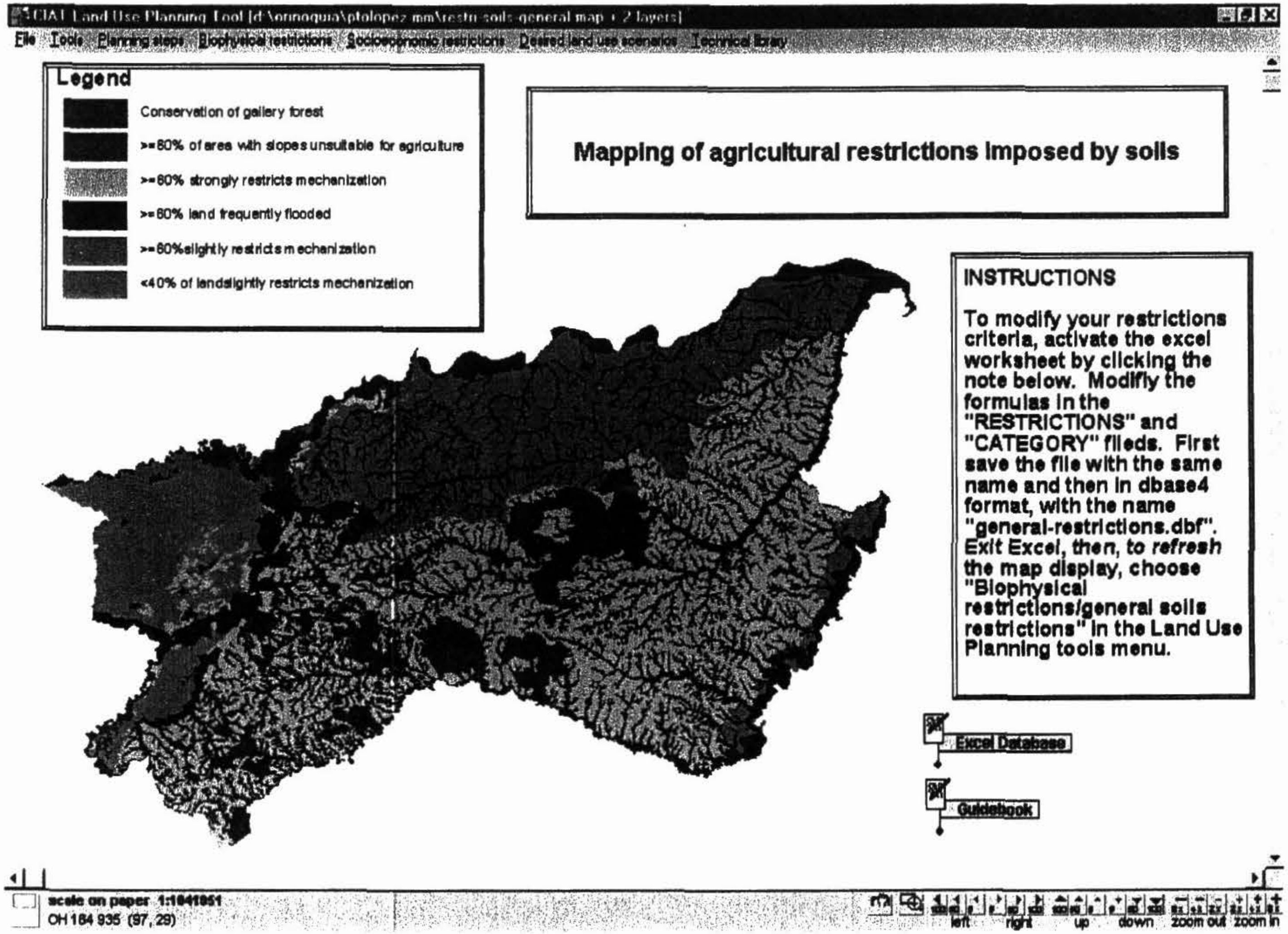

Figure 45: Map of areas with general soil restriction in the Municipality of Puerto López, as produced with the preliminary Land Use Planning Tool under development by the Land Use and Soils projects.

allows very low stocking rates. This area could be better "used" if allowed to be re-colonised by natural vegetation, assuming that the same amount of cattle could be raised on much smaller areas in the flat to slightly undulated high plains, on improved and well managed pastures. In this zone, there are extensive areas of degraded introduced pastures that could be much more productive if adequately managed. Conservation of the dissected portion of the municipality would be possible because of the actual low pressure on land. But some perceive the Colombian savannahs as an underdeveloped territory with great potential for producing food for the urban sectors of the country. National agro-industrial policies could induce pressure on the area if policymakers are not well informed of the restrictions. These restrictions must also be considered in the eventuality of a land reform to avoid unsuitable land being given to small farmers.

Contributors:
Nathalie Beaulieu, Maryory Rodriguez (pre-graduate student in Agricultural Engineering, Universidad del Valle and Universidad Nacionalde Palmira) Yolanda Rubiano (Doctoral student at the Universidad Nacional de Palmira), Edgar Amézquita, Phanor Hoyos.

Further reading:
Rodriguez, M., Rubiano, Y., Beaulieu, N. y Muñoz, O. (1999) Guía para la evaluación de la capacidad de uso de los suelos y su aptitud para cultivos específicos usando los estudios de suelos semi-detallados preparados por el IGAC (Colombia), la hoja de cálculo Excel y el sistema de información geográfica MapMaker Popular. CIAT, Cali, Colombia (downloadble from http://www.ciat.cgiar.org/sabanas/documentos.htm)

References:
IGAC (1978). Estudio general de suelos de los municipios de Cabuyaro, Fuente de Oro, Puerto López, San Carlos de Guaroa y la Inspección de Barranca de Upia. Departamento del Meta. Santafé de Bogotá..

IGAC (1996), ,Manual de códigos para los levantamientos de suelos, Instituto Geogáfico Augustín Codazzi, Subdirección de Agrología Santa Fé de Bogotá, Colombia.

3.6.3 Criteria has been developped to establish land use restrictions in function of geomorphological landscape types

Highlights:

- A table has been elaborated, describing soil limiting factors and land use restrictions for different geomorphological positions in different landscape types
- Landscape types have separately been mapped from the existing digitized soil map (IGAC, 1978) and Radarsat images. We have also shown that Landsat TM and JERS-1 can be used in the mapping of geomorphological landscapes, and used for land use planning in areas where semi-detailed soil maps are not available.

Purpose:

- To provide a simple approach for land constraints evaluation for the regional and departmental planners as well as for municipalities who do not have semi-detailed soil studies in a digital form.
- To explore how land use recommendations can be related to landscape types, drawn from satellite imagery and field surveys, complemented by soil sampling in the field or use of a soil map

Rationale:

A planning approach based on geomorphological landscapes appears very suitable because landscapes are concepts that can be intuitively shared by professionals of different disciplines as well as by the local population. In the savannas, soil constraints could eventually be related to the position within the landscapes, for specific landscape types. Landscape types can be digitized on the computer screen from geocoded satellite images. The cost of satellite images is becoming very affordable and these could be used as basic information for rural land use planning at the municipal and departmental levels.

Materials and methods:

The soil map described in section 3.6.2 and the soil constraints map that was derived from it were overlaid on different types of satellite images to determine if the restrictions classes could be distinctively mapped from the images.

On the basis of field visits and consultation with soil experts, the general relationship between soil constraints and the position within the landscape was established. A table has been elaborated, describing soil limiting factors and land use restrictions for different geomorphological positions in different landscape types. A quatitative analysis of how soil characteristics can be related to topographically derived factor such as position, slope, convexity and flow accumulation remains to be achieved.

Results:

Figure 46 shows a generalized map of landscape types, overlaid onto a portion of a JERS-1 image mosaic produced by the Japanese National Space Development Agency (NASDA, 1998). A more detailed version of this map was first derived from a RADARSAT-1 SAR image (Rubiano y Beaulieu, 1999), which unfortunately did not cover the entire municipality. We then completed it using a Landsat TM image and the soil map mentioned earlier. We found that most of the features visible on the high resolution Landsat TM or RADARSAT-1 images were also visible on the JERS-1 image mosaic produced by the Japanese National Space Development Agency (NASDA, 1998), which covers the municipality as well as 5 of the 7 departments under study. We therefore decided to derive interpretation keys from the Puerto Lopez municipality to help the department of Meta map the units in the neighbouring municipalities from the JERS-1 mosaic. Although this mosaic, with a pixel spacing of aproximately 100m, allows a less detailed analysis than the full-resolution JERS-1, RADARSAT-1 or Landsat TM images, it is presently the best data set we have in order to appreciate forest cover and geomorphology in the region.

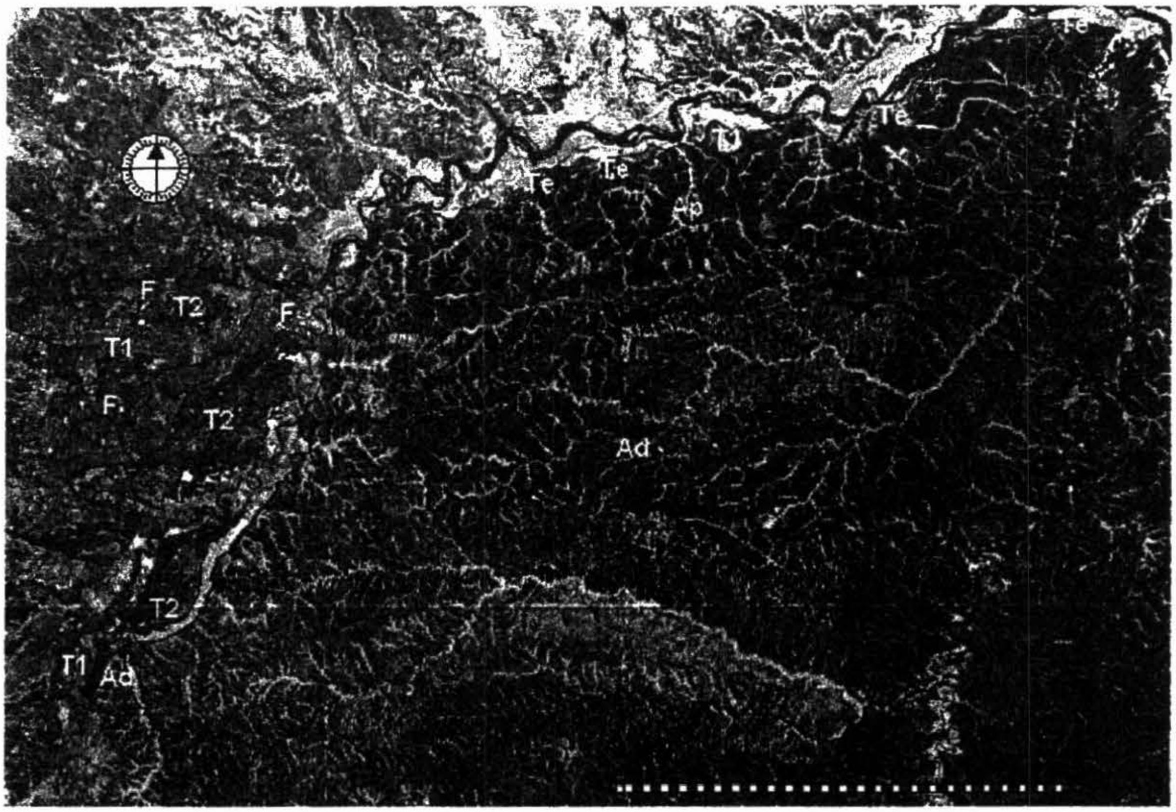

Figure 46: General map of landscape types ovelaid on a portion of a mosaic of JERS-1 images acquired in 1995 (©NASDA, 1998), over the municipality of Puerto López. Landscape types presented are the flat high planes (Ap), the dissected high plains (Ad), depositional alluvial terrasses (T1 and T2), floodplanes (F) and erosional terrasses (Te).

Impact:

A land use planning strategy that is based on landforms and landscape types would allow a more straightforward planning process where digitised semi-detailed soil studies are not available. This process would be more easily understandable by scientists of different fields, planners, and the local population. Recommendations based on landscape types can be further supported by soil or topographic data where available. The monitoring of the implementation of recommendations is much easier if these are expressed in relation with geomorphological positions. For example, it is easier to verify if the slopes in the dissected high plains are protected from mechanization and if improved pastures are in deed only cultivated at the flatter bottoms than to verify if a given geographical coordinate is being used as is recommended on a map. A better understanding of the distribution of soil limitations within the landscape will help planners and inspectors gain a "common sense" of what can and can't be done, a sense that the farmers themselves have often already acquired. This could avoid the dissected portions of the colombian savannas to be the object of a land reform or planned colonization, which could be very detrimental to their stability.

Contributors:
Yolanda Rubiano, Nathalie Beaulieu, Luis Marino Santana (Professor of Geography at the Universidad del Valle, Cali, Colombia), Edgar Amézquita

Further reading:
Rubiano, Y. y Beaulieu, N (1999). Uso de las imágenes RADARSAT en la cartografía de unidades de paisaje en la Orinoquia colombiana: estudio de caso en el municipio de Puerto López, Meta. Memorias del Simposio final GlobeSAR 2, "Aplicaciones de RADARSAT en América Latina", Buenos Aires, 17-20 de mayo 1999. (downloadble from http://www.ciat.cgiar.org/sabanas/documentos.htm)

Rubiano, Y., Santana, L.M., Beaulieu, N. (1999) Criterios para planificacion del uso de la tierra en los llanos orientales colombianos, basados en unidades de paisaje. Estudio de caso en el municipio de puerto lopez. Informe interno, CIAT. (downloadble from http://www.ciat.cgiar.org/sabanas/documentos.htm)

Beaulieu, N., Rubiano, Y., Vrieling, A, Rodriguez, M., Jaramillo, J.E., Muñoz, O.J., and Zakhia, N. (1999).Use of GIS in land resource management in the Colombian Orinoco Region. Presented at the 6th JIRCAS symposium "GIS Applications for Agro-environmental issues in Developping regions", organized by the Japan International Research Center for Agricultural Sciences, Tsukuba, Japan, 7-9 September 1999. (downloadble from http://www.ciat.cgiar.org/ sabanas/ documentos. htm)

References:

NASDA (1998). JERS-1 SAR mosaic, Global Rain Forest Mapping Project, South America, Sep/Dec 1995, Volume AM2. Set of 2 CD-ROM.

3.6.4 The risk of soil erosion over the municipality of Puerto López was evaluated using the Universal Soil Loss Equation

Highlight:

- Soil erosion risk was estimated and mapped over the Puerto López Municipality using the Universal Soil Equation using. Using a raster approach, parameters were derived from a 1:100 000 scale soil map, a Landsat TM satellite image and a Digital Elevation Model.

Purpose:
To map the distribution of the potential and actual soil erosion risk in order for the municipality to take this factor into account while planning agricultural development and conservation.

Rationale:
The planning of land use must take into account the risk of soil erosion. This risk can be assessed in a qualitative way. The Universal Soil Equation (Wischmeier and Smith, 1978) is an equation that has been empirically developed to predict the average annual

soil losses due to laminar sheet and rill erosion. It is the statistical summary of more than 10 000 plot-years of data collected on natural runoff plots in the eastern USA. Although it is a quantitative empirical determination that is often criticised, it is more often used to qualitatively locate the most critical areas for soil erosion. The equation is a multiplication of factors to account for rainfall erosivity, soil erodibility, relief, vegetation and conservation practices. The data availability for the constituting factors is low in Latin American countries and various assumptions are needed to come to satisfying values. An accurate application of the USLE would require much more research and experimental data in the Colombian Orinoco. In site of this, the method can be used to make a rough estimation of the spatial distribution of the erosion risk. Since it is the most widely used erosion prediction equation, it can also be used to compare results obtained for one site with the ones obtained by others on other sites, taking into account the assumptions that have been made for each of the parameters.

Materials and Method:
The equation reads:

$$A = R * K * L * S * C * P \qquad (1)$$

in which:

A	= the average annual soil loss	($t\ ha^{-1}\ y^{-1}$)
R	= the rainfall and runoff factor	($MJ\ ha^{-1}\ mm\ h^{-1}\ y^{-1}$)
K	= the soil erodibility factor	($t\ MJ^{-1}\ h\ mm^{-1}$)
L	= the slope length factor	(adimentional)
S	= the slope gradient factor	(adimentional)
C	= the cover and management factor	(adimentional)
P	= the conservation practice factor	(adimentional)

Determination of the rainfall erosivity factor, R
The erosive force of the local rainfall regime (the erosivity) is represented by the rainfall factor. The product of kinetic energy and rainfall intensity gives a good representation of this erosivity. The kinetic energy and the R factor can be calculated as follows (Foster *et al.* 1981):

$$e_m = 0.119 + 0.0873 \log(I_{30} * 2) \qquad (2)$$

$$R = \sum_{j=1}^{n} \left[e_m (I_{30} * 2) p \right]_j \qquad (3)$$

where e_m = kinetic energy ($MJ\ ha^{-1}\ mm^{-1}$)
I_{30} = maximum intensity in 30 min. ($mm\ h^{-1}$)
p = precipitation per shower occurrence (mm)
j = number of shower occurrences from 1 to n, n being the total yearly number of shower occurrences

However, detailed pluviographic data is needed to apply these equations. This data could not be obtained within the Puerto López municipality. In a neighboring municipality an erosivity study has been done using climatic data for two sequential years 1979 and 1980 (Restrepo and Navas, 1981 and 1982). They obtained a value of 1600 to 1700 $MJ\ ha^{-1}\ mm\ h^{-1}\ y^{-1}$. Furthermore an isoerodent map, showing lines of equal rainfall erosivity, was available for the whole of Colombia at a scale 1: 3.400.000 (IGAC, 1988). This map shows that the municipality lies in a zone with erosivity between 1500 and 3000 MJ ha^{-1} mm h^{-1} y^{-1}. Taking into account the location of the neighbouring municipality and the transition to other zones in the map, a value of 2000 MJ ha^{-1} mm h^{-1} y^{-1} was considered an acceptable estimate for Puerto López. Given the available data the same value was applied for the total area.

Determination of the soil erodibility factor, K

This factor quantifies the cohesive, or bonding character of a soil type and its resistance to dislodging and transport due to raindrop impact and overland flow. It can be linked to the soil properties through the soil erodibility nomograph (Wischmeier *et al.*, 1971). This nomograph uses the following inputs:

Percentage silt and very fine sand (2 - 100 µm)
Percentage sand (> 100 µm)
Percentage organic matter
Class for soil structure
Permeability class

The output is the soil erodibility in English units. This value can be converted to the metric system through multiplication by 1.292 (Foster *et al.*, 1981).

Table 44: Classes for soil structure and permeability in the soil erodibility nomograph.

Classes of soil structure	Permeability classes
1 Very fine granular	1 Rapid
2 Fine granular	2 Moderate to rapid
3 Medium or coarse granular	3 Moderate
4 Blocky, platy, or massive	4 Slow to moderate
	5 Slow
	6 Very slow

To determine the K factor over the municipality, we used a semi-detailed study prepared by IGAC (1978) for which the 1:100 000 scale maps had previously been digitized by the Land Use project at CIAT. In this study, the very fine sand fraction was not determined. Therefore an assumption had to be made. According to Amézquita (personal communication, July 1999), it is realistic to assume that 20 percent of the sand fraction of the soils in the area consists of very fine sand. The structure class of the present soils is therefore either 3 or 4. Structure class 3 was related to a low permeability, structure class 4 was related to a very low permeability. Each soil unit can contain various soil types. A weighted average K value was calculated for each unit, weighing the values found for each constituing soil by the percentage of area it occupied. The K-values calculated for the different soil units vary between 0.21 and 0.61 t MJ^{-1} h mm^{-1} with a mean value of 0.35 t MJ^{-1} h mm^{-1}. The most erodible soils occur near the rivers, where the percentage lime and very fine sand is usually higher. Knowledge of how soil properties vary with topography would have allowed us to elaborate a more detailed map of the K factor based on the available Digital Elevation Model.

Determination of the combined slope and slope length factor, LS

The effects of topography and hydrology on soil loss are characterized by the combined LS factor. According to Wischmeier and Smith (1978), the LS factor is calculated as follows:

$$LS = (L/72.6)^m * (65.41\sin^2 S + 4.56\sin S + 0.065) \qquad (9)$$

where L is the slope length (feet), S is the degree of slope and

m = 0.5 if S • 5.0 %
m = 0.4 if 3.5 % • S < 5.0 %
m = 0.3 if 1.0 % • S < 3.5 %
m = 0.2 if S < 1.0 %

ARC-INFO Macro Language (AML) programs provided by Hickey *et al.* (1994) have been used to calculate the LS-factor within the Arc/INFO Grid computing environment, using a Digital Elevation Model (DEM). This program establishes the high points from the DEM, then, following the flow direction, calculates a cumulative LS value down the slope. The user inputs a value for the minimum slope change required to cause deposition. This value was set at 0.5 %. The program is iterative and runs a number of times on the entire grid. To test the program a standard plot was constructed with a slope length of 22.1 m and a slope of 9 % (Mutchler *et al.*, 1988) and a grid spacing of 0.10 m. At the bottom of the slope the LS-factor should result in a value of 1.0. As this was the case, it was concluded that the program functioned well.

We used a grid DEM that had been derived from a mosaic of 58 topographic maps at 1:25000 scale, from which elevation contour lines and streams had been digitized by CIAT's land use project. High values of LS were found in the dissected portion of the high plains or '*altillanura*' and at the transition from '*altillanura*' to alluvial terraces. Values are highest at the bottom of the slopes. Values higher than 6.0 were hardly present and therefore ignored as possible errors. Their value was set to 6.0. The average value for the study area was 0.41. A very small part of the western portion of municipality is missing from the DEM coverage, so the USLE analysis was achieved for area that was covered by this DEM and by the soil study.

Determination of the land cover and management factor, C

The land cover and management factor is defined as the ratio of soil loss from an area with a specified cover and management to that from an identical area of tilled continuous fallow. The standard C-value is a weighted average of seasonal cover-management factor values.

A Landsat-TM satellite image of August 10^{th},1998 was classified to obtain actual land use on the basis of land use samples delimited in the field with a GPS receiver. On the basis of verification samples, it is estimated that the overall accuracy of this classification is 86%. The classes present in this map are improved pasture, native pasture (including burned areas), transitional vegetation, forest, fruit and rubber plantations, rice, open water, bare soil. Since fruit and rubber plantations were spectrally similar to transitional vegetation, and since there were only a few of these plantations, they were digitised on the screen around the samples that were located in the field. The very reduced part of the image that was affected by clouds was filled in with a classification of an image acquired on January 9th, 1996. There was quite a bit of confusion between native and improved pastures, because of the heterogeneity that both these classes present. However, the map did represent the general known distribution of improved pastures in the flat and slightly undulated high plains (*altillanura*), and native pastures in the dissected high plains (*altillanura disectada* or *serranía*).

C-values were determined on the basis of land use classes in this map as well as from estimations of the vegetative ground cover derived from the Normalized Difference Vegetation Index (NDVI) calculated from the image. Table 45 shows the values used in this study. The values for classes 1 to 5 were derived from Wischmeier and Smith (1978), the value for rice was taken from Roose (1977) and the C-factor for plantations from Pastor (1994).

Table 45: C-values for the land use classes derived from the Landsat-TM image

Land use classes in image classification	Description in Literature	Vegetation Cover	C-values
1 Introduced pastures	Permanent pasture, range	0	0.45
2 Natural pastures	and idle land without	20	0.20
	appreciable canopy	40	0.10
		60	0.042
		80	0.013
		95+	0.003
3 Transitional vegetation	Range land with	60	0.038
	appreciable brush or	80	0.012
	brushes with 50%	95+	0.003
	canopy cover		
4 Forest	Undisturbed forest land with 75 to 100 cover	-	0.0001-0.001
5 Bare soil	Bare soil	-	1.0
6 Water	-	-	0.0
7 Rice	Rice (intensive fertilization)	-	0.1 - 0.2
8 Tree plantations	Plantation	-	0.04

Where a range of data was given in literature, the highest value was taken. The vegetative ground cover was used to determine the C-values for Native and introduced pastures as well as for transitional vegetation. Linear interpolation was used to determine C-values corresponding to ground covers falling between the values in table 45. The average C-value that was obtained for the municipality is 0.092.

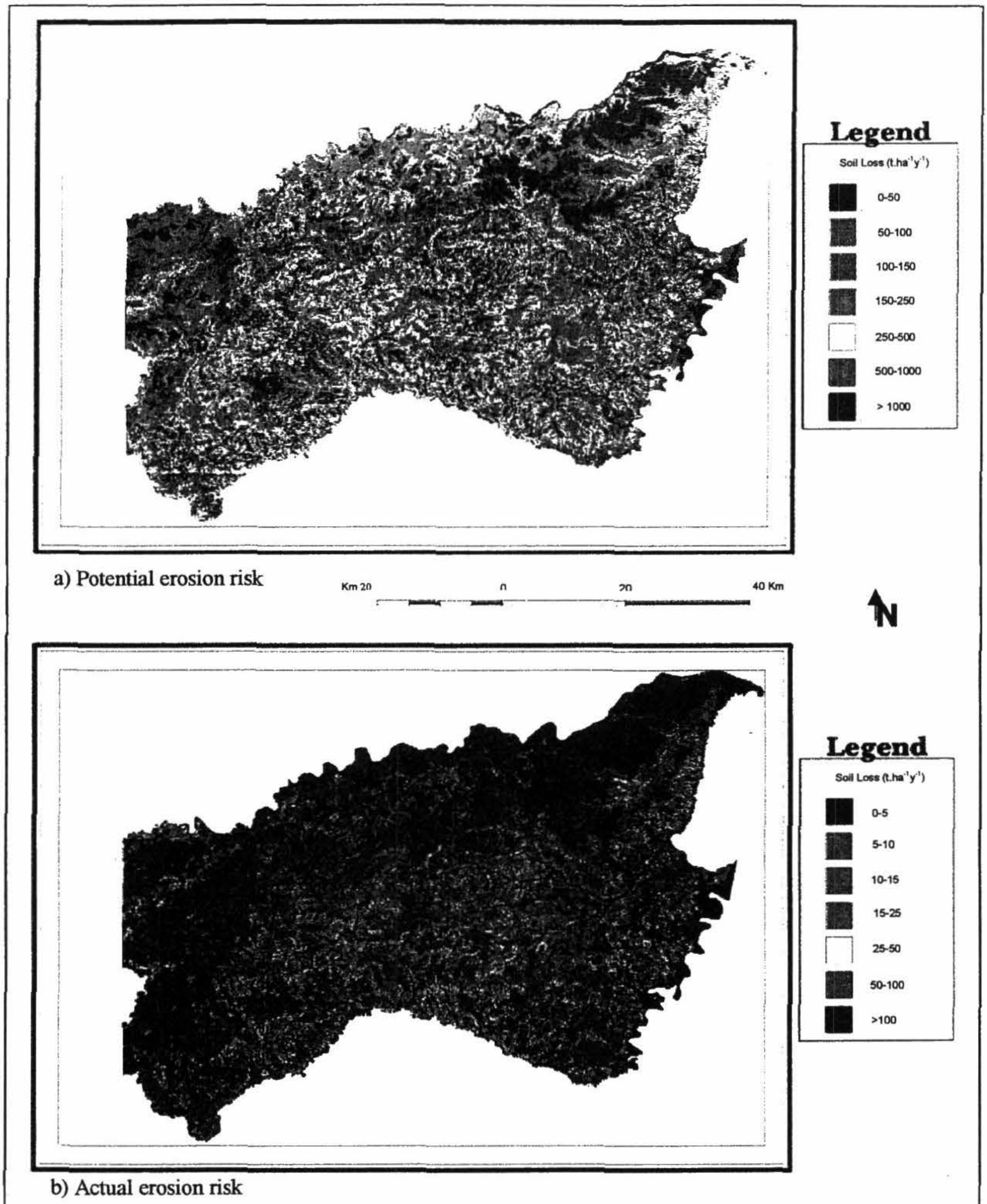

Figure 3: Potential and actual erosion risk estimated over the Municipality of Puerto López using the Universal Soil Loss Equation (USLE).

Determination of the conservation practice factor, P
A specific support practice, like contouring or contour strip cropping, can reduce the soil loss. This is accounted for in the conservation practice factor. As in the municipality hardly any support practices were encountered, this factor was fixed to 1.0. It remains to be said though that a few farmers practice contouring, although only on some of the small, cultivated plots. This was considered too insignificant to take into account in this study.

Results:
The various factors were combined to obtain the erosion risk maps. The potential soil erosion risk was determined by ignoring the C and P factors (which is equivalent to setting them to 1) and multiplying the R, K and LS factors. The averaged result for the municipality is 280 t ha^{-1} y^{-1}. The actual erosion risk considers the C and P factors. As we fixed the P factor to 1, we obtained the actual erosion risk by multiplying the potential erosion risk with the calculated C-factor. The average value obtained for the study area is 11 t ha^{-1} y^{-1}. Maps of potential and actual erosion risks are shown in figure 46a.

The potential erosion map of figure 46avaries mostly in function of the LS-factor, because the range in LS-values is much higher than the range for K-values. The actual erosion risk map in figure 46b shows less dependence on the LS factor because the C-values also have a wide range (the C value for bare soil is 1000 times as high as the value for forest).

Impact:
This analysis allows an assessment of the fact that, in the municipality of Puerto López, the soil erosion risks are concentrated along rivers and in the dissected high plains. This means that agricultural intensification should be conducted in the flat to undulated high plains (*altillanura*) or in the alluvial soils of the foothills (*piedemonte*), and that the gallery forest must be conserved on river banks. An explicit representation of this in the maps accompanying the land use plan Puerto López is presently preparing will certainly reinforce the application of these recommendations. This confirms the results presented in section 3.6.2 and also allows a more detailed appreciation of constraints, thanks to the use of a DEM derived from 1:25000 scale topographic maps. The maps could then be used for more detailed planning, for example at the village level.

Contributors:
Anton Vrieling (student in Tropical Agriculture at the Wageningen Agricultural University), Nathalie Beaulieu, Edgar Amézquita, Yolanda Rubiano.

References:
Foster G.R., McCool D.K., Renard K.G., and W.C. Moldenhauer, 1981. Conversion of the universal soil loss equation to SI metric units. Journal of Soil and Water Conservation 36(6): 355-359.
IGAC, 1978. Estudio general de suelos de los municipios de Cabuyaro, Fuento de Oro, Puerto López, San Carlos de Guaroa y la Inspección de Barranca de Upia

(Departamento del Meta). Instituto Geográfico "Agustín Codazzi", subdirección de Agrológica.

IGAC, 1988. Suelos y bosques de Colombia. Instituto Geográfico "Agustín Codazzi", subdirección de Agrológica.

IGAC, 1995. Suelos de Colombia; origen, evolución, clasificación, distribución y uso. Instituto Geográfico "Agustín Codazzi", subdirección de Agrológica.

Lal, R., 1990. Soil erosion in the tropics: principles and management. McGraw-Hill Inc., USA

Mutchler, C.K., C.E. Murphy and K.C. McGregor, 1988. Laboratory and field plots for soil erosion studies. *In:* R. Lal (ed.) Soil Erosion Research Methods. Soil Water Cons. Soc., Aukeny, IA

Pastor, R.P., 1994. Simulación hidrológica y de erosión de suelos utilizando el modelo distribuido ANSWERS: aplicación en la cuenca del Río Pejibaye, Cartago, Costa Rica. MSc tesis Centro Agronómico Tropical de Investigación y Enseñanza Turrialba, CR.

Restrepo, H. and J. Navas A., 1981. Características de la erosión física y química en el establecimiento de praderas en suelos de los Llanos Orientales. *In*: Instituto Colombiano Agropecuario. Programa nacional de suelos; informe de progreso 1981.

Restrepo, H. and J. Navas A., 1982. Resultados preliminares de la investigación sobre erosión en la Orinoquia Colombiana. Instituto Colombiano Agropecuario

Roose, E.J., 1977. Application of the Universal Soil Loss Equation of Wischmeier and Smith in West Africa. *In*: Conservation and soil management in the humid tropics (D.J. Greenland and R. Lal, eds.). Wiley, Chicester, UK

Wischmeier, W.H., Johnson C.B. and B.V. Cross, 1971. A soil erodibility nomograph for farmland and construction sites. Journal of Soil and Water Conservation 26(5): 189-193.

Wischmeier, W.H. and D.D. Smith, 1978. Predicting rainfall erosion losses - Agricultural handbook 537. United States Department of Agriculture.

Output 4. Institutional capacity for SWNM enhanced through the dissemination of concepts, methods, tools and training

Activity 4.1 Organize and coordinate field days and workshops

Highlight:

- Organized and coordinated 12 field days for 265 visitors (64% farmers and extensionists, 36% students).

A total of 12 field days have been held at San Isidro Farm between November 1998 and May 1999 with the participation of 265 visitors (64% farmers and extensionists, 36% students) as a way to expose and diffuse alternative technologies and approaches in the management of natural resources within crop-livestock and agroforestry systems.

Contributors:
C.A. Trujillo, J.G. Cobo and E. Barrios

Activity 4.2: Prepare bulletins on agropastoral systems and SWNM

Highlight:

- Edited and published a book on agropastoral systems for savannas of Latin America.

The project scientists in collaboration with a researcher from EMBRAPA and financial support from SWNM, edited and published a book on agropastoral systems for savannas of Latin America.

Activity 4.3: Promote and participate in specialized training courses, prepare training materials

Highlight:

- Participated in two training courses (Santander de Quilichao – Colombia, Santiago de los Caballeros – Dominican Republic) using the guide "Participatory Methods for the Identification and Classification of Local Indicators of Soil Quality at the Watershed Scale".

Participated in two training courses directed to farmer groups, government and non-government agencies (Santander de Quilichao – Colombia, Santiago de los Caballeros – Dominican Republic) using the guide for "Participatory Identification and Classification of local Indicators of Soil Quality at the Watershed Scale".

Contributors:
M.T. Trejo and E. Barrios

Activity 4.4 Publish research results in refereed journals and other publications

Highlight:

- Published 25 refereed journal articles, 5 refereed book chapters, 2 edited books, 27 non-refereed book chapters and 9 articles in conference proceedings.

The project team in collaboration with partners have published 25 refereed journal articles, 5 refereed book chapters, 2 edited books and 27 non-refereed book chapters, 9 articles in proceedings of the conferences. In addition to these publications, the team has also contributed to a guide on soil quality (see the list of publications – pages 152 to 158).

Guía #1. Instrumentos Metodológicos para la toma de Decisiones en el Manejo de los Recursos Naturales. CIAT. 1999. Método Participativo para Identificar y Clasificar Indicadores Locales de Calidad del Suelo a Nivel de Microcuenca". M.T.Trejo, E. Barrios, W. Turcios, H. Barreto.

Activity 4.5: Supervise postdoctoral research, graduate and undergraduate theses

Highlight:

- Supervised 20 undergraduate theses, 13 MSc theses and 11 Ph.D. theses.

The following is a list of undergraduate and graduate students who received training with the project scientists (Table 44).

Table 44. Training supported by PE-2 and MAS consortium of SWNM Program.

Name	Nationality	Education	Institution	Research theme
J. Lilienfein	Germany	Post-doc	Bayreuth Univ.	Nutrient/water fluxes
W. Wilcke	Germany	Post-doc	Bayreuth Univ.	Nutrient/water fluxes
R. Delve	U.K.	Post-doc	TSBF/CIAT	Organic matter database
M.A. Rondon	Colombia	Ph.D.	Cornell Univ.	Greenhouse gas fluxes
W. Trujillo	Colombia	Ph.D.	Ohio State Univ.	Carbon sequestration
S. Buhler	Switzerland	Ph.D.	ETH, Zurich	Phosphorus acquisition/cycling
S. Phiri	Zambia	Ph.D.	Norway Agric. Univ.	Phosphorus acquisition/cycling
Nelson Castañeda	Colombia	Ph.D.	Univ. of Gottingen	Genotypic variation in P acquisition & utilization in *A. pintoi*
J.J. Jimenez	Spain	Ph.D.	Univ. Complutense, Madrid	Earthworm dynamics
Y. Rubiano	Colombia	Ph.D.	Nacional, Palmira	Soil degradation indicators
R. Westerhof	Netherlands	Ph.D.	Bayreuth Univ.	Soil quality indicators
H. Neufeldt	Germany	Ph.D.	Bayreuth Univ.	Soil quality indicators
E. Madero	Colombia	Ph. D.	Nacional, Palmira	Soil structure
H. Rivera	Colombia	Ph. D.	CENICAFE	Erodibility of hillsides soils

Name	Nationality	Education	Institution	Research theme
T. Renz	Germany	M.Sc.	Bayreuth Univ.	Soil quality indicators
S. Fuhrmann	Germany	M.Sc.	Bayreuth Univ.	Soil quality indicators
A. Freibauer	Germany	M.Sc.	Bayreuth Univ.	Soil quality indicators
V. Laabs	Germany	M.Sc.	Bayreuth Univ.	Fate of agrochemicals
R. Gross	Germany	M.Sc.	Bayreuth Univ.	Fate of agrochemicals
T. Thiele	Germany	M.Sc.	Bayreuth Univ.	Podzolisation
Y. Zinn	Brazil	M.Sc.	EMBRAPA-CPAC	Soil organic matter
U. Schwantag	Germany	M.Sc.	Bayreuth Univ.	Water/nutrient fluxes
A. Schill	Germany	M.Sc.	Bayreuth Univ.	Water/nutrient fluxes
J. Mahambre	Burundi	M.Sc.	University of Norway	Drought adaptation in Common bean (Phaseolus Vulgaris L.)
H. Ruiz	Colombia	M.Sc.	Nacional, Palmira	Improvement of degraded Soils
C.P. Cerón	Colombia	M.Sc.	Nacional, Palmira	Local knowledge about soils and their management
R. Torres	Colombia	M.Sc.	Nacional, Palmira	Soil quality indicators
I. Valenzuela	Colombia	B.Sc.	Univ. Tecnológica Del Llano	Water movement
G. Perea	Colombia	B.Sc.	Univ. Tecnológica del Llano	Water movement
E. Torres	Colombia	B.Sc.	Univ. del Valle	Rainfall simC.P. Culator
M. Banguero	Colombia	B.Sc.	Nacional Palmira	Erodability in Hillside
L. Bejarano	Colombia	B.Sc.	Nacional Palmira	Erodability in Hillside
A. Salamanca	Colombia	B.Sc.	Nacional Palmira	Caracterización fisica de suelos bajo Desmodium
L. Alvarez	Colombia	B.Sc.	Univ. Amazonia	Genotypic differences in P acquisition efficiency of 10 genotypes of Arachis pintoi
D.M.Arias	Colombia	B.Sc.	Nacional, Palmira	Drop impact on soil structure
L. Cobo	Colombia	B.Sc.	Univ. del Valle	Rainfall simulator
Y. Conta Diaz H.. Baracaldo	Colombia	B.Sc.	Amazonia, Florencia	Determining root growth and distribution among native ...
G.P. Botero	Colombia	B.Sc.	Nacional, Palmira	Water movement
E.M. Quintero	Colombia	B.Sc.	Nacional Palmira	Soil quality indicators
Y.S. Suárez	Colombia	B.Sc.	Nacional Palmira	Soil quality indicators
L.X. Salamanca	Colombia	B.Sc.	Nacional Palmira	Soil quality indicators
X. Pernett	Colombia	B.Sc.	Nacional, Palmira	Climate studies in the llanos
A.R. Parrado	Colombia	B.Sc.	Univ. del Llano	Pastures and soil degradation – Llanos.
C. Zamorano	Colombia	B.Sc.	Nacional, Palmira	Soil quality indicators
C.L. Herrera	Colombia	B.Sc.	Nacional, Palmira	Soil quality indicators
B. Moréchal	Netherlands	B.Sc.	International Agri-cultural College Larenstein	Soil erosion
E. Claros	Colombia	B.Sc.	Nacional, Palmira	Participatory assessment of live barrier systems.

Activity 4.6 Foster linkage with institutions in the region and advanced research organizations

Highlight:

- Established and maintained collaborative links with partners.
  The project team has established and maintained linkages with a number of collaborators as listed below.

NARS:
CORPOICA – La Libertad, Colombia; A. Rincón, R. Valencia, J.J. Rivera, C.J. Escobar
CORPOICA – Macagual, Colombia, C. Escobar
EMBRAPA-CPAC, Brazil: L. Vilela, D. Resck, C. Magno da Rocha, A.G. de Araujo, J.E. da Silva.
EMBRAPA-CNPAB, Brazil; R. Boddey, S. Urquiaga, B. Alves

NGO'o:
CIPASLA
CENICAFE, H. Rivera
CRC (Corporación Regional del Cauca), J. Chavez
FEDEARROZ, G. Preciado
CIPAV, E. Murgueitio, S. Siadieagien
CIDIAT, Venezuela – R. Lopez
COLCIENCIAS, G. Urrego
INPOFOS, Ecuador – J. Espinosa
MONOMEROS COLOMBO-VENEZOLANO, R. Guerrero
CENIPALMA, P.L. Gómez, F. Munevar

Regional Universities:
Lavras, Brazil; Prof. A.S. Lopes
Uberlandia, Brazil; M. do Schneider, R.S. do Carmo Lima
UNELLEZ/CIELAT, Venezuela; L. Sarmiento, G. Sarmiento

Specialized Institutions:
Bayreuth University; Prof. W. Zech, W. Wilcke, J. Lilienfein, A. Freibauer, H. Neufeldt, R. Westerhoof, T. Renz, T. Thile, S. Fuhrmann, V. Laabs, W. Amelung.
Cornell University, USA; Prof. J. Duxbury, F. Fernandes
Ohio State University, USA; Prof. R. Lal
Michigan State University, USA; Prof. J. Ritchie, S. Daroub
University of Paris/ORSTOM, France, Prof. P. Lavelle
Macaulay Land Use Research Institute, UK; Prof. J. Wilson
University Bangor, Wales, UK; F. Sinclair
Technical High School, Univ. of Zurich, Switzerland; A. Oberson, M. Frossard
Agricultural University of Norway, Norway; Prof. B.R. Singh
University of Gottingen, Germany, Prof. N. Claassen

International Agricultural Research Centers:
CATIE, Costa Rica; D. Kass, J. Beer
ICRAF, Kenya; R. Buresh
TSBF, Kenya; M. Swift, C. Palm
CIRAD, France; M. Vales, M. Chatel
IBSRAM, Thailand; E. Craswell, F. Penning deVries
IFDC, USA; D. Friesen, W. Bowen

National Universities:
Universidad Nacional de Colombia, A. García, E. Madero
Universidad del Valle, H. Jiménez
Universidad de los Llanos, G. Romero
Universidad del Tolima, H.F. Libreros
Universidad de Caldas, W. Chavarriaga
Universidad de los Andes, R. Rosales
Universidad Distrital de Bogotá, G. de las Casas

Universidad Centro Americana y Universidad Nacional Agraria, Managua Nicaragua and with Escuela Agrícola Panamericana Zamorano – Honduras.

Complementary and Special Projects

Research activities reported have been supported from a number of donors (Table 45).

Table 45. List of donors of Complementary and Special Projects:

Donor/Project	Duration	Total Pledge (US$)
ETHZ, *Zurich*, Switzerland Assessing the impact of adapted germplasm on the phosphorus fertility of low phosphorus –supplying tropical soils	1998 – 2001	140,000
DFID – UK Carbon-nitrogen Relations of Soil Organic Matter from Deep-Rooted Grasses in the South American Tropics	1996 – 1999	303,395
PRONATTA, Colombia Impacto de diferentes usos y manejos del suelo en los cambios físicos, químicos y biológicos de los suelos de la Altillanura bien drenada de los Llanos de Colombia	1996 – 1999	51,480
COLCIENCIAS, Colombia Sostenibilidad del Recurso Tierra de la Orinoquía en Realción a su Uso Actual y Potencial	1996 – 1999	172,800
DFID – UK Confronting Soil Erosion and Nutrient Depletion in the Humid/Subhumid Tropics	1998 – 1999	156,037
DFID – UK Potential of Thitonia diversifolia to enhance phosphorus mineralization and cycling	1998 - 2000	20,000
SWNM Managing Acid Soils: Water and Nutrient Fluxes as Indicators of Sustainable Land Use in the Brazilian Savanna	1996 – 1999	360,000
ACIAR Integrated nutrient management in tropical cropping systems: Improved capabilities in modelling and recommendations.	1999-2002	434,130

List of Staff

Senior Staff
Richard J. Thomas
I.M. Rao
Edgar Amézquita
Edmundo Barrios
José I. Sanz
Miguel A. Ayarza

Visiting Scientists
Astrid Oberson

Postdoctoral Fellow
R. Delve
W. Wilcke
J. Lilienfein

Consultants
Myles Fisher
Samira Daroub
Phanor Hoyos

Research Associates
Neuza Asakawa
Marco Antonio Rondón

Research Assistants
Gloria Isabel Ocampo
Irlanda Isabel Corrales
Mariela Rivera
Gloria Marcela Rodríguez
Gonzalo Borrero
Luis Fernando Chavez
Carlos Guillermo Meléndez
Diego Luis Molina
Jenny Quintero
Juan Guillermo Cobo

Secretaries
Carmen de Tchira
Cielo Nuñez

Specialists
Edilfonso Melo
José Arnulfo Rodríguez
Jesús Hernando Galvis

Technicians
Hernán Mina
Amparo Sánchez
Arvey Alvarez
Martin Otero
Jarden Molina
Pedro Herrera
Flaminio Toro
Gloria Constanza Romero
Carlos Arturo Trujillo P.

Workers
Josefa Salamanca
Héctor Unda
Luis Soto
Jaime Romero
Nixon Betancourt
Joaquin Cayapú
Dayro Franco
Jahir Cayapú

List of Publications

Refereed journal articles:

1. Cobo, J.G., Kass, D., Muschller, R., Arze, J., Barrios, E., Thomas, R. 1999. Abonos verdes de leñosas y no leñosas como fuente de nitrógeno a cultivos anuales. Agroforesteria en las Américas 6(23): 11-13.
2. Decaens, T., Rangel, A.F., Asakawa, N., Thomas, R.J. and Lavelle, P. 1999. Carbon and nitrogen dynamics in ageing earthworm casts in grasslands of the Eastern plains of Colombia. Biol. Fert. Soils 28, *In press*.
3. Decaens, T., Mariani, L. and Lavelle, P. 1999. Soil surface macrofaunal communities associated with earthworm casts in grasslands of the Eastern Plains of Colombia. Applied Soil Ecology, in press.
4. Lilienfein, J., Wilcke, W., Ayarza, M.A., Vilela, L., do Carmo Lima, S. and Zech, W. 1999. Partitioning of Phosphorous, Sulphur and Molybdenum in Differently Used Brazilian Savannah Oxisols. Geoderma, submitted.
5. Lilienfein, J., Wilcke, W., Ayarza, M.A., Vilela, L., do Carmo Lima, S. and Zech, W. 1999. Annual Course of Matric Potential in Differently Used Savanna Oxisols, Brazil. Soil Science of America Journal, submitted.
6. Lilienfein, J., Wilcke, W., Ayarza, M.A., Vilela, L., do Carmo Lima, S. and Zech, W. 1999. Soil Acidification in *Pinus caribaea* forests on Brazilian Savanna Oxisols. Forest Ecology and Management, submitted.
7. Lilienfein, J., Wilcke, W., Thomas, R., Vilela, L., do Carmo Lima, S. and Zech, W. 1999. Nutrient Concentrations in Soil Solution of Brazilian Oxisols under Conventional and No-Tillage During the Beginning Rainy Season. Soil Science Society of America Journal, submitted.
8. Lilienfein, J., Wilcke, W., Thomas, R.J., Vilela, L., Carmo Lima, S. and Zech, W. 1999. Nutrient concentrations in soil solution of Brazilian Oxisols under conventional and no-tillage during the beginning of the rainy season. Soil Sci. Soc. Am. J. Under revision.
9. Logan, K.A.B., Thomas, R.J. and Raven, J.A. 1999. Hydrogen ion production and ammonium uptake by two tropical forage grasses. J. Plant Nutr. 22, 53-66.
10. Logan, K.A.B., Thomas, R.J. and Raven, J. A. 1999. Effect of ammonium and phosphorus supply on H^+ production in gel by two tropical forage grasses. J. Plant Nutr., in press.
11. Neufeldt, H., Ayarza, M.A., Resck, D.V.S. and Zech, W., 1999. Distribution of Water-Stable Aggregates and Aggregating Agents in Oxisols of the Brazilian Cerrados. *In:* Sustainable Land Management for the Oxisols of the Latin American Savannas (R. Thomas and M. Ayarza, eds.). Pp. 51-63.
12. Neufeldt, H., da Silva, J.E., Ayarza, M.A. and Zech, W., 1999. Phosphorus Fractions under Different Land-Use Systems in Oxisols of the Brazilian Cerrados. *In:* Sustainable Land Management for the Oxisols of the Latin American Savannas (R. Thomas and M. Ayarza, eds.). Pp. 146-158.

13. Oberson, A., Friesen, D., Tiessen, H., Morel, C. and Stahel , W. 1999. Phosphorus status and cycling in native savanna and improved pastures on an acid low-P Colombian oxisol. Nut. Cycl. in Agroecoystems, in press.
14. Rangel, A.F., Madero, E., Thomas, R.J., Friesen, D.K. and Decaens, T. 1999. Ion exchange properties of casts of the anecic earthworm (*Martiodrilus carimaguensis* Jiménez and Moreno) in a Colombian savanna Oxisol. Pedobiologia, in press
15. Rangel, A.F., ThomasR.J., Jiménez, J.J. and Decaens, T. 1999. Nitrogen dynamics associated with earthworm casts of *Martiodrilus carimaguensis* Jiménez and Moreno in a Colombian savanna Oxisol. Pedobiologia, in press.
16 Rangel, A.F., Madero, E., Thomas, R.J., Friesen, D.K and Decaéns, T. 1999. Ion exchange properties of casts of the anecic earthworm (*Martiodrilus carimaguensis* Jimenez and Moreno) in a Colombian savanna Oxisol. Pedobiologia, in press.
17. Rangel, A.F., Thomas, R..J., Jiménez, J.J. and Decaéns, T. 1999. Nitrogen dynamics associated with earthworm casts of *Martiodrilus cariamaguensis* Jiménez and Moreno in a Colombian savanna Oxisol. Pedobiologia, in press.
18. Rao, I.M., V. Borrero, J. Ricaurte and Garcia, R., 1999. Adaptive attributes of tropical forage species to acid soils. IV. Differences in shoot and root growth responses to inorganic and organic phosphorus sources. J. Plant Nutr. 22 (7): 1153-1174.
19. Rao, I.M., Borrero, V., Ricaurte, J., and Garcia, R., 1999. Adaptive attributes of tropical forage species to acid soils. V. Differences in phosphorus acquisition from inorganic and organic phosphorus sources. J. Plant Nutr. 22 (7): 1175-1196.
20. Rao, I.M., Friesen, D.K. and Horst, W.J. 1999. Opportunities for germplasm selection to influence phosphorus acquisition from low-phosphorus soils. Agroforestry Forum, in press.
21. Rivera-Posada, J.H., R. Lal, E. Amézquita, O. Mesa-Sánchez, B. Chaves-Córdoba. 1998. Erodibilidad de cinco suelos de la zona cafetera central colombiana mediante simulación de lluvias.. Revista del Centro Nacional de Investigaciones de Café-CENICAFE 49(3):197-210.
22. Rivera-Posada, J.H., R. Lal, E. Amézquita, O. Mesa-Sánchez, B. Chaves-Córdoba. 1998. Movimiento del agua y procesos fundamentales en la erosión de cinco suelos de la zona cafetera central colombiana. Revista del Centro Nacional de Investigaciones de Café-CENICAFE 49(4):308-324.
23. Wenzl, P., Mancilla, L.I., Mayer, J.E., Rai, I.M. and Heberle-Bors, E. 1999. A novel approach to enrich less abundant cDNAs using paramagnetic beads; a theoretical simulation. Nucl. Acid Res. (in review).
24 Wenzl, P., Chavez, A.L., Mayer, J.E., Rao, I.M., and Nair, M.G. 1999. Two di-hydroxycinnamolylquinic acid esters from roots of nutrient-deprived *Brachiaria* species. Phytochemistry (in review).
25 Zhiping, Q., Rao, I.M. Ricaurte, J., Amézquita, E., Sanz, J.I., and Kerridge, P. 1999. Root distribution effects on nutrient uptake and soil erosion in crop-forgae systems on Andean hillsides. Trop. Agric.. (in review).

Refereed book chapters:

1. Fisher, M.J. 1999. Crop growth and development - flowering physiology. In: *Forage Seed Production. Volume II. Tropical and Subtropical Species* (D.S. Loch and J.E. Ferguson, *eds.*). CAB International, Wallingford. pp. 81-92.
2. Rao, I.M., and Terry, N., 1999. Photosynthetic adaptation to nutrient stress. In: M. Yunus, U. Pathre and P. Mohanty (eds.), Probing Photosynthesis: Mechanism, Regulation and Adaptation. Taylor & Francis, U.K.
3. Rao, I.M., Friesen, D.K., and Osaki, M. 1999. Plant adaptation to phosphorus-limited tropical soils. In: M. Pessarakli (ed.) Handbook of Plant and Crop Stress. Marcel Dekker, Inc., New York, USA. Pp. 61-96.
4. Thomas, R.J., Ayarza, M.A. and Lopes, A.S. 1999. Management and conservation of acid soils in the savannas of Latin America: Lessons learned from the agricultural development of the Brazilian cerrados. In "The use of nuclear techniques to develop management practices for increasing crop production and soil fertility in acid soils". Proceedings of a consultants meeting organized by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Vienna March 1-3, 1999.
5. Thung, M. and Rao, I.M., 1999. Integrated management of abiotic stresses. In: S.P. Singh (ed.), Common Bean Improvement in the Twenty–First Century. Kluwer Academic Publishers, Dorddrecht, The Netherlands. Pp. 331-370.

Edited books:

1. Thomas, R. Ayarza, M.A. (eds.) Sustainable land management for the Oxisols of the Latin American savannas: dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia, 231p.
2. Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. 1999. Sistemas Agropastoriles en Sabanas Tropicales de América Latina. CIAT, Cali, Colombia and EMBRAPA, Brazil, 313 p.

Non-refereed book chapters:

1. Amézquita, E., Friesen, D. and Sanz, J.I. 1999. Indicadores de Sostenibilidad: Parámetros Edafoclimáticos y Diagnóstico del Perfil Cultural. *In:* Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. (eds.). Sistemas Agropastoriles en Sabanas Tropicales de América Latina, CIAT, Cali, Colombia and EMBRAPA, Brazil.
2. Amézquita, M.C. 1999. Planeación y Diseño de Ensayos Agropastoriles. *In:* Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. (eds.). Sistemas Agropastoriles en Sabanas Tropicales de América Latina, CIAT, Cali, Colombia and EMBRAPA, Brazil.
3. Amézquita, M. C., Chatel, M., Guimarães, E.P., Ospina, Y., and Silva, J. 1999. Análisis Estadístico de un Ensayo Exploratorio para la Toma de Decisiones

Metodológicas. *In:* Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. (eds.). Sistemas Agropastoriles en Sabanas Tropicales de América Latina, CIAT, Cali, Colombia and EMBRAPA, Brazil.

4. Ayarza, M.A., Vilela, L., Pizarro, E.A. and da Costa, P.H. 1999. Sistemas Agropastoriles Basados en Leguminosas de Usos Múltiples. *In:* Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. (eds.). Sistemas Agropastoriles en Sabanas Tropicales de América Latina, CIAT, Cali, Colombia and EMBRAPA, Brazil.
5. Ayarza, M.A., Vilela, L., Pizarro, E. A. and da Costa P. H. 1999. Agropastoral Systems Based on Legumes: An Alternative for Sustainable Agriculture in the Brazilian *Cerrados. In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
6. Freibauer, A., Westerhof, R., Ayarza, M.A., da Silva, J.E. and Zech, W., 1999. Short Term Variation Aggregation and Particulate Organic Matter under Crops and Pastures. *In:* Sustainable Land Management for the Oxisols of the Latin American Savannas (R. Thomas and M. Ayarza, eds.). Pp. 77-88.
7. Fuhrmann, S., Neufeldt, H., Westerhof, R., Ayarza, M.A., da Silva, J.E. and Zech, W., 1999. Soil Organic Carbon, Carbohydrates, Amino Sugars and Potentially Mineralizable Nitrogen under Different Land-Use Systems in Oxisols of the Brazilian Cerrado. *In:* Sustainable Land Management for the Oxisols of the Latin American Savannas (R. Thomas and M. Ayarza, eds.). Pp. 110-122.
8. Freibauer, A., Westerhof, R., Ayarza, M.A., da Silva, J.E. and Zech, W. 1999. Short-Term Variation in Aggregation and Particulate Organic Matter under Crops and Pastures. *In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
9. Friesen, D.K., Ayarza, M.A., Thomas, R.J., Amézquita, E. and Sanz, J.I. 1999. Strategic systems research for the Latin American savannas. *In:* (S. Fujisaca (ed.). System and Farmer Pariticipatory Research: Developments in Research on Natural Resource Management, in press.
10. Fuhrmann, S., Neufeldt, H., Westerhof, R., Ayarza, M.A., da Silva, J.E. and Zech, W. 1999. Soil Organic Carbon, Carbohydrates, Amino Sugars, and Potentially Mineralizable Nitrogen under Different Land-Use Systems in Oxisols of the Brazilian *Cerrados. In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
11. Gómez-Carabalí, A., Rao, I.M., Beck, R.F., and Ortiz, M. 1999. Rooting ability and nutrient uptake by tropical forage species that are adapted to degraded andisols of hillsides agroecosytems . In: N. Gaborcik (ed.) Grassland Ecology V, Slovakia (invited article).
12. Guimarães, E.P., Sanz, J.I.., Rao, I.M. and Amézquita, E. 1999. Investigaciones en Sistemas Agropastoriles: Qué Hemos Aprendido y Qué Debemos Hacer en el

Futuro. *In:* Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. (eds.). Sistemas Agropastoriles en Sabanas Tropicales de América Latina, CIAT, Cali, Colombia and EMBRAPA, Brazil; pp. 301.312.

13. Lopes, A. Ayarza, M.A. and Thomas R.J. 1999. Sistemas agropastoriles en las sabanas de America latina Tropical: Lecciones del Desarrollo Agricola de los Cerrados de Brasil. In : Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. (eds.), p. 9-30. Sistemas Agropastoriles en Sabanas Tropicales de America Latina. CIAT, Cali, Colombia and EMBRAPA, Brazil.
14. Neufeldt, H. Zech, W. and Thomas R. 1999. Introduction: Sustainable land management for the Oxisols of the Brazilian Cerrados. In: Sustainable land management for the Oxisols of the Latin American savannas: dynamics of soil organic matter and indicators of soil quality. p. 1-9. Thomas, R. and Ayarza, M (eds.), CIAT, Cali, Colombia.
15. Neufeldt, H., Ayarza, M.A., Resck, D.V.S. and Zech, W. 1999. Distribution of Water-Stable Aggregates and Aggregating Agents in Oxisols of the Brazilian *Cerrados*. . *In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
16. Neufeldt, H., Resck, D.V.S., Ayarza, M.A. and Zech, W. 1999. Soil Organic Matter in Oxisols of the Brazilian *Cerrados. In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
17, Neufeldt, H., da Silva, J.E., Ayarza, M.A. and Zech, W. 1999. Phosphorus Fractions under Different Land-Use Systems in Oxisols of the Brazilian *Cerrados*. *In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
18. Rao, I.M., Ayarza, M.A., Herrera, P. and Ricaurte J. 1999. El papel de las raíces de especies forrajeras en la adquisición, reciclaje y almacenamiento de nutrientes en el suelo. Memorias de Curso Internacional "Investigación y Desarrollo de Sistemas de Producción Forrajera en el Trópico" (del 1 al 31 de Octubre de 1996).. CIAT, Cali, Colombia. (in press)
19. Renz, T.E., Neufeldt, H., Ayarza, M.A., da Silva, J.E. and Zech, W. 1999. Acid Monophosphatase: An Indicator of Phosphorus Mineralization or of Microbial Activity? A Case Study from the Brazilian *Cerrados. In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
20. Renz, .T.E., Neufeldt, H., Ayarza, M.A., Resck, D.V.S. and Zech, W. 1999. Microbial Biomass, Microbial Activity, and Carbon Pools under Different Land-Use Systems in the Brazilian *Cerrados. In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.

21. Sanz, J.I. Zeigler, R.S., Sarkarung, S., Molina, D.L. and Rivera, M. 1999. Sistemas Mejorados Arroz-Pasturas para Sabana Nativa y Pasturas Degradadas en Suelos Acidos de América del Sur. *In:* Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. (eds.). Sistemas Agropastoriles en Sabanas Tropicales de América Latina, CIAT, Cali, Colombia and EMBRAPA, Brazil.
22. Thomas, R., Ayarza, M.A., Neufeldt, H., Westerhof, R., Zech, W. 1999. General conclusions. In: Sustainable land management for the Oxisols of the Latin American savannas: dynamics of soil organic matter and indicators of soil quality. p. 215-227. Thomas, R. and Ayarza, M (eds.), CIAT, Cali, Colombia.
23. Westerhof, R., Vilela, L., Ayarza, M.A. and Zech, W.. 1999. Carbon Fractions as Sensitive Indicators of Quality of Soil Organic Matter. *In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
24. Westerhof, R., Vilela, L., Ayarza, M.A. and Zech, W. 1999. Labile N and the Nitrogen Management Index of Oxisols in the Brazilian *Cerrados. In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
25. Westerhof, R., Vilela, L., Ayarza, M.A. and Zech, W. 1999. Characterizing Labile and Stable Nitrogen. *In:* R.J. Thomas and M. Ayarza (eds.) Sustainable land management for the Oxisols of the Latin American savannas: Dynamics of soil organic matter and indicators of soil quality. CIAT, Cali, Colombia and EMBRAPA-CPAC, Brazil.
26. Westerhof, R., Buurman, P., van Greithuysen, C., Ayarza, M.A., Vilela, L. and Zech, W., 1999. Aggregation Studied by Laser Diffraction in Relation to Plowing, Soil Organic Matter and Lime in the Brazilian Cerrados. In: Sustainable Land Management for the Oxisols of the Latin American Savannas (R. Thomas and M. Ayarza, eds.). Pp. 64-76.
27. Westerhof, R., Vilela, L., Ayarza, M.A. and Zech, W., 1999. Carbon Fractions as Sensitive Indicators of Quality of Soil Organic Matter. In: Sustainable Land Management for the Oxisols of the Latin American Savannas (R. Thomas and M. Ayarza, eds.). Pp. 123-132.

Non-refereed conference presentations:.

1. Amézquita, E., Preciado, G. and Thomas, R.J. 1999. Changes in the soil physical conditions as the time and intensity of use increase in tropical savanna (Oxisols) soils of Colombia, South America. Paper submitted to the 10^{th} ISCO Meeting, Purdue University. West Lafayette, Indiana, USA. May 23-28.
2. Amézquita, E. and Chavez, L.F. 1999. La compactación y sus efectos en la productividad de los suelos. Paper presented at the Congreso Costarricense de la Ciencia del Suelo, San José, Costa Rica.

3. Ayarza, M.A., Rao, I.M. and Barrios, E. 1999. Potencial de los mecanismos suelos-planta y de los sistemas integrados en el uso eficiente de los nutrimentos disponibles en suelos tropicales. Invited paper presented at XLV Annual Meeting of PCCMC, Guatemala City, Guatemala.
4. Rao, I.M., Singh, S., Ricaurte, J. and Teran, H. 1999. Genotipos de frijol común (*Phaseolus vulgaris*, L.) adaptados a suelos tropicales y eficientes en el uso de nutrientes. Invited paper presented at XLV Annual Meeting of PCCMA, Guatemala City, Guatemala.
5. Ricaurte, J., Zhiping, Q., Filipe, D., Rao, I.M. and E. Amézquita. 1998. Distribución radicular, absorción de nutrientes y erosión edáfica en sistemas de cultivos y forrajeros en laderas del Cauca, Colombia. Suelos Ecuatoriales (in press).
6. Thomas, R.J., Ayarza, M.A. and Lopes, A.S. 1999. Management and conservation of acid soils in the savannas of Latin America: Lessons from the agricultural development of the Brazilian Cerrados. *In:* Proceedings on The Use of Nuclear Techniques to Develop Management Practices for Increasing Crop Production and Soil Fertility in Acid Soils. IAEA, Vienna, Austria. (in press).
7. Thomas, R. and Zapata, F. 1999. Development of Management Practices for Sustainable Crop Production System on Tropic Acid Soils Through the Use of Nuclear and Related Techniques. Report of Consultants Meeting, FAO/IAEA Division, Vienna, Austria.
8. Trejo M., Barrios E., Turcios W. and Barreto H. (1999) Método Participativo para identificar y clasificar Indicadores Locales de Calidad del Suelo a nivel de Microcuenca. Instrumentos Metodológicos para la Toma de Decisiones en el Manejo de los Recursos Naturales. CIAT, CIID, BID, COSUDE.
9. Wenzl, P., Rao, I.M., Mayer, J.E. and Roca, W. 1999. Aluminum tolerance and other traits contributing to acid soil adaptation in a tropical forage grass, *Brachiaria decumbens*. Invited paper presented at an international workshop on "Genetic Analysis and Engineering of Aluminum Tolerance in Plants", Campinas, Brazil.

Guides:

1. Guía #1. Instrumentos Metodológicos para la toma de Decisiones en el Manejo de los Recursos Naturales. CIAT. 1999. Método Participativo para Identificar y Clasificar Indicadores Locales de Calidad del Suelo a Nivel de Microcuenca". M.T.Trejo, E. Barrios, W. Turcios, H. Barreto.

Other documents:

1. Guimarães, E.P., Sanz, J.I.., Rao, I.M. and Amézquita, E. 1999. Research on Agropastoral Systems: What we have learned and what we should do in the future. *In:* Guimaraes, E.P., Sanz, J.I., Rao, I.M., Amézquita, M.C. and Amézquita, E. (eds.). Sistemas Agropastoriles en Sabanas Tropicales de América Latina, CIAT, Cali, Colombia and EMBRAPA, Brazil; pp. 301.311.

List of Acronyms

ACIAR	Ausralian Centre for International Agricultural Research, Australia
AUN	Agricultural University of Norway, Norway.
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (para América Central), Costa Rica.
CENICAFE	Centro Nacional de Investigaciones en Café, Chinchiná, Colombia
CENIPALMA	Centro de Investigación en Palma de Aceite, Colombia
CIAT	Centro Internacional de Agricultura Tropical, Colombia
CIDIAT	Centro Internacional de Desarrollo Integral de Aguas y Tierras, Venezuela.
CIELAT	\Centro de Investigaciones Ecológicas de los Andes Tropicales, Venezuela.
CIPASLA	Consorcio Interinstitucional para la Agricultura Sostenible en Laderas, Colombia.
CIRAD	Centre de Coopération Internationale en Recherche Agronomique poour le Depeloppement, France
CNPAB	Centro Nacional de Pesquisa de Agrobiologia, Brazil
COLCIENCIAS	Instituto Colombiano para el Desarrollo de la Ciencia y la Tecnología "Francisco José de Caldas", Colombia
CORPOICA	Corporación Colombiana de Investigación Agropecuaria, Colombia.
CPAC	Centro de Pesquisa Agropecuaria dos Cerrados (*of* EMBRAPA)
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
ETH	Institut for Plant Science, Zurich
FAO	Food and Agriculture Organization of the United Nations, Italy
FEDEARROZ	Federación Nacional de Arroceros, Colombia
IAEA	International Atomic Energy Agency, Vienna, Austria
IBSRAM	International Board for Soil Research and Managment
ICRAF	International Centre for Research in Agroforestry, Nairobi, Kenya
ICRISAT	International Crops Research Insttitute for the Semi-Arid Tropics, India
IFDC	International Fertilizer Development, USA
INPOFOS	Instituto Internacional de Fósforo y Potasio, Ecuador
LAC	Latin American and the Caribbean
MAS	Management of Acid Soils (*of* SWNM *of the* CGIAR), CIAT Colombia.
NARS	National Agricultural Research Systems
NGO	Non-Governmental Organization
ORSTOM	Institut français de recherche sicentifique pour le developpement en coopération, France.
PRONATTA	Programa Nacional de Transferencia de Tecnología, Colombia
SOL	Supermercado de Opciones para Laderas

SWNM	Soil, Water and Nutrient Management (*systemwide program of the* CGIAR), CIAT Colombia.
TSBF	Tropical Soil Biology and Fertility Program, Nairobi, Kenya
UNELLEZ	Universidad Nacional Experimental de los Llanos Orientales Exequiel Zamora, Venezuela