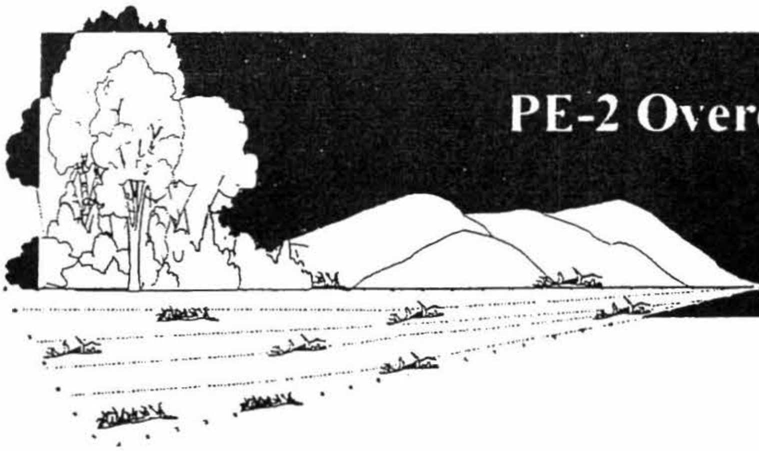
PE-2 Overcoming soil degradation



Annual Report 1998

CIAT
Centro Internacional de Agricultura Tropical

PE-2: Confronting soil degradation: Developing strategies for productivity enhancement and resource conservation

Project manager: R.J. Thomas

PROJECT OVERVIEW

Objective: To identify strategic principles 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 Egos.

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.

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.); Aas (Norway).
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%; Strengthening 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

2. Project work breakdown structure

Confronting soil degradation: developing strategies for productivity enhancement and resource conservation

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

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Output 1 Soil, water and nutrient management constraints assessed and plant components characterized for improved production and resource conservation	**Output 2** Strategies to protect and improve soil quality	**Output 3** Diagnostic and predictive tools developed to combat soil degradation	**Output 4** Institutional capacity enhanced for strategic research on soil, water and nutrient management
1.1 Determine and characterize edaphic and climatic constraints 1.2 Characterize plant components for production potential and nutrient use efficiency 1.3 Determine rooting strategies of crop and forage components 1.4 Test compatibility of plant components in different systems (including farmer participation) 1.5 Determine impact of systems on production and the resource base	2.1 Determine nutrient release rates of component residues and green manures 2.2 Estimate nutrient budges in contrasting systems 2.3 Identify key processes in nutrient cycles to minimize losses and improve use efficiency in systems 2.4 Estimate contribution of different systems to soil organic matter accumulation 2.5 Determine the effects of soil biota on soil fertility and structure 2.6 Develop strategies to reduce soil loss and improve soil structure 2.7 Develop methods to improve water infiltration and storage 2.8 Test indicators to assess soil quality	3.1 Identify dynamic soil properties and test their suitability as soil quality indicators 3.2 Develop diagnostic kit to assist farmers and extensionists in resource management decision making 3.3 Compile data bases to feed into simulation models and decision support systems 3.4 Calibrate simulation models to predict system performance and overcome site specificity 3.5 Develop a decision support system to assist in resource management decision making 3.6 Test diagnostic tools with NARS and farmers	4.1 Organize and coordinate field days and workshops 4.2 Prepare bulletins on agro-pastoral systems and soil, water and nutrient mana-gement projects 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

PE-2 Team logframe 1998 Version: Fe27, 1998

Narrative summary	Names	Year	AES	Verifiable indicators	Means (and source) of verification	Critical assumptions beyond control of project team
Goal: Productive and regenerative agricultural systems for marginal and degraded soils of the hillsides and lowlands based on efficient resource use and conservation	Team	02	All	Yields in farmers' fields increased; land degradation halted/reduced. Yields per unit area and input increased. Changes in land use	Farmer surveys Regional/national production statistics Land use surveys (satellite imagery, rapid rural appraisals	Socioeconomic conditions are conducive to farmers' adoption of new technologies. Farmers adopt technologies. Land survey data available.
Purpose: To identify strategic principles for protecting and improving soil quality through the efficient and sustainable use of soil, water and nutrient resources in agro- and agro-silvopastoral systems.	Team	02	All	Technologies for soil improvement/management developed. Limiting soil-plant-water processes identified. Compatible plant components identified for low fertile soils in crop-livestock systems	Scientific publications Guidelines on soil-crop management published	Economic analyses of options available. Effective linkages with PE-3,4 and 5. Socioeconomic inputs available from other projects e.g. PE-3, BP-1
Outputs:						
1. Soil, water and nutrient management constraints assessed and system plant components characterized for improved production and resource conservation.	Team	99	SV.HS	Soil and water management constraints identified with farmer and NARS participation.	Annual Report Reviews published	Literature available Farmers actively 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)
	EA	98	HS,FM	Literature reviewed and summary document prepared.	Document of synthesized results	
	Team	98	All	Questionnaire produced and farmers interviewed in at least two agroecosystems. Tables of constraints in the three agro-ecosystems. First AES will be savannas, then hillsides	Detailed tables published in Annual Report	
	IR	99	SV	Plant components identified and matched to edaphic/climatic constraints.		
2. Strategies developed to protect and improve soil quality	RT,DF, EA	99	SV	Recommendations of practices and plant components for efficient N and P management systems.	Project reports and publications	Operational funds available for chemical analyses. Continuity of long-term experiments Modeling expertise available from partners e.g. IFDC, Michigan State Univ. USA
	RT	98	SV	Data of N cycles and budgets determined at least four differing production systems.		
	Team	99	SV,HS	Soil properties, management practices and		

	Team MF,EB,RT	99 99	SV SV	plant components that affect N capture and fluxes identified. N and P dynamics modeled Processes of C sequestration identified		Soil biology expertise from ORSTOM/Univ. of Paris available
3. Diagnostic and predictive tools developed to combat soil degradation.	Team EA Team EA,EB, RT RT EA EB,RT	00 98 99 99 99 99 99	All HS All HS,FM SV,HS SV HS	List of Soil Quality indicators prepared and available to monitor degradation in reference sites of 3 AES. Tool designed for estimating soil erosion and training manual written Decision-making kit for soil and water management produced Map of risk assessment of soil degradation (erosion, soil nutrients) for hillsides and forest margins 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	Annual Reports and 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. Lab. Facilities available with staff in Pucallpa (with ICRAF) Collaboration with MW (UNEP) on land quality indicators at reference sites. Collaboration with GH in FM and GL in HS/CA and NB for Sav.
4. Institutional capacity enhanced for strategic research on soil, ter and nutrient management	Team EA MF Team RT	98 98 98 98 98		Nine undergraduate, three Master's and one Ph.D. theses submitted. Workshop held on soil physics Workshop on C sequestration held At least three projects with partners submitted to donors Initiate ELABS	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 1998

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

- The main biophysical constraints have been identified for the three agroecosystems of interest to CIAT. These constraints were identified through a process of consultation with NARS, experts from specialist research organizations and other international agricultural research centers. Although at a broad scale, the identification of constraints is helping us better focus our efforts and comparative advantages in areas where our impact can be maximized. This information will be combined with questionnaire data on farmer and indigenous knowledge of soils and soil management in order to ensure that appropriate solutions to the constraints are developed.
- Three different landscapes were identified in the Colombian "llanos" which require different soil management strategies. Low rates of water infiltration have been identified as a major, previously undetermined constraint. Strategies to overcome this constraint include the careful use of machinery and the inclusion of a grass-legume pasture phase in suitable cropping systems from the Colombian llanos.
- In the hillsides of the Cauca valley the first phase of crop systems experiments has been completed and a second phase, focusing on improved fallow agroforestry and other novel rotations has begun. Promising technologies that have been used and optimized on-station are moving to on-farm via client demand and collaborators. One of these is the use of sugar cane live barriers that yield enough sugar to feed a typical farm family and promote the formation of natural terraces via erosion control

Output 2: Strategies developed to protect and improve soil quality

- Studies on the use of green manures in both the hillside and savanna agroecosystems have shown that there are variations in decomposition rates that need to be taken into consideration in order to improve the nutrient use efficiency and nutrient recycling in crop-livestock systems. Losses of nitrogen from green manures via volatilization and leaching may have a significant impact on the environment in the hillside environment where green manures are being widely adopted. Nitrogen dynamics have been determined in monocropped rice and maize, rice-cowpea and maize-soybean (legume green manure and grain crops) in the savannas. The results suggest that split fertilizer applications are more efficient in terms of nitrogen use than the inclusion of green manures in crop rotations.
- Work done by collaborators has confirmed that in both Bahia State and in the western "llanos" of Venezuela, introduced African grasses sequester carbon in the soil, including *Hyparrhenia rufa*. The introduced grasses have higher rates of N turnover and greater internal remobilization of N than the native savanna species.
- Data from soil physical studies has shown that free water movement down the soil profile is increased drastically under pastures in the savannas. In addition the improvement of soil structure via pastures results in a better distribution of nutrients and increased soil water storage capacity. This is particularly important as the soil physical conditions of the native savanna are not adequate for crop production. Both

deep tillage and the integrated use of crops and pastures can improve the physical conditions.

Output 3: Diagnostic and predictive tools developed to combat soil degradation

- A set of soil quality indicators (SQI's) has been developed for some savanna Oxisols of both Brazil and Colombia. This work represents the first phase of our efforts to develop a soil quality monitoring system that will eventually be used by the land users themselves. Through the development and use of questionnaires we will refine the set of SQI's. Twenty three scientific articles on SQI's are in various stages of publication. These articles contribute new knowledge on the dynamics of soil organic matter in savanna Oxisols.

Output 4: Institutional capacity enhanced for SWNM

- The project team has been heavily involved in training activities during this year. Thirteen field days have been held at the site of the hillsides activity in Colombia. The III ELAFIS (Escuela Latin Americana de Fisica de Suelos) was held in CIAT with 50 participants. Fifty under-, post-graduate and post-doctoral fellows are associated with the project.
- A publication on agropastoral systems is in preparation with contributions from NARS and other collaborators. In addition a state-of-the-art document on lessons learned from the exploitation of the Brazilian *cerrados* is nearing completion.
- A newsletter and brochure of the SWNM has been distributed to collaborators and donors.
- The project has 40 refereed articles and 10 invited book chapters, in various stages of publication.

Progress towards achieving output milestones of the project logframe in 1998

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

Soil, water and nutrient management constraints identified:
Through literature surveys and collaborative links the main biophysical constraints in the savannas, hillsides and forest margins have been identified at a broad scale. Soil physical constraints of poor rates of water infiltration, susceptibility to surface crusting have been identified as important, previously unforeseen constraints. Questionnaires have been developed to solicit farmer perceptions of soil constraints and soil quality. Together with our biophysical research, these activities are helping us better identify constraints in specific sites and to better target our research towards developing strategies and diagnostic and predictive tools to combat soil degradation. A joint activity with PE-4 has been initiated to advance this work in terms of focusing at smaller micro-and macro-catchment scales by using GIS. A student from King's College London has been contracted for this purpose.

Plant components and their interaction with the environment

Studies on the use of different plant components in time and space have indicated the importance of root studies in adapting plants to marginal environments. On-farm work, in close collaboration with the farmer community in the hillsides, is beginning to influence the choice of crops to be studied further. These are the first steps the project has taken towards a farmer participatory approach via community-based organizations in the hillsides. In the Brazilian *cerrados* this approach is more advanced as, via on-farm research, forage legume components have been introduced and farmers are now producing their own seed. The adoption of agropastoral systems is beginning to occur. CIAT's inputs into this has been the introduction of improved grass and legume germplasm into crop-livestock systems on farm in the Uberlandia area (with links to IP-5) and an increased understanding of soil-plant processes which contribute to more efficient and productive systems. In the targeted area farmers are well organized via cooperatives and field visits and technology transfer is occurring spontaneously in parallel with the spread of no-tillage systems from Southern Brazil.

Output 2: Strategies to protect and improve soil quality

Strategies for the use of organic materials

Research on green manures indicates a need for more effort to synchronize the release of nutrients with crop demand in order to avoid inefficient use of scarce nutrients. These studies are helping us develop further the concept of linking organic material decomposition in the soil with *in vitro* digestibility test in order to develop a proxy test that is useful for both animal nutrition and nutrient cycling. Links with IP-5 are important in this respect. There is a need for further germplasm characterization in order to identify accessions of plant components with plant compositional factors such as higher lignin, polyphenols etc., that will decrease rates of organic material decomposition in the soil. The research also indicates the need for activities on timing and placement of organic materials. To this end the appointment of a joint post-doctoral fellow between CIAT and TSBF in Africa, is a key development whereby the project can gain from existing experience and knowledge and rapidly develop strategies and decision support tools for the use of organic materials.

Identification of inefficiencies in Nitrogen and Phosphorus cycling

Linked to the above activity the project has developed sufficient knowledge of nitrogen and phosphorus cycling to indicate points of entry to improve the cycling of these main limiting nutrients in marginal acid soils. These include promotion of deeper rooting plants to scavenge for nitrate-N. Substantial amounts of nitrate-N appear to accumulating under legume green manures and N-fertilized crop rotations in the savannas and represent large losses from the soil-plant continuum. On the other hand legume components have been shown to have an, as yet unidentified mechanism, for improving phosphorus cycling. From this work the project has identified possible problems in matching N and P supplying processes in the soil. This work will result in better guidelines for the use of N and P resources.

Mechanism of carbon accumulation under pastures

Further research has confirmed that introduced African grasses have the ability to accumulate soil carbon over and above that of the native vegetation. Rates of plant productivity especially N turnover via litter appear to have been underestimated in the past. These activities are helping us examine the extent and mechanism of carbon accumulation under pastures.

Strategies to reduce soil loss and improve soil structure

A new methodology to measure water movement in the field is an important step that takes "classical" soil physical methodology from the laboratory into the field so that realistic studies can be undertaken. This is pioneering work in soil physics and as the methods are generally simple and low cost, they should be able to be transferred to NARS rapidly. The research confirms that pasture phases in crop-livestock systems improve the soil in terms of physics, chemistry and biology.

Output 3: Diagnostic and predictive tools developed to combat soil degradation

Soil quality indicators

A list of soil quality indicators for some Oxisols has been developed and details published in a special project report. These parameters need to be tested and validated elsewhere in order to assess their general applicability. This work is the first step to develop meaningful indicators of the state of the soil that are of use to researchers, extensionists and farmers. This information will be combined with our survey/questionnaire activities in order to relate farmer knowledge with scientific knowledge. The indicators will aid farmers in monitoring how land use changes and technological interventions are affecting the soil resource. They will act as early warning indicators of degradation.

Decision support tools

Progress on the development of decision making support tools requires the use of information and knowledge accumulated from outputs 1 and 2 of this project. To a certain extent the project is still at the information gathering and testing stages which are required before guidelines and decision support tools are produced. This applies with respect to the objective of producing a decision tree for an "arable layer" and a kit for soil and water management. We expect faster progress in the development of a decision support tool for the use of organic resources mentioned above under Output 2. This is because through collaborative linkages, we can speed up the development and testing of existing tools. In a similar way we expect progress to be made on the refinement of existing models such as the DSSAT crop models via collaborative links with the model originators. The latter are best placed to efficiently handle any required refinements because they have access to model codes. We will continue to foster such collaborative linkages to achieve our objectives in this area.

Output 4: Institutional capacity enhanced for SWNM

The project is exceeding its planned objectives in this output. Fifty students and trainees are associated with the project mainly at bachelor and master levels. One workshop has been held and another one is planned before the end of the year. In addition plans are underway to develop a "school of soil biology" for the region. Field days are helping us communicate our results to the farming community ensuring that we have a mechanism for rapid uptake. The project's publication record is second to none within the center. This is particularly due to our efforts at establishing collaborative linkages with some 25 institutions and via our participation in the systemwide SWNM program. Seven collaborative projects have been submitted to donors.

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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

Activity 1.1.1 To produce tables of biophysical constraints of the three agroecosystems of interest to CIAT

Highlights:

- The main biophysical constraints have been identified for three agroecosystems of interest to CIAT.

Purpose:

To identify the main biophysical constraints to agricultural production in order to better target technological interventions.

Rationale:

Problem identification is the first step in the research and development process. There is a need for a more in-depth study of the biophysical constraints to agricultural production and the extent of land degradation problems. The latter in particular has only been studied at a broad scale. Policy makers need more accurate information on land degradation in order to establish sets of priorities for interventions.

Results:

Table 1 shows the main biophysical constraints identified by the MAS consortium (NARS, SRO's and IARC's). The data is relevant for the broad regional scale. Within any region there will be variations. For example in the hillsides of Cauca farmers often apply excessive amounts of chicken manure to the crop plots. While nutrient depletion may be occurring at the overall farm scale, fields or plots are accumulating nutrients. Similarly soil erosion is perceived to be a major constraint but there is little information on the losses of soil in some plots or fields and gains in others due to soil movement within a micro-catchment area.

This activity is preliminary and will be followed up by an in-depth study in collaboration with PE-4 where the tools of geographic information systems can be applied.

Impact:

The initial characterization of the constraints helped to identify the first target area for the MAS project. As the activity develops we expect to be able to influence policy makers with more accurate estimates of areas under threat of, or undergoing, serious land degradation.

Table 1. The main biophysical constraints in the three agroecosystems of interest to CIAT.

Agroecosystem	Prevailing constraints	"Best-bet" solution/technological option
Savannas	• Soil erosion (water and wind) • Nutrient depletion • Loss of soil structure including crusting, compaction	• Maintenance of soil productivity under crop-livestock systems • Management of biomass • More resource efficient cropping systems • Integrated nutrient management • Optimal use of water • Maintenance/improvement of soil structure
Forest margins	• Weed invasions • Nutrient depletion • Soil compaction • Loss of soil structure	• Crop rotations including trees • Integrated nutrient management • Management of biomass • Maintenance/improvement of soil structure • Maintenance of functional biodiversity • Economically viable resource conservation technology • Sustainable management of the adjacent areas • Improved fallow systems
Hillsides	• Soil erosion • Nutrient depletion	• Economically viable soil conservation technologies • Optimal use of water • Integrated nutrient management • Improved fallow systems

Contributors:
R. Thomas, I. Rao, M. Ayarza, J. Sanz, E. Amezquita, M. Fisher (CIAT). Members of the MAS consortium.

1.1.2 Evaluation of soil physical characteristics under different land use systems in "Los Llanos"

Highlights:

- The three different landscapes identified in the "llanos": Altillanura plana, Altillanura ondulada and Altillanura disectada, present different soil conditions for plant growth and therefore, require different soil management systems.
- The intensive use of machinery in the preparation of soil for monocrop production has reduced drastically the rates of water infiltration. This is a result of loss of soil structure and also sealing of the surface layers.

Purpose:

To characterize the physical, chemical and biological conditions of landscapes and land use systems in the Colombian "llanos".

Rationale:

Soils of "Los Llanos" are susceptible to physical, chemical and biological degradation once they are brought into cultivation. There is a need to characterize these soils further in order to assess their suitability for cultivation and to develop soil management systems that will allow increases in productivity in a sustainable manner. Through a special project funded by PRONATTA, evaluations are being made of the physical, chemical and biological conditions of soils under different landscapes and uses.

Results:

Accumulative infiltration values show differences between land use systems (Table 2). Infiltration is higher in the "Altillanura ondulada" where higher values of sand content (69.5%) were found. Under the "Altillanura plana" and "disectada" the values were almost a half of that on "A.ondulada", showing that the landscape affects the behavior of this property. This aspect needs be taken into account for the planning of agricultural activities. One aspect that should be mentioned in relation to the values found, is that a cumulative infiltration of 218 mm/2 h could be considered as a medium value. This is equivalent to 109 mm/h, in a region where rains are heavy and could reach intensities higher than 100 mm/h in five minutes. When this occurs a great amount of run-off is produced.

Table 2. Accumulative infiltration, sand content, total porosity and presence of mycorrhizae in different land use systems in "Los Llanos"

	Accumulative Infiltration (mm/2 h)	Sand Content (%)	Total Porosity (%)	Spore (VAM) number/100g
Land System:				
Altillanura ondulada	218a	69.5a	39.9b	366a
Altillanura plana	121b	36.8c	46.8a	361a
Altillanura disectada	103b	53.4b	46.7a	402a
Soil use System				
Perennial crop (rubber)	306a	43.8c	45.0bc	404a
Low savannas	173b	62.4a	49.4a	370a
High savannas	117bc	51.2b	43.5c	367a
Improved pasrures	100bc	51.1b	46.5bc	338a
Agropastoral systems	96bc	51.2b	44.1bc	541a
Monocrops	13c	41.5c	45.6bc	542a

Figures with the same letter mean non-significant difference ($P<0.05$).

Human intervention as evaluated by the different soil use systems, has affected the cumulative infiltration. It has been reduced from 306 mm/2 h under perennial crops (rubber) to 13 mm/2 h in annual monocrops. The causes of this negative effect must be understood to avoid further soil degradation and to promote rainfall acceptability.

Total porosity in "A. ondulada" is low for agricultural purposes, and reflects the high sand content found. Cultivation has affected total porosity. In high savannas, it has increased slightly (but not significantly) under improved pasture (46.5%), agropastoral systems (44.1%) and under annual monocrops (45.6%) compared with the original value (43.5%). In the low savannas (more organic matter), porosity has higher values.

The presence of mycorrhizae in the first five centimeters of soil was low in all the systems. However, the presence of mycorrhizae, is a resource that should be considered as useful for future soil improvement.

Impact
The reduction of the infiltration rate as the use of machinery increases (monocrops), shows the fragility of soil structure and indicates that intensive use of machinery will result in soil degradation. Adequate practices of soil tillage should be developed to avoid degradation. The low cumulative infiltration under crops indicates that monocropping is an unsustainable land use option for the "llanos". Perennial crops or pastures on the other hand improve water infiltration.

Contributors: P. Hoyos, E. Amézquita, D. Molina, R. Thomas, L.F. Chavez, E. Almaza, G. R. Salamanca.

1.1.3 Determination of field capacity (upper limit of available water) and wilting point (lower limit of available water) under field conditions

Highlights:
- Field capacities of soils subjected to different tillage treatments ranged from 18.7 to 19.6% as gravimetric moisture content. This was little changed by increased tillage.
- Available water was low and was a function of depth.

Purpose:
To characterize the water relations of the soils of the Colombian "llanos".

Rationale:
Field capacity is the maximum amount of water that a soil can retain against gravity. It is the percentage of water in the soil 48 hours after a heavy rainfall or irrigation and is measured as the percentage of water at different depths in a soil profile. Field capacity is affected by the horizon distributions in the soil profile and by the management systems to which the soil is subjected. Optimal water supplies are required for agricultural production but little information is available on the water dynamics of the Oxisols of the Colombian "llanos".

Methods
To study the advance of the wetting front and field capacity, a test was made on plots subjected to different harrowing intensities and on a natural savanna at the end of the dry season (February). Plots of 1 m previously surrounded by a metal frame into each tillage

treatments received different amounts of water (0, 150, 300 mm) and the moisture content determined after 48 hours.

Results
The lower limit of available water (no addition of water) ranged from 13.5% to 15.1% for the different treatments with little differences between them. The amount of water remaining in the profile at each depth was lower in the top layers (0-5 and 5-10 cm) and higher in the deeper ones, irrespective of the treatment (Table 3). This indicates that there is a gradient of moisture content at the end of the dry season and that the wilting point as determined by equilibrium at 1.5 Mpa, does not represent the field condition as it gives only one value that represents the whole profile. When 150 mm and 300 mm of water were added, there was a general increase in the moisture content, but it was higher in the upper layers. Between 150 and 300 mm of water addition, the differences in moisture content at all depths were small indicating that field capacity was reached. In this research the moisture content values obtained at 300 mm were accepted as field capacity as they represented the maximum amount of water retained by the soil profile. Figure 1 represents the values and concepts of field capacity (upper limit of available water), wilting point (lower limit of available water) and water availability for the natural savanna condition.

Table 3. Gravimetric moisture content (%) at different depths and tillage treatments before (lower limit) and after 48 hours after irrigation for field capacity determination. Matazul, Feb. 28 – March 4 1998.

Harrowing Passes	Water added (l/m^2)	Depth of sampling						Average
		0 - 5	5 - 10	10 - 20	20 – 30	30 - 50	50 - 70	
		Gravimetric moisture content (%)						
	0	10.8c	11.9b	14.7b	15.5b	15.8b	18.1a	14.5
0	15	15.6b	17.3a	17.7a	17.5a	21.0a	21.3a	18.4
	30	20.0a	20.5a	18.3a	18.1a	17.2ab	18.3a	18.7
	0	9.5c	14.2c	17.2b	16.2b	16.4a	17.3a	15.1
6	15	16.6b	16.0b	17.2b	16.6ab	17.4a	16.8a	16.8
	30	21.2a	20.3a	19.9a	19.4a	17.7a	19.2a	19.6
	0	9.0b	11.6c	14.0b	14.4c	15.6a	16.5b	13.5
12	15	15.1a	15.8b	18.3a	16.3b	17.3a	17.8ab	16.8
	30	15.5a	19.2a	19.6a	18.6a	19.1a	20.5a	18.8
	0	11.8b	13.2b	15.2b	16.0b	16.1b	18.0c	15.1
24	15	17.6a	17.2a	17.6ab	17.8ab	17.8ab	19.4b	17.9
	30	18.2a	17.7a	18.5a	19.3a	19.4a	20.4a	18.9

Different letters in the same column indicates significant (<0.05) statistical differences

Impact:
These soils presented very low values of water storage capacity. The tillage treatments used, did not have any influence on it. It is necessary to develop practices to improve water storage capacity. A combination of tillage and organic matter addition should be considered.

Contributors: E. Amézquita, I. Valenzuela, G. Perea, D. Molina, P. Hoyos, J. Galvis, A. Alvarez.

1.1.4 Soil strength and penetrability in the Culticore Experiment, Carimagua

Highlights:

- Mechanical soil strength, resistance to rupture and penetrability show high values in the "Llanos".
- Some soil management practices used in Culticore have reduced the values of resistance to rupture and penetrability and can be used as references for the decisions on soil management improvement.

Purpose:

To evaluate how soil and crop management systems influence the soil strength, measured as resistance to rupture and penetrability in the Culticore Experiment.

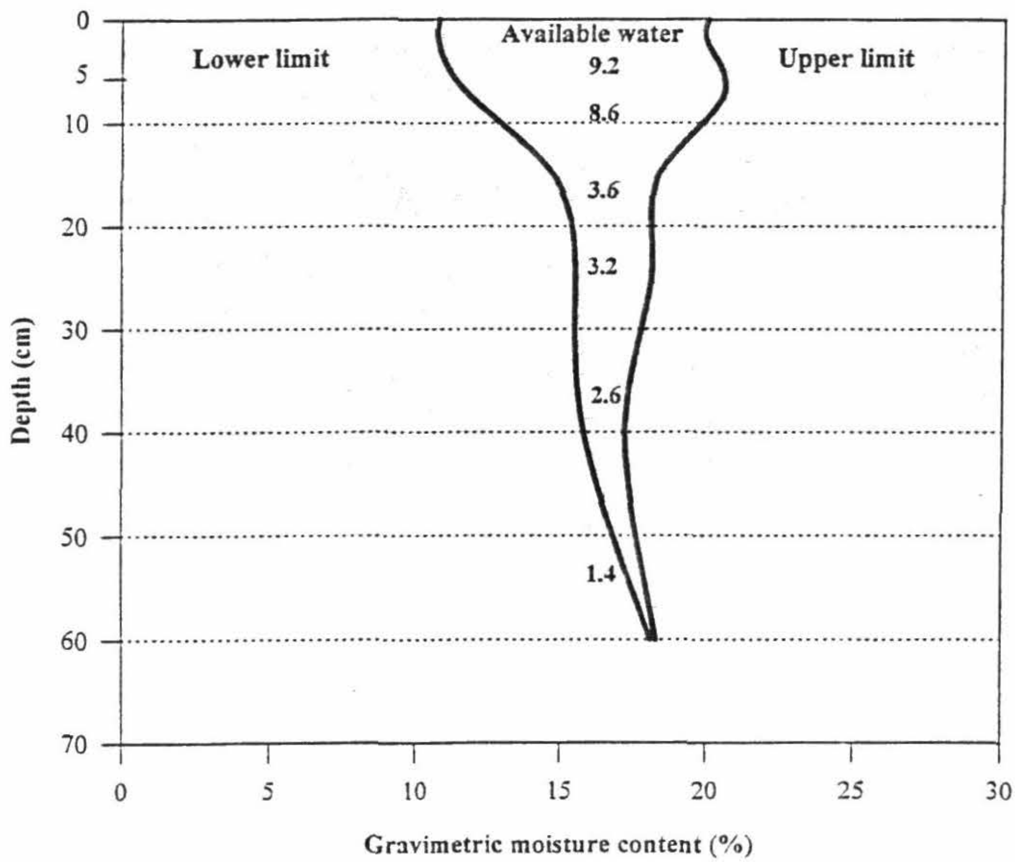


Fig. 1. Upper and lower limits of available water in a soil profile (Oxisol) under savanna condition, Matazul.

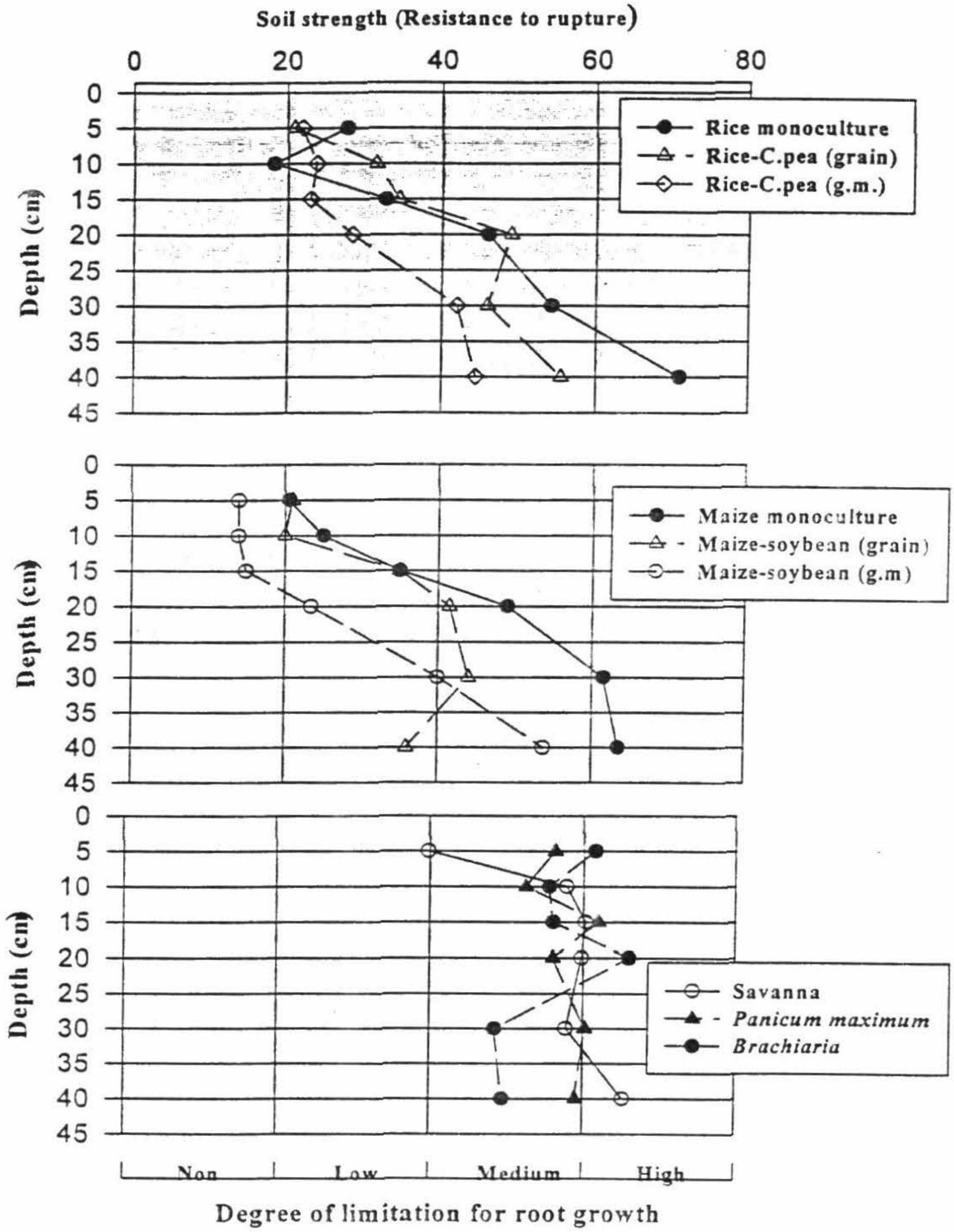


Fig. 2. Soil strength at different depth and management systems in Culticore, Carimagua

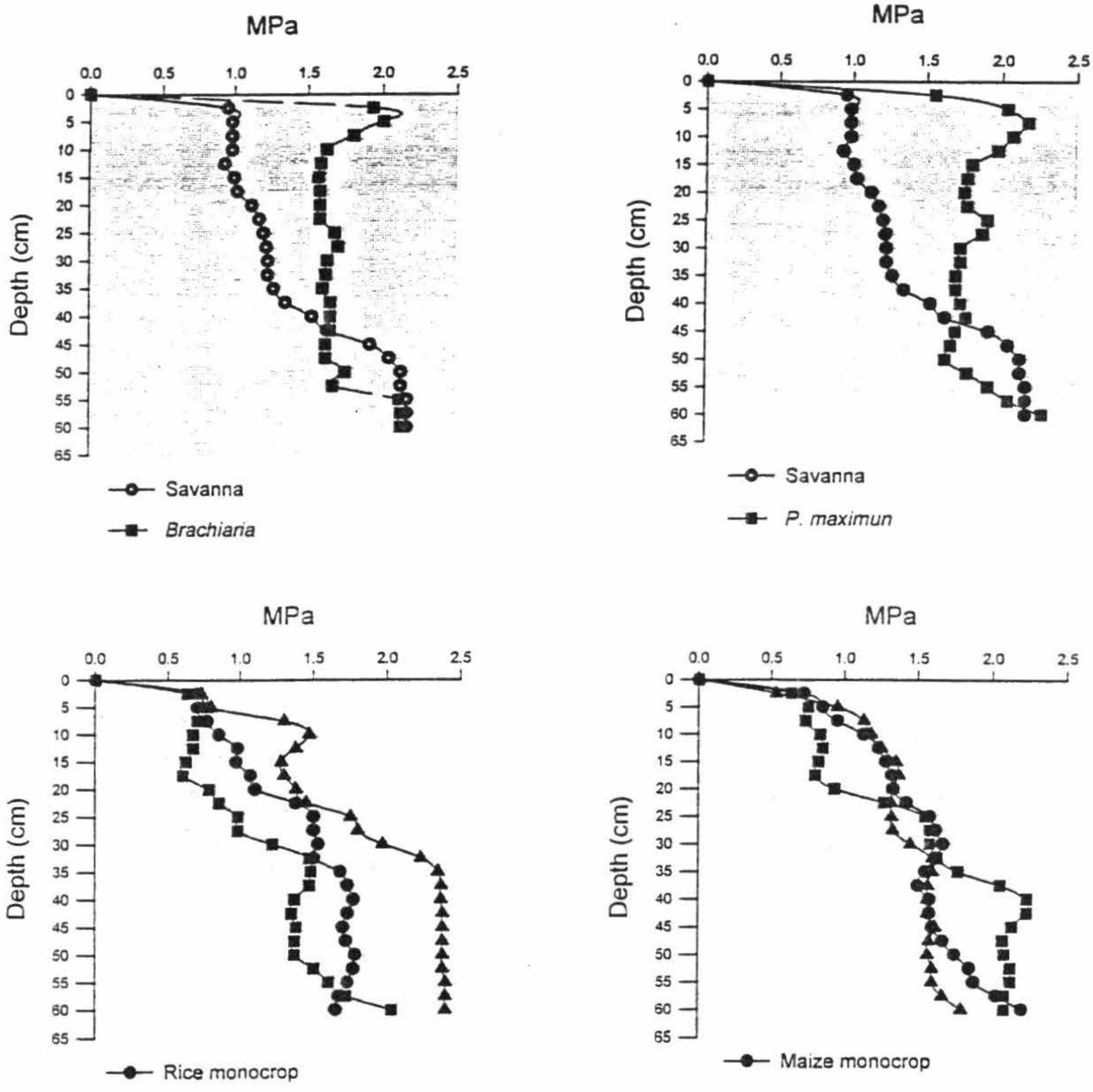


Fig. 3. Effect of different soil uses on penetrability in Culticore, Carimagua

Rationale:
Improved soil and crop management systems need to be developed for the Altillanura in order to overcome the constraints of these low fertile acid soils. Soil physical constraints have been little studied and understood to date.

Results:
After five years of treatments in the Culticore experiment (see PE-2 annual report 1997 for details), changes in the soil physical conditions have been found. In this report, the behavior of soil strength is analyzed. Resistance to rupture and penetrability are two parameters that can be used as indicators of suitability for agricultural purposes and they can be measured in the field with portable and cheap apparatus.

Figure 2 shows the values of resistance to rupture. It can be seen that the resistance of soil to rupture is lower in the treatments that have received tillage (rice and maize) compared with pastures. There are also differences between treatments with and without a legume. Legumes tend to decrease the resistance values especially in the rotation maize-soybean-green manure.

The shape of the curves shows that the use of machinery (a combined effect of chisel and harrowing) has influenced the first 25-30 cm, in relation to savanna.

The values under savanna and pastures (*Brachiaria* and *Panicum maximum*) were high when compared with those of maize and rice. *Panicum* and *Brachiaria* presented values even higher than savanna, indicating that the introduction of pastures and animals (trampling) has caused compaction in the shallow layers.

In the lower part of the figure a first approximation of interpretation of the values, based of field observations is presented. Critical values for root growth seem to be those higher than 40 Kpa.

The mechanical impedance to penetrability is shown in Figure 3. *Brachiaria* and *Panicum maximum* had higher values compared to the savanna until the 40-45 cm depth, showing that trampling has caused compaction. Rice and maize showed lower values. This parameter followed the same trends as those of resistance to rupture.

Impact.
Some of the soil and crop management practices used in Culticore are showing that there are solutions for improvement of soils in "Llanos", which involve integrating crops and pastures.

Contributors: E. Amézquita, D. Friesen, R. Thomas, C.G. Meléndez, L.F> Chavez, J. Galvis, A. Alvarez, I.M. Rao

Activity 1.2. Characterize components for production potential and nutrient use efficiency

1.2.1 Determine differences in shoot and root attributes among native and introduced pasture systems in the forest margins

Highlight

- Showed that the presence of legume in association with the grass pasture improved the acquisition of not only N but also other nutrients, particularly Ca from the soil

Purpose:
To determine differences in shoot and root attributes among native and introduced pasture systems in the forest margins

Rationale:
Introduced pastures in the piedmont region of Caqueta, Colombia are found in different states of degradation due to: (a) low fertility in soil (low P and high Al); (b) susceptibility of *Brachiaria* to spittlebug, and (c) overgrazing. The extent of pasture and soil degradation has a major impact on milk and meat production, which are economically important activities of the Caqueta region. Widespread adoption and utilization of introduced legume-based pastures in different production systems in this region will depend in part upon their rooting patterns that contribute to rapid establishment and efficient extraction and utilization of nutrients for growth.

Materials and Methods: A field study was conducted on-farm by two undergraduate students from the University of Amazonia in collaboration with CORPOICA-Macagual. The objective of this investigation was to determine root growth and distribution and to test relationships among root growth, shoot growth and nutrient acquisition in native pastures compared with introduced grass pastures and grass + legume pastures at 4-month intervals during the year. Pasture treatments selected for the study included: degraded native pasture (*Homolepis aturensis* + *Axonopus compressus* + *Paspalum notatum*), introduced grass pasture (*Brachiaria decumbens*/B. *humidicola*) and grass + legume association (*B. decumbens/B.humidicola/Arachis pintoi*). A number of plant attributes including leaf biomass, stem biomass, root biomass, root length, arbuscular-mycorrhizal colonization, and nutrient acquisition were measured in pastures under grazing.

Results and Discussion: Shoot growth or forage yield was greater in introduced pastures compared with native pasture (Table 4). Comparison of shoot and root characteristics of native and introduced pastures indicated that native pasture develops much finer root system than the introduced pastures, as revealed by greater values of specific root length which is a measure of the fineness of the root system. The introduction of the legume, *A. pintoi* decreased the specific root length of legume-based pasture compared with the grass pasture. This observation has important implications for maintaining productive pastures. Introduced grass and legume genotypes that can mimic the fine root characteristics of native pastures can acquire nutrients such as P and Ca from low fertility soils and maintain productivity of the pasture.

Impact: The presence of legume in association with the grass pasture improved the acquisition of not only N but also other nutrients, particularly Ca from the soil. This observation indicates that the presence of legume in an association could not only improve the supply of N to the grass but also increase the availability of other major nutrients in topsoil due to recycling. This improved supply of N and Ca could improve the forage quality of the associated grass and contribute to greater milk and beef production

The above activity was carried out in close collaboration with two other CIAT projects, IP-5 and PE-5.

Table 4. Differences in shoot and root attributes among native and introduced pasture systems in the piedmont region of Caqueta, Colombia.

Plant attributes	Pasture systems		
	Native pasture[1]	Introduced grass pasture[2]	Introduced grass-legume pasture[3]
Shoot biomass (t/ha)	0.93	2.34	4.53
Root biomass (t/ha)	1.52	2.44	1.81
Root length (km/m^2)	7.13	8.04	3.53
Specific root length (m/g)	46.1	33.0	22.1
Shoot N uptake (kg/ha)	11.1	19.6	60.0
Shoot P uptake (kg/ha)	1.24	3.11	6.25
Shoot K uptake (kg/ha)	10.3	32.0	62.8
Shoot Ca uptake (kg/ha)	2.74	7.17	31.4
Shoot Mg uptake (kg/ha)	1.72	4.72	12.5

[1]Native pasture: *Homolepis aturensis + Axonopus compressus + Paspalum notatum*
[2]Introduced grass pasture: *Brachiaria decumbens + B. humidicola*
[3]Introduced grass-legume pasture: *B. decumbens + B. humidicola + Arachis pintoi*

Contributors: Y. Conta Diaz, H. J. Baracaldo, G. Ruiz, C. J. Escobar, I. M. Rao and C. E. Lascano (CIAT).

1.2.2 Determine differences in nutrient acquisition and utilization by maize

Highlight

- Found that maize responded to increased levels of lime application by improving the efficiency of nutrient acquisition per unit root length.

Purpose:
To determine differences in nutrient acquisition and utilization by maize

Rationale:
Inhibition of root growth has been shown to be a primary effect of Al toxicity in acid soils. Decrease in nutrient concentration or in total nutrient content in plants exposed to toxic levels of Al in soil solution may be due to decreased nutrient absorption brought about by reduction in root growth, or due to direct Al inhibition of nutrient uptake. Previous field research showed that the subsoil root development of acid soil adapted maize is limited by lack of movement of applied lime from topsoil to subsoil. It is known that the acid soil

adapted maize cultivar (Sukuani V110) responds to increased levels of lime application to topsoil. It is generally believed that this response in terms of increased grain yield is mostly due to a decrease in Al toxicity to root system development. However it is not clear whether it could also be due to improvement in nutrient uptake processes.

Materials and Methods:
Response to lime (calcite) applications in terms of shoot and root attributes of field-grown maize (Sikuani V110) were determined during grain filling in a clay loam Oxisol at Carimagua.

Results and Discussion:
Lime application improved shoot growth and grain yield as a result of enhanced nutrient acquisition (Table 5). Root biomass production and root length were not much affected by lime application. However, nutrient (N, P, K, Ca) uptake efficiency (nutrient uptake per unit root length) was markedly improved by the increase in lime applications. This observation suggests that the greater availability of Ca in soil solution with the increase in lime application might have alleviated the inhibitory effects of Al on nutrient uptake processes at the plasma membrane of roots.

Results on root distribution indicated that rooting ability of maize was limited in subsoil layers. This was mainly due to the lack of movement of lime to subsoils. Further work is in progress to determine the importance of subsoil liming on root growth, root distribution and nutrient acquisition by maize. This research is needed to improve the productivity of maize in order to increase profitability to producers

Table 5. Shoot and root attributes of maize (cv. Sukuani V110) in response to lime (calcite) applications to a clay loam Oxisol at Carimagua, Colombia.

Plant attributes	Lime treatments					LSD
	L0	L1	L2	L3	L4	(P = 0.05)
Grain yield (t/ha)	2.40	1.70	2.81	3.00	4.10	0.65
Shoot biomass (t/ha)	4.23	5.22	7.28	7.01	5.61	NS
Root biomass (kg/ha)	394	398	468	348	296	NS
Root length (km/m^2)	4.41	3.56	3.35	3.72	2.18	1.09
Shoot N uptake (kg/ha)	44.3	65.5	83.7	77.1	68.8	NS
Shoot P uptake (kg/ha)	7.08	9.43	12.1	12.4	9.94	NS
Shoot Ca uptake (kg/ha)	4.30	5.15	10.2	13.1	11.8	6.53
Shoot K uptake (kg/ha)	69.0	98.9	153	143	143	72
N uptake efficiency (μg/m)	1049	1829	2540	2043	3263	1629
P uptake efficiency (μg/m)	165	264	367	327	469	200
Ca uptake efficiency (μg/m)	101	144	307	352	551	245
K uptake efficiency (μg/m)	1653	2756	4655	3770	6735	3077

L0 = L0-K80-Mg20; L1 = L400-K120-Mg20; L2 = L800-K120-Mg-20; L3 = L1600-K120-Mg20; L4 = L3200-K120-Mg20; Lime and nutrient levels are in kg/ha. NS = not significant.

Contributors: . I. M. Rao, D. K. Friesen, C. G. Melendez and J. Ricaurte.

Activity 1.2.3. Prototype agrosilvopastoral systems for ecologically sound intensification of production in the hillsides (INTERPROGRAM Project).

Highlights:

- First phase cropping systems experiments concluded and second phase focusing on improved fallow agroforestry systems and novel rotations initiated.
- Promising technologies used and optimized on-station moving to on-farm by client demand *via* collaborators (IPRA, CIPASLA).

Purpose:
Develop sustainable agrosilvopastoral systems that improve soil quality, water management, and efficiency and productivity of land and labor.

The Interprogram Project was conceived as a CIAT activity designed to integrate approaches from its Natural Resource Management and Genetic Resources divisions (Fig.4). The purpose of the project is to develop principles for the design of sustainable agrosilvopastoral systems that improve soil quality, water management, and the efficiency and productivity of land and labor (Sanz, 1994). CIAT researchers closely interact with a local consortia, CIPASLA (Interinstitutional Consortium for Sustainable Hillside Agriculture), which includes local farmer organizations, government institutions and NGO's to ensure that client priorities and demands are fully addressed as well as providing adequate channels for dissemination of promising technological options through the CIAL (Farmer-led Agricultural Research Committees) network.

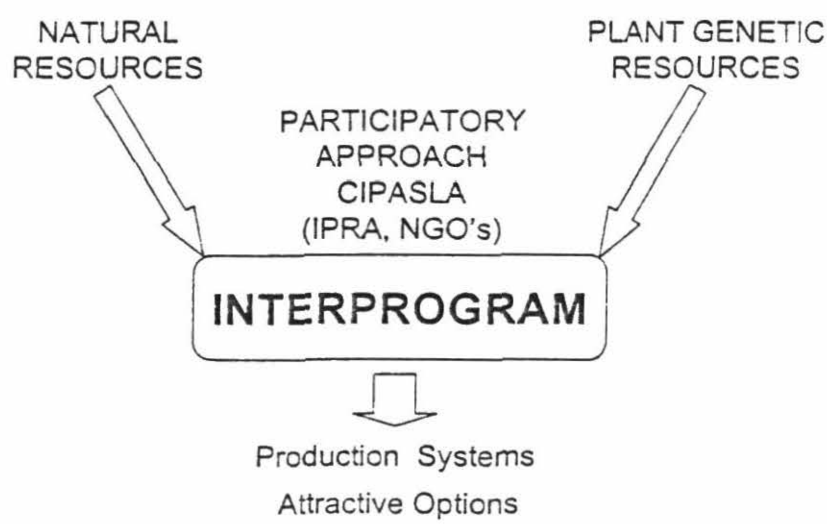


Fig.4 Conceptual model of Interprogram Project's role

Most Interprogram Project activities are housed at San Isidro farm in Pescador, Cauca Region. This farm is typical for the region (< 5 ha, varied slopes 10-45%, low soil available P, acid soils of volcanic origin) and is located at 1500 m.a.s.l. with 1800 annual bimodal rainfall and a mean temperature of 21°C. Different farm management alternatives have been established since its conception about 4 years ago to provide a "supermarket of options" for the hillside farmer community. These options have included farming systems and genotype trials participatory evaluations where they have been ranked according to farmer preferences and adopted accordingly.

San Isidro farm can be divided according to cropping history into two zones based on land use previous to CIAT's arrival. Zone 1 (Barbecho 1) was continuously cropped to beans for five years with considerable applications of chicken manure every semester (>6 ton/ha). Zone 2 (Barbecho 2), on the contrary, was left in natural fallow with an almost exclusive cover of the naturalized grass *Mellinis minutiflora* for two years. A comparison of soil chemical characteristics for Zone 1 and 2 (the way the farm was received by the Interprogram Project in June 1994) is presented in Table 6.

Table 6. Soil chemical characteristics at the beginning of the Interprogram Cropping Systems Experiment at San Isidro Farm, Pescador, Cauca.

		ELEMENT								
	pH	C	P	K	Ca	Mg	S	Zn	B
		%	ppm	-------- meq/100 g ------			------------ ppm ----------		
Site 1									
Barbecho 1									
0-5	5.23	8.34	12.87	1.47	3.73	2.74	84.4	3.98	0.60
5-10	5.23	7.77	12.67	1.39	3.33	2.66	100.4	4.14	0.57
10-20	5.20	5.12	6.67	1.62	1.09	0.55	100.2	3.69	0.30
20-40	5.28	2.98	1.73	0.83	0.58	0.19	106.6	4.53	0.06
40-60	4.97	1.43	2.23	0.15	0.83	0.29	23.3	6.90	0.04
Site 2									
Barbecho 2									
0-5	5.20	5.28	5.50	0.38	1.75	0.78	64.0	3.90	0.29
5-10	5.20	5.05	5.00	0.30	1.51	0.44	74.8	3.67	0.23
10-20	5.20	3.60	2.80	0.15	0.84	0.24	72.1	6.65	0.20
20-40	5.20	1.91	2.10	0.05	0.75	0.20	29.8	8.40	0.07
40-60	5.30	0.93	2.50	0.03	0.63	0.24	19.6	4.03	0.02

Activity 1.2.3.1. Indigenous intercropping systems as an example of efficient use of natural resources in hillside agroecosystems

Highlights:

- An indigenous intercropping system (cassava+maize+beans) provided a more efficient use of farm space and time as indicated by a Land Equivalent Ratio (LER) greater than one.

Purpose:
Compare contributions of cassava, maize and bean to farm productivity when planted as monocrops or an indigenous intercropping system.

Rationale:
Monocropping has often led to soil degradation and increasing production costs make their economic and environmental sustainability questionable especially for small scale hillside farmers. Intercropping, the simultaneous cultivation of two or more compatible crops on the same plot of land, has provided a way of using incoming light, water and available nutrients more efficiently. Local farmers have developed an intercropping system in which beans, maize and cassava coexist and yield on the same plot at 3,6 and 15 months respectively. This is an important alternative for resource poor hillside farmers who often lack enough land for rotations and possibility for reduced or no nutrient inputs.

Methods:
A field experiment was set up at the San Isidro farm following a random complete block design replicated three times with the following treatments: cassava, maize, beans as monocrops, and the intercrop (cassava+maize+beans). Plot size was 400 m^2. Planting distance was 90 cm between rows for all crops. Distance within rows was 100 cm for cassava, 50 cm for maize and 10 cm for beans. Bean and maize monocrop yields were determined each semester season and cassava after 15 months. In the intercrop, cassava uses the same spacing as in the monocrop. Beans and maize are planted in the cassava inter-rows at a rate of four bean rows followed by one maize row. Bean, maize and cassava intercropped were harvested once each after 3, 6 and 15 months respectively. Crop yields for maize and bean monocrops are the sum of yields for three semesters. Chicken manure fertilization was applied to bean and maize monocrops in the way recommended by the farmers in the region (6 ton/ha = 210 kg N, 66 kg P, 114 kg K). Later results indicated that this application rate was excessive and commonly used as a response to the high nutrient variability found in chicken manure from different sources. Planting of cassava is done by placing cuttings in holes in the soil previously fertilized with chicken manure.

Results:
The intercropping alternative as an adaptive local strategy makes good sense when we look at land equivalent ratios (LER) (Mead & Willey, 1980). This measure is frequently used to assess the advantage of intercrops over monocrops. It refers to the requirements to grow monocrops and get as much as an intercrop. It is calculated as the sum of the relative crop yields that is:

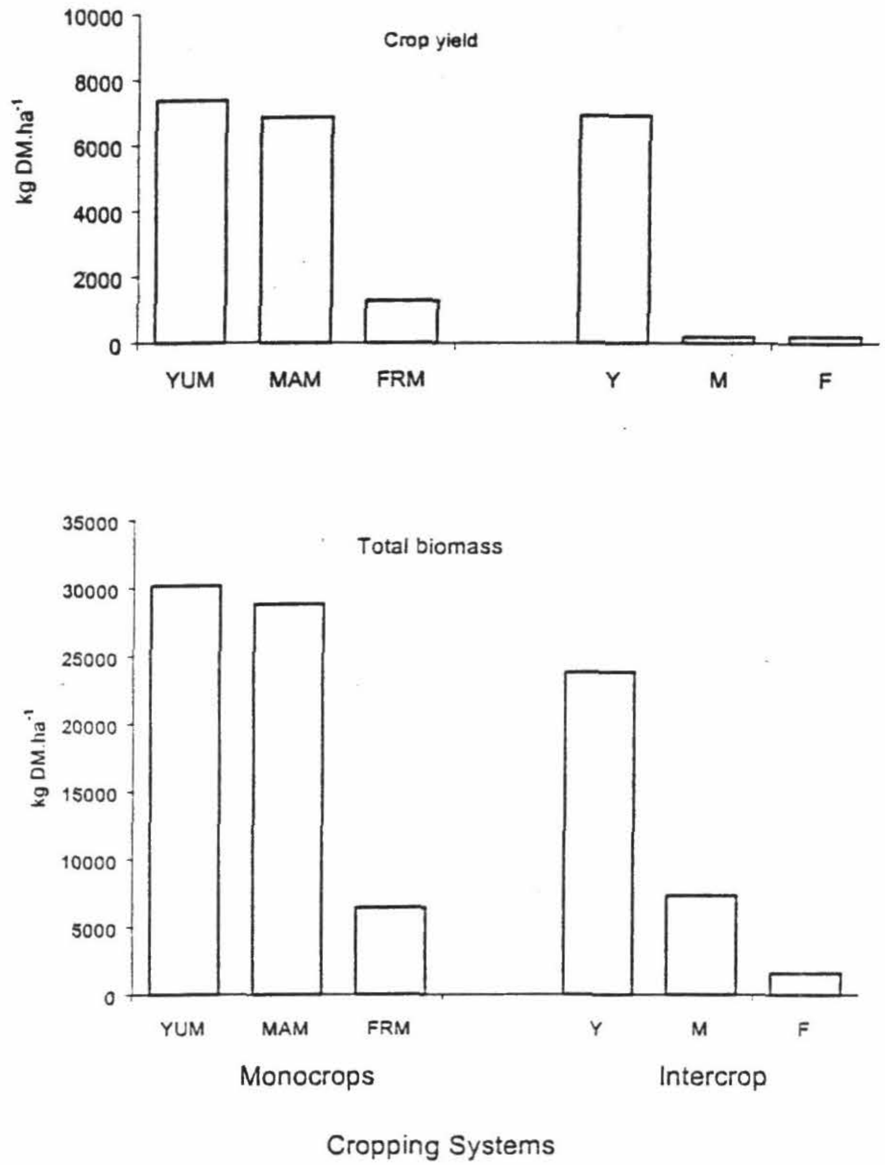


Fig. 5. Cassava, maize and bean crop yields and total biomass as affected by cropping system (monocrop vs. intercrop). YUM= cassava monocrop, MAM= maize monocrop, FRM= bean monocrop, Y/M/F= cassava, maize and beans in intercrop.

LER = RY cassava (C) + RY maize (M) + RY beans (F) = YI/YM + MI/MM + FI/FM
where I = Intercrop and M = Monocrop

The value of 1.0 for LER is the critical value, above which the intercrop is favored, and below which the monocrop is favored. The calculations for the cassava systems studied shows an LER = 1.12 indicating a greater efficiency of natural resource use (space, light, water, nutrients) by intercrops than monocrops. Furthermore, using non-crop yields in the calculation generates an LER = 1.33 which suggests that the advantage is even greater in the production of biomass which may have other important uses in the farm (i.e. animal feed, composting, cooking, etc.).

Impact:

- Intercropping is a native practice with a more efficient use of natural resources and more studies should be directed to assess its economic and environmental impact on-farm.
- The value of non-crop products and their potential uses should be highlighted when assessing economic benefits as they are considerably higher in intercrops than in monocrops.
- A challenge remains in finding ways to manage the variability of chicken manure nutrient quality as it will allow for a more efficient use of this important nutrient input.

Contributors: E.Barrios, J.I.Sanz, R.Thomas, N.Asakawa (CIAT), A.Meléndez, C.Trujillo (CIPSALA).

Activity 1.2.3.2. Yield potential of cassava as affected by contrasting cropping systems

Highlights:

- High plasticity of cassava allows the maintenance of similar crop yields despite increasing competition by associated crops and covercrops.

Purpose:

To study the effect of different cassava cropping systems on crop yield.

Rationale:

Cassava cultivation is an important land use in Colombian hillsides not used for coffee cultivation. Current management practices include tillage of steep soils and planting cassava cuttings in holes previously fertilized with a measure of chicken manure (about 250g = 9 g N, 3 g P, 5 g K) during the rainy season. This practice leads to considerable topsoil losses (about 130 ton/ha) because of the low bulk density of these volcanic ash soils (Sanz, 1995). The challenge is to find productive ways of maintaining soil cover while the cassava canopy develops to provide its own soil cover.

Methods:

A randomized complete block design with three replications was established in Zone 1 (Barbecho 1) at San Isidro farm in October 1994 /harvested in January 1996 and the second cycle from March 1996/harvested in June 1997. Plot size was 400 m^2. Three treatments namely cassava monocrop, cassava + legume cocktail covercrop (*Arachis pintoi CIAT 17434, Stylosanthes guianensis CIAT 184, Centrosema macrocarpum CIAT 5713, Desmodium heterocarpum CIAT 13089, Chamaecrista rotundifolia CIAT 8990*), and cassava+maize+beans intercrop were compared for their productivity.

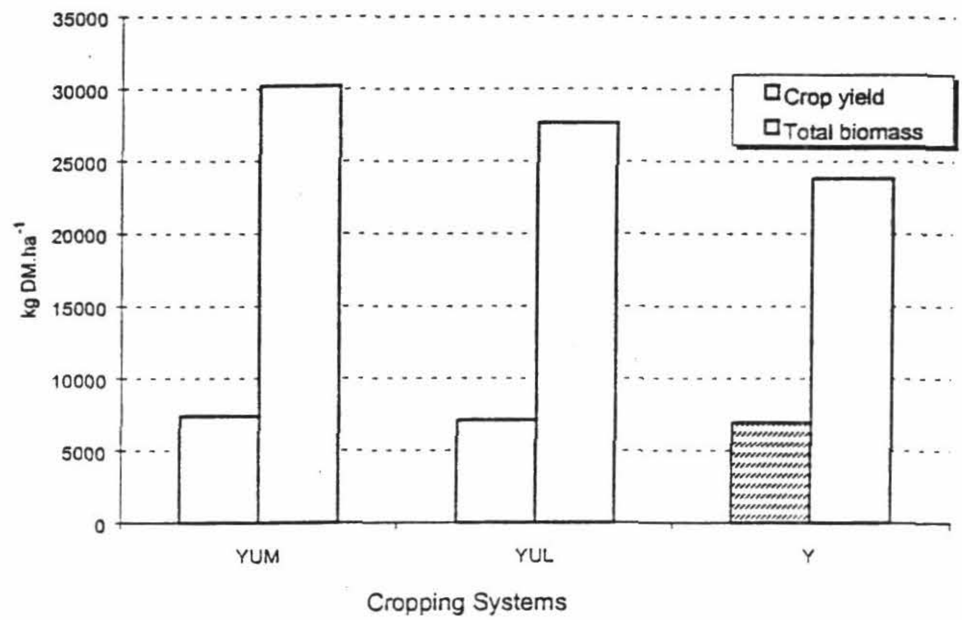


Figure 6. *Total biomass* and crop yield for cassava cropping systems in Colombian hillside soils. YUM= cassava monocrop, YUL= cassava + legume covercrop, Y= cassava in intercrop

It is evident from Figure 6 that cassava yield was little affected by cropping systems which generated different degrees of interspecific competition, by crops or covercrops, as compared to intraspecific competition during monocropping.

Impact:

- The considerable plasticity of cassava as expressed by stable yields despite the presence of competition suggests that we need to explore more intercropping options as well as getting a better understanding of mechanisms by which cassava avoids competition.

Contributors: E.Barrios, J.I.Sanz, R.Thomas, N.Asakawa (CIAT), A.Meléndez, C.Trujillo (CIPASLA).

Activity 1.2.3.3. Novel rotational systems for the hillside ecoregion

Purpose:
To conduct simultaneous adaptation and production studies in crop rotational systems (highland rice/beans) in collaboration with CIRAD/CIAT Rice Project and CIAT's Bean Project.

Rationale:
Rice is an important part of the diet for hillside families. It is commonly produced in lowlands and transported and sold at the hillsides. Food security would be considerably affected by the capacity to produce rice on site and thus adapted plant genetic resources

should be incorporated into novel cropping systems options. The adaptation and yield potential of beans, as part of the rotation, would be evaluated simultaneously as it represents the local option for this cereal/legume rotation.

RT-1 Adaptation and productivity of Upland Rice/Bean rotation for acid and low P volcanic ash soils

Establishment date: April 1998

Treatments: Rice adaptation, bean adaptation, rice production, bean production.

Experimental design: Random blocks with three repetitions and plot size is 10 m by 10 m. Rice plots will be bean plots the following season and *vice versa*. Sixty (60) rice lines resulting from crosses between Madagascar materials (height/cold tolerance) and Brazilian materials (soil acidity/drought tolerance) are being evaluated for hillside conditions in Pescador, Cauca. Simultaneously, Twenty-five (25) bean lines are being evaluated for tolerance to soil acidity, root rot, anthracnose, as well as low cooking time. Rice and bean yields using the best option available (Rice: Latisdahy x Fofifa 62-3, Beans: Caucayá) are also evaluated in production plots and compared with potential improved lines from adjacent adaptation trials.

Results:
This is a long-term trial initiated six months ago (March 1998) and therefore, at this point in time, only half of the rotation has taken place and further reporting is considered premature.

Contributors: E.Barrios, S.Beebe, I.M. Rao, J.Borrero, Y.Ospina (CIAT), A.Meléndez, C. Trujillo (CIPASLA), M.Vales, M.Chatel (CIRAD).

The project links with IP-4 and IP-1.

Activity 1.3: Determine rooting strategies of crop and forage components

1.3.1 Determine differences in rooting strategies of crop-forage system components in the Andean Hillsides

Highlight
- Field studies showed that (i) the presence of cover legumes can improve potassium acquisition by cassava; and (ii) elephant grass can be used as an effective grass barrier to reduce soil erosion in Andean hillsides.

Purpose:
To determine differences in rooting strategies of crop-forage system components in the Andean Hillsides

Rationale:

Rooting characteristics and root competition between crop and forage components of hillsides crop-livestock systems could have important effects on nutrient acquisition and plant growth as well as soil loss. A strategic research experiment was established in 1994 in Cauca, Colombia, to generate principles based on rooting strategies for improving crop-livestock production while conserving the natural resource base. As part of this experiment, the present study was undertaken to determine the effects of root distribution on nutrient acquisition and soil erosion in crop-forage systems on Andean hillsides soil.

Materials and Methods:

Soils at the site are medium to fine textured Oxic Dystropepts derived from volcanic-ash deposits. Treatments (crop and forage systems) were established on steep slopes (43-46%). Six treatments, cassava (*Manihot esculenta* cv. algodona) monocrop, cassava + cover legumes (*Centrosema acutifolium* CIAT 5277 and *Arachis pintoi* CIAT 17434) intercrop, elephant grass (*Pennisetum purpureum* cv. Mott) pasture, imperial grass (*Axonopus scoparius* cv. imperial) pasture (*Brachiaria dictyoneura* CIAT 6133), introduced legume-based pasture pasture (*B. dictyoneura* + *A. pintoi* CIAT 17434 + *C. macrocarpum* CIAT + *S. guianensis* CIAT 184) and naturalized pasture (*M. minutiflora*) were selected to determine differences in dry matter partitioning, leaf area index, nutrient composition, root distribution (0-80 cm soil depth), nutrient acquisition and soil loss.

Results and Discussion:

Root biomass distribution by soil depth (0-80 cm) was 44% greater in the top 0-10 cm soil depth under cassava intercropped with cover legumes than under the cassava monocrop (Figure 7). However, root length density values were similar between the two systems indicating that the roots of cover legumes were coarser than the cassava crop. Elephant grass had significantly greater root biomass and root length density than imperial grass. Total root biomass (0-80 cm soil depth) of the elephant grass was 2.2-fold greater and mean root length density across the soil profile was 3.8-fold greater than that of the imperial grass (Table 7). This observation indicates that elephant grass developed a more abundant and extensive fine root system than imperial grass. This characteristic could help reduce soil erosion on steep slopes. In fact, measurements of soil losses or gains in different systems showed soil losses in cassava systems and soil gains in cut and carry grass systems (Table 8). Nevertheless, the presence of cover legumes in cassava intercrop markedly reduced soil loss. The soil gain under elephant grass was greater than that under the imperial grass system.

Table 7. Differences in total root biomass and mean root length density among crop-forage systems in a volcanic-ash soil of the Andean hillsides.

Soil depth (cm)	Cassava systems		Forage grasses		LSD[§]
	Cassava monocrop	Cassava intercrop	Elephant grass	Imperial grass	
	Root biomass (kg/ha)				
Total (0-80 cm)	1060	1570	9300	4250	2700
	Root length density (cm/cm^3)				
Mean (0-80 cm)	0.37	0.42	11.6	3.04	3.4

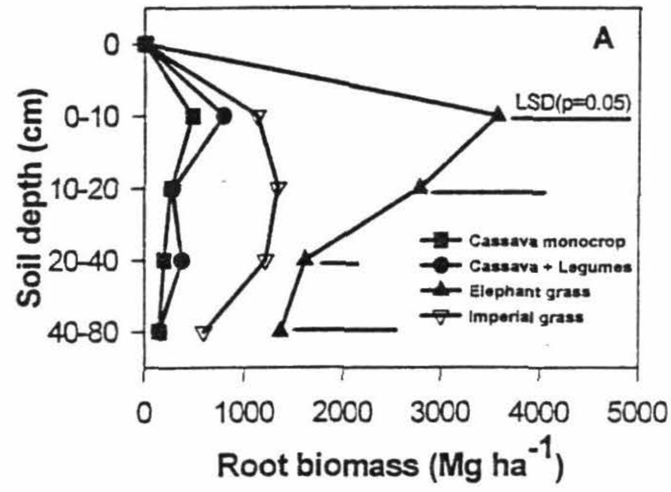
[§]LSD = least significant difference (0.05 probability level).

Table 8. Soil losses or gains under crop-forage systems in a volcanic-ash soil of the Andean hillsides.

Crop-forage system	Soil loss (-) or gain (+)[§]	Slope
	(t/ha/6 months)	(%)
Cassava monocrop	-193±27	46
Cassava intercrop	-50±24	43
Elephant grass pasture	+96±31	43
Imperial grass pasture	+60±30	43

[§] Values are mean ± S.D. of 3 replications.

Differences in shoot and root attributes and nutrient acquisition among crop-forage systems are shown in Table 9. Cassava root (dry) yield was not affected by the presence of cover legumes. This was mainly because cassava leaf biomass and leaf area index were maintained when associated with cover legumes. Among the two grass systems, elephant grass had greater leaf biomass. This was associated with greater root biomass production in elephant grass (Figure 7). The greater root biomass in cassava + cover legumes was associated with reduced weed growth when compared to cassava monocrop.



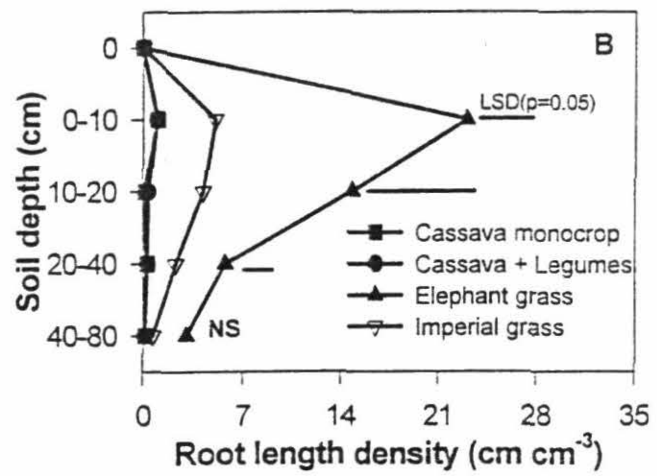


Figure 7. Distribution of root biomass (A) and root length density (B) among crop-forage systems in a volcanic-ash soil of the Andean hillsides. LSD = least significant difference (0.05 probability level). NS = not significant.

Shoot N, P, K and Ca uptake was greater by cassava intercropped with legumes than by the cassava monocrop (Table 9). The presence of cover legumes did not reduce acquisition of nutrients by cassava crop. In fact, the acquisition of K was greater though not significantly when associated with cover legumes than when grown as monocrop. This may be attributed to the recycling of K via legume litter. Shoot Mg uptake was similar by both cassava systems. Elephant grass with its abundant and extensive fine root system acquired markedly greater amounts of N, P, and K from soil although shoot Ca and Mg uptake was similar by both forage grasses.

Table 9. Comparison of plant attributes among crop-forage systems in a volcanic-ash soil of the Andean hillsides.

Plant attributes[§]	Cassava systems				Forage grasses		LSD[¶]
	Cassava mono-crop	Cassava intercrop			Elephant grass	Imperial grass	
		Cassava	Legumes	Total			
Leaf biomass	1240	1360	610	1970	1930	1320	NS
Leaf area index	2.78	2.70	1.66	4.36	3.38	3.48	NS
Shoot biomass	6390	6230	1420	7660	3370	3430	2900
Dry root yield	2570	2300	-	-	-	-	NS
Shoot N uptake	98	95	36	130	49	28	46
Shoot P uptake	9.3	9.7	2.8	12	12	6	5.8
Shoot K uptake	56	69	26	94	83	29	59
Shoot Ca uptake	38	37	12	50	20	19	17
Shoot Mg uptake	18	16	4.2	20	13	13	NS

[§] All attributes in units of kg ha^{-1} except leaf area index which is m^2 m^{-2}.
[¶] LSD = least significant difference (0.05 probability level); NS = not significant.

Naturalized pasture (*M. minutiflora*) developed finer root system than the introduced legume-based pasture (*B. dictyoneura* + *A. pintoi* + *C. macrocarpum* + *S. guianensis*) but recycling of K and Ca via roots was greater with the introduced legume-based pasture than that of the naturalized pasture (Table 10).

Table 10. Comparison of plant attributes between naturalized and introduced legume-based pasture in a volcanic-ash soil of the Andean hillsides.

Plant attributes	Naturalized Pasture	Introduced legume-based pasture
Shoot biomass (t/ ha^{-1})	9.14±1.69	7.44±1.43
Leaf area index (m^2 m^{-2})	2.63±0.64	2.93±1.19
Root biomass (t/ha^{-1})	3.00±0.43	4.94±2.52
Total Root length (km m^{-2})	24.6±0.7	17.4±5.7
Specific root length (m g^{-1})	71.8±20	31.6±1.7
K partitioned to roots (kg ha^{-1})	4.1±2.7	15.1±6.9
Ca partitioned to roots (kg ha^{-1})	5.7±0.7	15.5±5.8

Values are mean ± S.D. of 3 replications.

Impact:

An appreciation of plant attributes of individual components that are beneficial to associated component(s) in nutrient acquisition from infertile soils is of paramount importance in designing compatible system components for enhanced productivity and resource use efficiency in crop-pasture systems. The results obtained indicate that intercropping of cassava with cover legumes, *Arachis pintoi* and *Centrosema acutifolium*, can not only improve potassium acquisition by cassava crop but also contribute to reduced soil erosion from the steep slopes. Comparison of plant attributes of naturalized pasture with those of the legume-based pasture indicated the benefit of legumes in recycling of K and Ca via roots in addition to biological nitrogen fixation. Comparison of root and shoot attributes of elephant grass with imperial grass suggested that elephant grass can be used as an effective grass fodder (barrier) to reduce soil erosion in Andean hillsides.
This activity was carried out in collaboration with CIAT Project, PE-5.

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Activity 1.4 Test compatibility of plant components in different systems

1.4.1. Double purpose sugarcane live barriers for erosion control in hillside agroecosystems

Highlights:

- Sugarcane live barriers can yield enough sugar to satisfy a considerable proportion of hillside family sugar consumption.

Purpose:
To assess the agronomic productivity of sugarcane live barriers in a hillside agroecosystem.

Rationale:
Live barriers for erosion control have encountered limited rates of adoption because the sole objective of soil erosion control is not attractive to farmers. The inclusion of dual purpose live barriers attempts to increase adoption rates by providing alternatives that have an economic incentive in addition to environmental services. Sugarcane barriers are being increasingly incorporated as a way to provide sugar for household consumption and as a by product reduce soil erosion in steep hillside farms. Sugarcane barriers established at San Isidro farm in Pescador, Cauca were harvested after 15 month growth to assess their agronomic productivity.

Methods: Sugarcane live barriers were established following contour lines. A 10-15 cm deep/ 10 cm wide trench was prepared and 50 cm cuttings (containing at least 5 internodes) were laid flat in such a way that two internodes from one cutting would coincide with two internodes from the next cutting. The trench line was then filled with soil again. Chicken manure at a rate of 0.5 Kg (about 10 g N, 6 g P, 10 g K)/m of barrier was used at establishment. This method of establishment was successful in generating a live barrier dense enough for soil erosion control purposes.

Results:

The most important component of the barrier biomass were the canes accounting for 72% of the total (Table 11). The mean number of stems produced was about 22/m of barrier with a mean productivity of close to 11 kg of sugar (panela) /m of barrier. The variability observed among the replicate barriers can be explained by the land use given to the plot just above the barrier and their position in the landscape. For instance barrier #1 had no fertilizer inputs as it was located below a fallow plot, while barriers #2 and #3 were located below cassava and maize production plots receiving about 3 ton chicken manure/ha every semester. The observation of barrier #3, lowest in the slope, presenting greater productivity and sugar yields than barrier #2 may simply be due to receiving a greater amount of nutrients washed downslope. It is evident from this table that with close to 150 m of sugarcane barriers enough sugar is produced to cover an important proportion of household consumption. It becomes important to evaluate this calculation on-farm to have a more realistic assessment of the impact of this technology on household food security.

Table 11. Agronomic productivity of dual purpose sugarcane barriers (var. CC87-45) in a hillside agroecosystem (guarapo= sugarcane juice, bagazo= bagasse, panela= brown sugar bar)

Barrier			Biomass (kg)[1/]				Yield (kg)		
#	Length (m)	# canes	canes[2/]	leaves[2/]	Litter[2/]	total	guarapo[3/]	bagazo[3/]	panelas[4/]
(1)	63	1111	672 (59.1)	263 (23.1)	203 (17.8)	1138	358 (53.3)	314 (46.7)	71 (84)
(2)	63	1393	1430 (74.9)	274 (14.4)	206 (10.7)	1910	668 (46.7)	762 (53.3)	140 (166)
(3)	50	1295	1419 (77.1)	246 (13.4)	176 (9.5)	1891	492 (34.7)	927 (65.3)	132 (157)
Total	176	3799	3521 (72.0)	783 (16.0)	585 (12.0)	4889	1518 (43.1)	2003 (56.9)	343 (407)

1/ Fresh weight
2/ Values in parenthesis refer to plant component weight as a percentage of total weight
3/ Values in parenthesis refer to yield of different products as a percentage of stem weight
4/ Values in parenthesis refer to number of panelas produced

Impact:

- Sugarcane live barriers have shown the potential to provide a considerable proportion of farmer household sugar demands and also contribute in the reduction of soil erosion

Contributors: E.Barrios, J.I.Sanz, E.Amézquita, R.Thomas (CIAT), A.Meléndez, C.Trujillo (CIPASLA).

1.4.2. Improved fallow systems for recuperation of degraded soils in hillside agroecosystems

Purpose:

Identify plant species able to promote a rapid regeneration of soil fertility by their capacity to import nutrients (i.e. N-fixation), have access to recalcitrant soil nutrient pools and provide an increased capacity to recycle nutrients.

Rationale:
Typical cropping cycles in Cauca hillside agroecosystems include annual crops (maize, beans, etc.) as monocrops or rotations that are followed by cassava (two cycles = 30months) and then soils are left to "rest" or fallow because of nutrient depletion and loss of soil structure. 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 (6-10 yrs) for sufficient regeneration by 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. The improvement of fallows is an adequate technological entry point because it is of low risk for the farmer, is of relatively low cost and can have the incentive of generating additional products besides soil fertility improvement (i.e. fuelwood).

Methods: Three experiments (2 on-station, 1 on-farm) were established in 1997/1998 and only titles are presented here.

BM-1 Improved fallows using Indigofera constricta, Calliandra calothyrsus and Tithonia diversifolia.

BM-2 Improved fallows using Indigofera constricta and Calliandra calothyrsus (At Finca Benicio Velazco)

BM-3 Improved fallow using Sesbania sesban, Tephrosia sp. and Mucuna deerengianum.

Results:
This is a long-term trial initiated ten/six months ago (November/April 1998) and therefore, at this point in time, the first annual sampling has not taken place yet and further reporting is considered premature.

Contributors: E.Barrios, R.Thomas, I.M. Rao, E.Amézquita, M.Rondón, N.Asakawa, A.Meléndez, G.Ocampo (CIAT), C.Trujillo (CIPASLA).

Activity 1.5 Determine impact of systems on production and the resource base

These activities have been reported under activities 1.2.3 and 1.4 above.

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Output 2. Strategies developed to protect and improve soil quality

Activity 2.1 Determine nutrient release rates of component residues/green manures

Green manures as a source of nutrients for crops in tropical hillside agroecosystems

Highlights

- Green manures showed variation in decomposition rates
- Losses of nitrogen from green manures via volatilization and leaching may have a significant impact on the environment

Purpose:
To evaluate different green manures and organic materials as a potential source of nutrients to crops in improved fallow or slash and mulch systems.

Rationale:
Green manures (slash and mulch) and biomass transfer (cut-and-carry) systems have shown great potential as a complementary or alternative source of nutrients in tropical hillside agroecosystems where farmers have limited access to purchased inputs. In order to include green manures and other organic materials in alternative cropping systems, it is essential to know their nutrient input, patterns of nutrient release and subsequent recovery by successive crops.

Methodology:
The magnitude and timing of nutrient release was assessed by field and greenhouse experiments and correlated with chemical characteristics (quality) of organic materials as a means of defining selection criteria for green manures and other organic residues.
Plant materials were analyzed for macro and relevant micronutrients as well as forage quality measures (lignin, polyphenols and the *in vitro* digestibility assay).
Field evaluations assessed decomposition (weight and nutrient release) of five green manures (*Canavalia brasiliensis, Mucuna pruriens* var.IITA, *M. pruriens* var. TLALT, *M. pruriens* var. Brunin, *M. deerengianum*) and three organic materials (*Cratylia argentea, Tithonia diversifolia, Indigofera constricta*) using the mesh bag technique for a period of 12 weeks.
Greenhouse experiments evaluated the nitrogen (N) contribution to upland rice (Oryzica Savana 10), grown on hillside soil, of five green manures (*Canavalia brasiliensis, Mucuna pruriens* var.IITA, *M. pruriens* var. TLALT, *M. pruriens* var. Brunin, *M. deerengianum)* and four organic materials (*Cratylia argentea, Tithonia diversifolia, Indigofera constricta, Calliandra calothyrsus*) surface applied at the rate of 100 Kg N/ha as compared to equivalent N fertilizer applications as urea.

Some of the same greenhouse experimental treatments were used to simultaneously estimate gaseous losses of nitrogen as nitrous oxide (a powerful greenhouse gas associated with global climate change) due to liberation of the nitrogen from decomposing litter added to soil. Details of the methodologies used are presented in the report of project SW-2 Output 3.1.

Results:

Chemical characterization (quality):

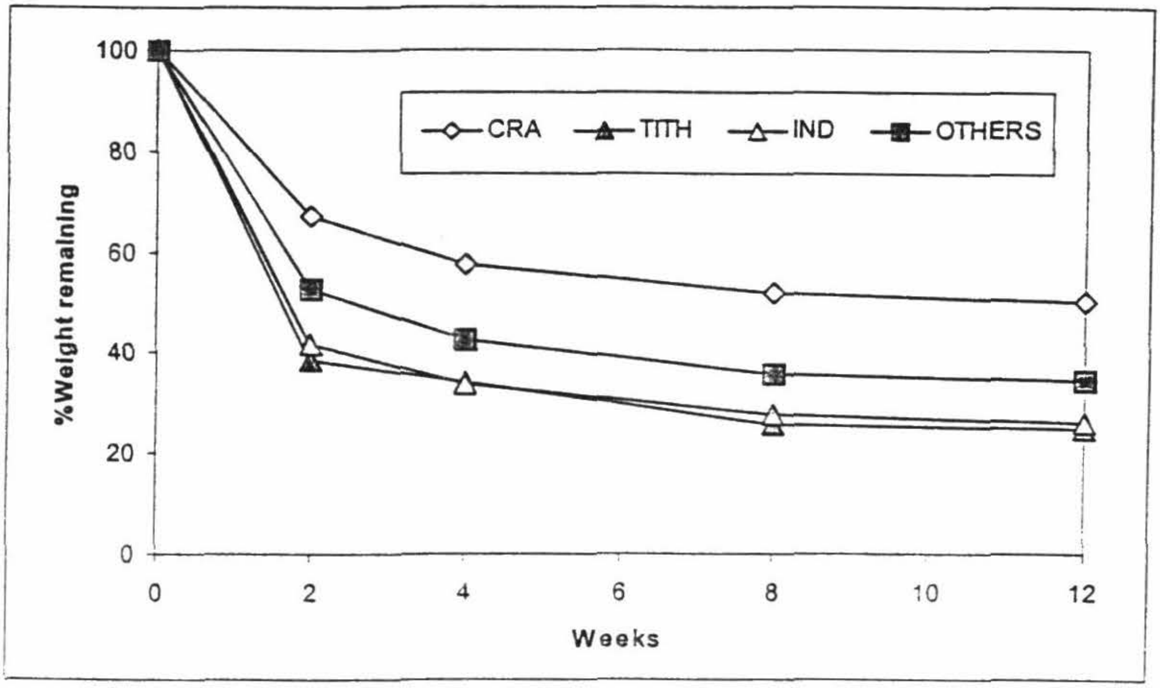
Green manures and organic materials used showed contrasting chemical characteristics (Table 12). Among the green manures, *M. deerengianum* presented the highest N and P nutrient concentrations and also comparatively high lignin and polyphenol contents. *Cratylia argentea* and *Calliandra calothyrsus* had the highest lignin and polyphenol concentrations respectively. *T. diversifolia*, on the other hand, had the highest N concentration among other organic materials and lowest levels of lignin and polyphenols. The quality indices often used to predict decomposability showed an inverse close correlation (r>-0.90) with the *in vitro* digestibility assay (IVDA) used for forage evaluation. This is a potentially important finding since IVDA provides another tool to screen fast decomposing/fast nutrient release green manures and organic materials from those with medium and slow nutrient release patterns.

Table 12. Plant quality indices and the *in vitro* digestibility assay for green manures and other organic materials (CRA = C. argentea, TITH = T. diversifolia, IND = I. Constricta, CAN = C. brasiliensis, CALL = C. calothyrsus, MPIITA = M. pruriens var. IITA, MPTLALT = M. pruriens var. TLALT, MDEE = M. deerengianum, MPBR = M. pruriens var. Brunin)

Plant Material	C:N Ratio	L:N Ratio	(L+P):N Ratio	In vitro digestibility
	%	%	%	%
CRA	13.5	5.4	6.9	46.5
TITH	9.9	1.2	3.4	77.4
IND	11.6	1.8	4.0	72.4
CAN	12.0	1.8	4.0	69.6
CALL	18.6	5.5	12.4	28.1
MPIITA	12.3	1.7	4.1	71.5
MPTLALT	11.9	1.7	4.0	69.1
MDEE	9.8	1.5	3.5	70.4
MPBR	11.0	1.3	3.3	70.0

Field studies:

Plant chemical characteristics will affect the decomposability of green manures and organic materials and thus the magnitude and timing of their nutrient release (Fig.8a,b). Tissue nutrient concentrations varied among plant species studied and nutrient release was proportional to the decomposition rate. Materials with a higher proportion of structural components, i.e., high C/N, L/N and (L+P)/N ratios and low digestibility values in their biomass (i.e. C. argentea), had slower decomposition and nutrient release rates than *T.diversifolia* and *I.constricta* biomasses which have a lower proportion of structural components. The green manure group showed intermediate decomposition and nutrient release rates.



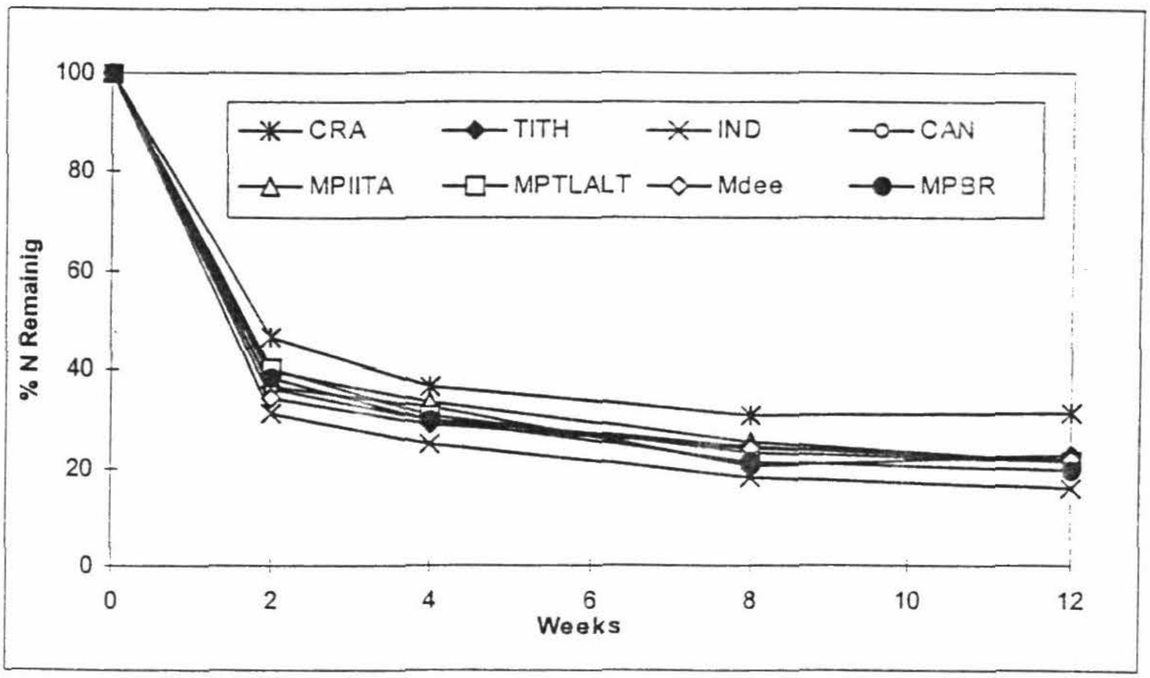


Fig.8a,b Decomposition and N release rates for green manures and other organic materials on a hillside agroecosystem.

A considerable number of publications comparing decomposition rates of green manures and other materials as sources of nutrients focus on the leaf tissue. Common residue management practices in the field, however, are likely to leave other plant tissues in the field as well. We compared the decomposition and nutrient release rates of leaves, stems or leaves+stems for *M.pruriens* var.IITA in order to have a more realistic picture of what would be actually happening in farmer fields (Fig. 9). Decomposition and nutrient release rates for leaves clearly overestimate rates found in the field. These results suggest that studies aiming at field recommendations should use materials as they are to be applied in the field.

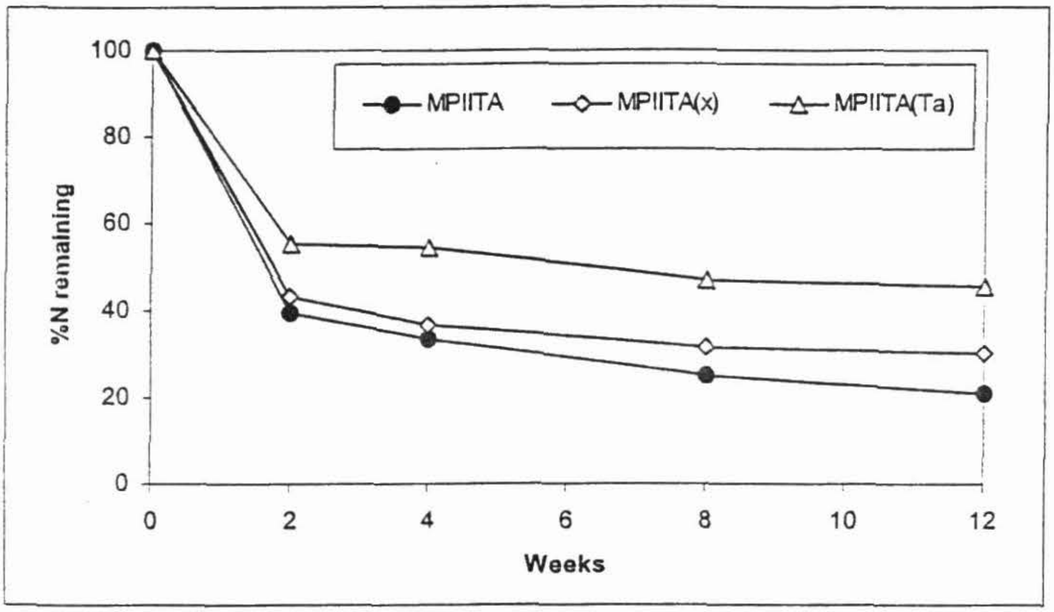


Fig. 9 Nitrogen release from different plant parts (Δ, leaves; ●, stems) and total aboveground biomass; ◇ for *M.pruriens* var. IITA on a hillside agroecosystem.

Greenhouse studies:

Nitrogen release from green manures and organic materials, surface applied to hillside soil sown to upland rice, presented differences as shown in Fig. 8b. These differences had an effect on the response of a subsequent crop as shown in Fig.10. The rapid nitrogen release of *T.diversifolia* and *I. constricta* in the first 2 weeks of incubation in the field (about 70% of total plant N) and consequent high loss potential could explain the lower above-ground rice biomasses for these treatments in the greenhouse. It should be pointed out that the experimental set up using a capillary watering system reduced soil aeration in pots used and could have created favorable conditions for denitrification and thus N losses. An equivalent N rate when applied as urea (C100) gave the best response as measured by crop dry weight and N content. Even halving the rate (C50) had a greater significant effect on crop above ground biomass than most organic amendments. The *Mucuna* group had a relatively similar effect on the crop while the rest of the treatments did not differ much from the control (C0) with no N application.

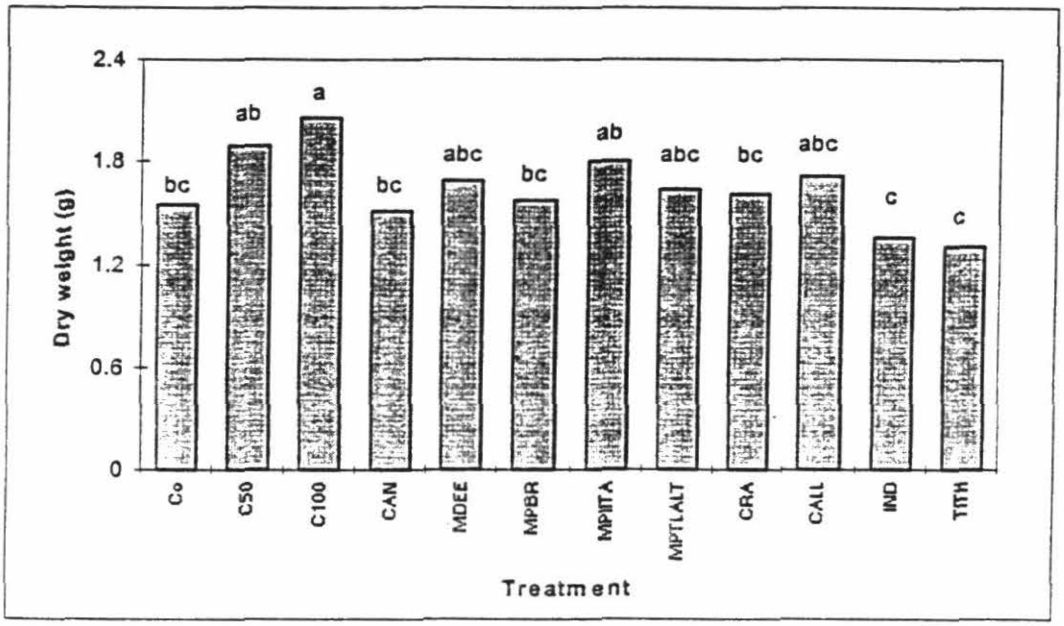


Fig.10. Upland rice (Oryzica Savana10) dry weight following application of 100 Kg of N equivalents of green manures and other organic materials after 12 weeks growth (C0 = control, C50 = 50 Kg N, C100 = 100 Kg N). Significance levels ($P<0.05$)

Nitrous oxide losses from decomposing green manures

Fig. 11 presents the evolution of N_2O fluxes during the growth of upland rice in selected pots in the greenhouse where equivalent doses of nitrogen (100 kg N/ha) from different sources was added: selected treatments were: Control without added N (C0); Fertilizer N as Urea (100N); green manures of *Tithonia divesifolia (TI); Indigofera constricta (IC), Calliandra callotirsus (CA) and Mucuna deerengianum (MD).*

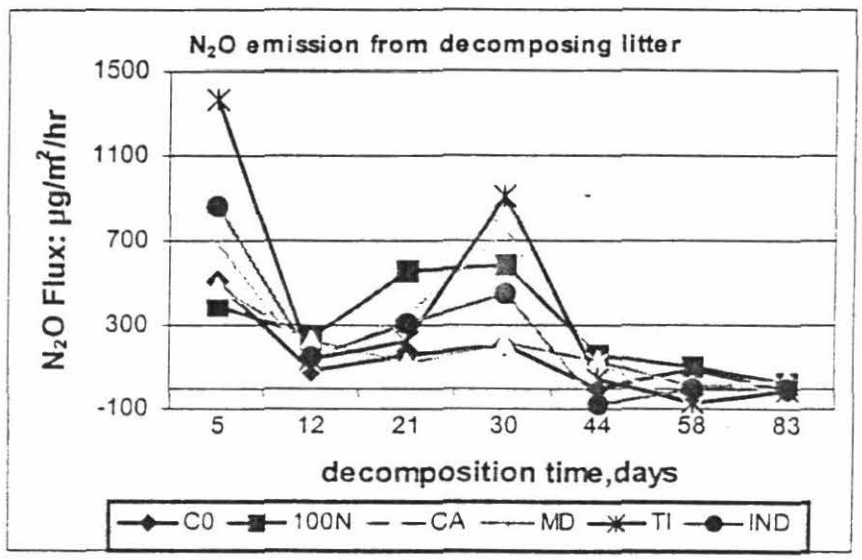


Fig. 11. Emission of nitrous oxide from various sources of nitrogen under greenhouse conditions

N_2O emissions were highest at the beginning of the experiment suggesting that most of the gaseous losses occur soon after sowing rice. This finding opens the possibility to study management options to reduce N losses via retardation on release rates or alteration of the microenvironment to prevent conditions favorable for denitrification. A second peak of N_2O was noticed one month after application of N suggesting liberation of N from less easily decomposable litter fractions or more likely, the decay of the microbial biomass generated in the initial stages of decomposition.

Differences in patterns of N_2O emissions were registered among different N sources; general trends in emissions seems to follow the same patterns of N release from the decomposing litter. Losses were highest for *Tithonia* and *Indigofera* while *Mucuna* was intermediate. Control without fertilizer and *Calliandra* showed the lowest N_2O emission while fertilizer N had intermediate losses with a release pattern different from that of the other treatments. As was previously mentioned, water management created anaerobic conditions at the bottom of the pots which is know to favor denitrification, for such a reason it is intended to repeat this experiments with selected treatments under better controlled water status, to have best assessment of gaseous losses during the first week of decomposition.

Impact:
The results show the diversity of decomposition and nutrient release patterns even within the same genus (i.e. Mucuna) and highlight the value of screening new farming system components, using the methodology described, to achieve an efficient nutrient cycling and minimal environmental impact.

They also indicate that fast decomposing green manures and organic materials added to soils can present a high N loss potential and a low recovery by a subsequent crop. This may have important implications for existing for slash and mulch systems such as the maize/Mucuna system in Central America. The challenge now is to assess the net nutrient recoveries using isotopic techniques as well as designing combinations of organic and inorganic nutrient inputs where nutrient loss is minimized by synchronizing nutrient availability with crop demand. The findings suggest that there is a need to screen germplasm for slower nutrient release patterns. This can be achieved by selection for compositional factors that control decomposition such as lignin and polyphenols.

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Activity 2.2 Estimate nutrient budgets in contrasting systems and
Activity 2.3 Identify key processes in nutrient cycles to minimize losses and improve efficiency in systems

Highlights:

- Nitrogen dynamics have been determined in monocropped rice and maize, rice-cowpea (green manure + grain crop), maize-soybean (green manure + grain crop).

- Green manures were shown to be inefficient in terms of nitrogen use as a result of substantial loses via volatilization and leaching

Purpose:
To determine the nitrogen dynamics under monocultures and crop rotations on a Colombian savannas Oxisol

Rationale:
Farmers in the savannas of Latin America are facing severe economic and environmental problems. The withdrawal of subsidies on inputs and transport in Brazil for example has placed severe strains on the production systems. There is an urgent need to improve the efficiency of available inputs for these crop and pasture systems. After phosphorus, nitrogen is the most limiting nutrient. Inputs can come from fertilizers and/or biologically fixed N. We have examined the dynamics of N cycling in crop rotations and crop-pasture systems which include legume green manures and N fertilizers in an on-station experiment (Culticore experiment) at the Carimagua research station.

Materials and Methods:
Studies were carried out in an experiment established in 1993 on well-drained silty clay Oxisols (tropeptic haplustox, isohyperthermic) at Carimagua on the Colombian eastern plains (mean annual rainfall 2240 mm, and temperature 27°C). The experiment is a split-plot design with 4 replications in which alternative systems (in sub-plots, size 0.36 ha) based on upland rice or maize (main plots) are compared with respect to their effects on various soil properties and processes including nutrient cycling. In addition to monocultures, rice and maize (respectively) are rotated with grain legumes (cowpeas or soybeans), green manures (GM) or "improved" grass-legume pasture leys. Native savanna plots are maintained for baseline comparisons. Systems based on rice and maize were limed, respectively, with 500 and 2000 kg ha^{-1} of dolomite prior to establishment and maintained thereafter with annual applications of 200 kg ha^{-1}. Urea was applied in 3 splits to rice (20, 30 and 30 kg-N ha^{-1}) and 2 splits to maize (40 and 80 kg ha^{-1}). A starter application of urea (20 kg-N ha^{-1}) was also applied to the legumes at sowing. Other nutrients (P, K, Mg, S and Zn) were applied at adequate levels.

Recovery of fertilizer N was determined using ^{15}N-labelled urea in enclosed microplots (1.0 m × 1.0 m for rice and 2.25 m × 2.0 m for maize, each embracing 3 crop rows) installed in the large experimental plots (one microplot for each split application). Samples were taken from the middle row at maturity and separated into grain, straw and weeds. Soil was sampled to a depth of 60 cm in intervals of 15 cm by excavating a pit centered on the row to 30 cm depth and by augering beyond 30 cm; roots were extracted from soil samples by hand picking. Total dry matter was measured after oven-drying at 70°C. Total N concentration and ^{15}N enrichment for plant material and soils were determined by continuous flow isotope ratio mass spectrometry via dry combustion of samples (Europa Scientific-Roboprep-Tracermass).

The decomposition of crop residues, GMs and forage litter collected from the field plots was studied using standard litter bag techniques. Four replicate sets of six bags each containing approximately 10 g dry weight of plant material were either placed on the soil surface and covered with similar plant material or buried 5 cm below the soil surface in each treatment. At each sampling date, one of each set of each plant material was removed, washed, dried and analyzed for dry matter and nutrient content. N release rate and half-life were calculated using the exponential decay model, $X = X_0 \times exp(-kt)$, where X is the amount of N remaining, X_0 is the initial amount, k is the rate constant for N release and t is time.

The fate of N derived from crop residues and GMs was estimated using materials labelled with ^{15}N produced in pots supplied with labelled ammonium sulfate. Recovery of ^{15}N from incorporated residues by subsequent crops as well as its fate in the soil to 40 cm depth was determined in microplots. Sampling and analytical procedures were similar to those described above.

The dynamics of mineral N in soil profiles was determined by periodic sampling using a 5-cm diameter 1-m long stainless steel auger fitted with a plastic liner. Ten cores were sampled at random per plot, divided into sections of length 0–10, 10–20, 20–40, 40–60, 60–80 and 80–100 cm, mixed by depth and subsampled. Subsamples were sealed in plastic bags and stored moist in an ice-chest prior to transport to the laboratory where they were immediately extracted with 1 *M* KCl. Subsamples were dried for moisture content. Ammonium and nitrate (NO_3) in the extracts were determined using an autoanalyzer.

The minimum climatic, soil and crop phenological data sets were collected for the DSSAT crop simulation models.

Results and Discussion:

The mean composition and half-lives for N release from crop and GM residues determined in litterbags are shown in Table 13. As indicated by their standard deviations, there was considerable variation between seasons in the rate of N release from residues, especially from those applied to the soil surface. Variation in residue composition was insufficient to explain the variability in litter decomposition; however, the comparatively higher variability in surface applied residues in comparison with buried residues suggests that it was related to environmental factors such as interseasonal variation in temperature and, more especially, moisture at the soil surface. In gross terms, release rates were higher from GMs than from cereal residues, as expected from their compositions. However, neither C/N ratio nor lignin/N ratio explained the comparatively minor differences in decomposition and N release rates observed between rice and maize residues or between cowpea and soybean GMs.

Nitrogen release from residues and GMs was exceedingly fast (Table 13). Based on the simple exponential decay model, incorporated GMs released 90% of their N content within 40–60 days of application. For crop residues, 90% N release occurred within 4 months of incorporation. Such rapid release carries with it the risk of substantial N loss before succeeding crops are sufficiently well established to recover the mineralized N from the soil. Experiments with ^{15}N-labelled residues indicated recoveries by crops of 9–14% with apparent losses ranging from 15–50%; with the remaining N being incorporated into the soil organic N pool (PE-2 Ann. Rep. 1997). Recovery of N was least from legumes, which decomposed most rapidly.

Table 13. Effect of composition and management on the rate of release of N from crop residues and green manures (GM) in an Oxisol[§]

Material applied	% N	C/N	Lignin/N	Half-life of N release (days)	
				Surface applied	Buried (5 cm)
Rice residues	0.93 (0.20)	47 (12)	7.8 (0.7)	79 (70)	39 (16)
Maize residues	0.89 (0.14)	51 (6)	11.9 (3.1)	43 (17)	35 (8)
Cowpea-GM	2.90 (0.09)	16 (3)	4.8 (0.8)	32 (15)	12 (2)
Soybean-GM	2.39 (0.26)	17 (1)	3.7 (1.1)	36 (11)	18 (1)

[§] values are means (standard deviations in parentheses) from 3 rice or 2 maize seasons, respectively.

In contrast to crop and GM residues, N recovery from fertilizers was greater (Table 14). From 25–40% of applied urea was recovered in total biomass (including roots and weeds); about 34–46% was found in the soil to 60 cm depth. Fertilizer N recovery in biomass in rice systems (where the application was split in 3) was greater than recovery in maize systems (where the application was split in 2). Part of the difference was due to the greater weed growth in rice systems. Poor recovery of N derived from the GM (incorporated in late 1994) by the 1995 rice and maize crop is reflected in the absence of any significant dilution of fertilizer N in the crop in the GM systems compared to the monoculture systems (Table 14).

Table 14. Total recovery of fertilizer urea-N in grain and harvest residues, and in the soil profile at harvest, in monocultures and green manure rotations on an Oxisol at Carimagua.

N Pool	Rice systems		Maize systems	
	Monoculture	GM rotation	monoculture	GM rotation
	- - - - (% applied) - - - -		- - - - (% applied) - - - -	
Rice grain	7	9	14	19
Straw + roots + weeds	31	30	11	12
Soil (0–60 cm)	45	46	44	34
Total recovery	84	85	70	65

Combining results from recovery of N derived from fertilizer and GM in rice grain and soil pools, and considering the amounts of N recycled from rice residues, N balances were calculated for soils under rice monoculture and rice-GM rotation systems (Table 15). These estimates indicate that even with fertilizer and GM inputs, there is a net drain on soil N reserves under these systems, although the rotational system is near balance. Negative balances were probably due principally to volatilization and, more importantly as shown below, leaching of N derived from fertilizer and GMs. Total losses under rice monoculture and rice-GM were approximately 80 and 150 kg-N ha^{-1}, respectively.

Table 15. Estimated soil nitrogen balances under rice systems on an Oxisol

Inputs / exports from soil N pool	Rice monoculture	Rice-GM rotation
	--- (kg-N ha^{-1}) ---	
Residues	+11	+12
Fertilizer	+20	+19
Green manure	0	+23
Plant uptake	-79	-59
Change in N pool	-48	-5

Sequential measurements of soil profile mineral N concentrations taken through the dry season following incorporation of GM residues under monoculture and rotational systems, revealed a progressive build-up of mineral N concentration in the surface layers. This mineral N began to move downwards through the soil profile with the first rains of the wet season (Figure 12). Most of the mineral N was in the form of NO_3-N with a total NO_3 content to 1-m depth about 5 to 6 times greater than that in native savanna soil; quantities

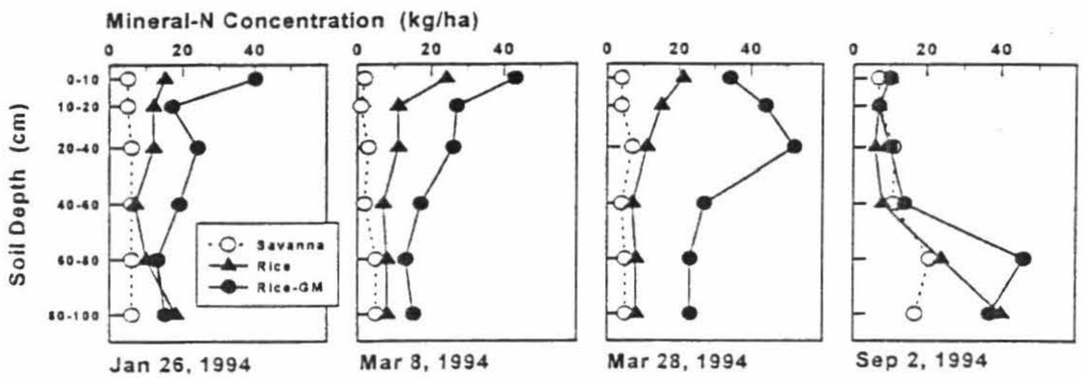

Figure 12. Evolution of mineral N concentrations in an Oxisol profile under savanna, rice monoculture and rice-green manure systems through the dry season (January to March) and after the rice harvest (September).

of N in the profile were qualitatively related to the N content of the residues applied. Moreover, total soil profile (0–100 cm) contents of mineral N under rice and rice-GM systems over and above that found under native savanna prior to sowing rice in 1994 (40 and 130 kg-N ha^{-1}) were of similar magnitude to the losses estimated above (Table 15). Similar measurements taken at approximately 2-week intervals through the rainy season indicated a substantial movement of NO_3 (derived from both residues and fertilizer applications) through the soil profile under both rotations and monocultures (results not shown). This movement essentially rendered the N recycled from residues and GMs inaccessible to the subsequent crop. By rice harvest in September, most mineral N had leached below 60 cm depth (Figure 12).

The CERES rice model was used to evaluate the availability and fate of N derived from GM residues in the rice-GM system commencing from the date of incorporation of residues. There was reasonable agreement between observed and predicted rates of N release from cowpea GMs (results not shown). However, concentrations of mineral N in the soil profile were underestimated and fluxes through the profile overestimated through

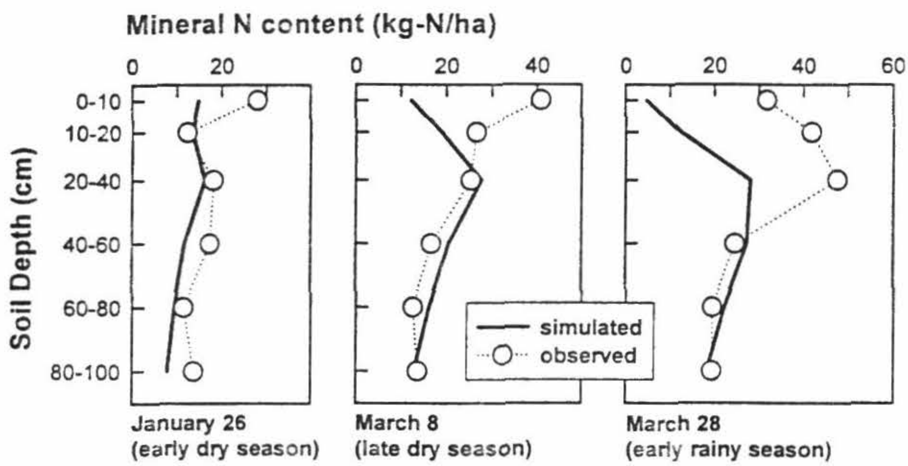

Figure 13. Observed and predicted mineral N profiles in a silty-clay Oxisol in a rice-green manure rotation through the dry season following green manure incorporation the previous November 19.

the intervening dry season between GM incorporation and rice sowing (Figure 13). Differences could be due to underestimation of soil N mineralization rates or to failure to account for the effects of positive surface charge on oxidic clay minerals in Oxisols which may significantly affect NO_3 retention and transport in these soils near natural pH (4.3). When adsorption coefficients were included in the simulation, predicted NO_3 leaching was agreed much more closely with observed values.

Conclusions:

Legume green manures supply substantial quantities of biologically fixed N to cropping systems provided there is an efficient *Rhizobia-legume* symbiosis. Under the humid tropical conditions of the Colombian savannas, this green manure-N is released rapidly to the soil and, because it is less easily managed, crop recovery is less efficient than split applications of N fertilizer whose supply could be more easily synchronized with crop demand. In a high leaching environment, poor N supply-demand synchrony can result in substantial leaching of NO_3 below the crop rooting zone and eventual contamination of the ground water. Prediction of NO_3 production and flux in soil under crop production systems involving legume rotations would aid in system management to minimize N losses to the environment and increase the efficiency of N utilization by crops. The CERES-rice simulation model was able to predict N fluxes in the rice-GM system when anion retention on oxidic mineral surfaces was considered. However, much broader testing is required using GMs with more diverse decomposition characteristics and soils with different abilities to retain nitrates.

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Activity 2.4 Estimate contribution of different systems to soil organic matter accumulation

Highlights

- Confirmation from both Bahia State of Brazil and from the western "llanos" of Venezuela that introduced African grasses sequester carbon in the soil, including *Hyparrhenia rufa*, a species not reported earlier as having this capacity.
- Introduced grasses have higher rates of N turnover and greater internal remobilization of N than the native savanna species.
- Litter of the introduced species has very wide C:N ratios.

Purpose
To provide understanding of the interactions between N and C cycling in soils of Latin America where African grasses are introduced. This will help determine the magnitude and potential to sequester C of the more than 35 million ha already sown to these grasses in the region and their contribution to mitigate global warming caused by increasing carbon dioxide concentrations. The purpose of the project is to answer the questions raised above that have been openly debated in the literature, in particular the key role of carbon and nitrogen cycling in determining residence times of the newly-acquired soil organic matter. This is unknown at this stage for the pastures and soils of the neotropics.

The objectives of this special project is to investigate the role of nitrogen in the carbon sequestration process at a number of representative sites in the South American savannas by examining aspects of both carbon and nitrogen cycling in pasture and agropastoral systems. The project is financed by the UK Department for International Development and brings together collaborators from CIAT, Empresa Brasilera de Pesquisa Agropecuaria/Centro Nacional de Pesquisa de Agrobiologia EMBRAPA/CNPAB, Seripédica, Brazil; Centro de Investigaciones Ecológicas de los Andes Tropicales CIELAT, Universidad de los Andes, Mérida, Venezuela and the Macaulay Land Use Research Institute MLURI, Craigiebuckler, Aberdeen, United Kingdom.

Rationale
The conversion of tropical ecosystems to agriculture and pastures is seen as a particularly important source of the increasing concentration of CO_2 in the atmosphere. There are conflicting opinions about the net contribution of conversion of clearing of wooded lands in the tropics. However, the sowing of introduced grasses on the largely treeless lands of the South American savannas has been shown to sequester C at rates from 3 to 14.7 t ha^{-1} yr^{-1}.

The residence time of this newly sequestered C in the savannas, and the rate at which it might continue in the longer term are unknown. Rates may fall to perhaps 10% of the rates reported earlier by Fisher *et al.* (1994) within 20 yr. However we do not yet know the dynamics of C in the soil under pastures. In particular questions remain on the range of C:N ratios in soils accumulating carbon.

Results
Intensive soil sampling was carried throughout the year at sites in Brazil (Itabela, Goiânia and Campo Grande), Colombia (Matazul Farm and Carimagua) and Venezuela (Guanare and Barinas).

A second meeting of the partners was held in CIAT 2-4 October, 1997 to agree common methodologies. Topics discussed were methodologies to measure net primary productivity and decomposition above and below ground, microbial biomass, the fractionation of soil organic matter, and methodologies to assess soil macro-fauna biomass.

Brazil. Rates of decomposition of above-ground litter were measured at Itabela and regrowth of *B. brizantha* of different ages was measured over 45-day intervals. On an oxisol near Goiânia, measurements were made of root yield to a depth of 20 cm on pastures of *B. brizantha* (cv. Marandu) of different ages and differing degrees of degradation. Root decomposition was measured in degraded *B. decumbens* pastures also growing on an oxisol near Goiânia.

Data collected at the Itabela site before this project started but only recently analyzed show that the rate of litter disappearance is much faster than reported elsewhere. The corollary is that net primary productivity is much higher than previously estimated and could explain the source of the C sequestered in the soil. The finding is consistent with the hypotheses on which the project is based.

Re-growth measurements on pastures of *B. brizantha* showed that re-growth rates depend on pasture age. Two-year-old pastures re-grew at 2.2 g m^{-2} day^{-1} while one that was 7 years old only re-grew at 1.2 g m^{-2} day^{-1}. Rate of re-growth could be useful to predict pasture health since the chemical analysis does not always show differences between pastures of different productivity. These results were obtained during the autumn/winter season, but they will be repeated during the summer.

The methodology to evaluate root distribution with depth in pastures of different ages was evaluated and image techniques were calibrated for studies of root dynamics. Preliminary measurements of root dry matter revealed that the root mass diminishes drastically in the deeper soil layers.

The total root yield of *B. brizantha* (cv. Marandu) near Goiânia increased significantly with the age of the pastures, ranging from 4.7 t ha^{-1} in the first year, 8.8 t ha^{-1} in the 3-year-old pasture and as much as 18.0 t ha^{-1} in 6-year-old pasture. Fine roots (less than 2.0 mm diameter) increased from 1.4 t ha^{-1} in the first year to 3.5 t ha^{-1} in the third year when the pasture was in its highest production level. From the third to the sixth year the fine roots decreased to 1.2 t ha^{-1}, when the pasture showed a significant decline in shoot productivity. It is concluded that total root yield in the soil surface layer is not directly related to shoot yield. However, yield of fine roots does seem to be related to shoot yield. It is clear from these results that roots are an important source of carbon in soil under tropical pastures of the Brazilian savanna.

The half-life of decomposing roots of *B. decumbens* in the field near Goiânia was about 224 days. However, using nylon bags with very small mesh to keep termites from eating the root material increased the half-life to 301 days. When the soil was limed, which greatly reduces termite activity, half-life was about 275 days with no difference between excluding termites or not. It has long been observed that degraded pastures have many termite mounds, but these data confirm that they play an important role in decomposition of root litter on the poor acid soils of Brazilian savanna.

At Campo Grande, root content in the 0-40 cm depth was evaluated under three pastures of *Brachiaria brizantha* cv. Marandu. Two of the pastures were 20 years old, but one was fertilized (with N, P and K) every year since 1985 and limed when necessary, while the other was not fertilized and is now degraded. The third pasture was sown in August 97 with lime and fertilizer. There were 16.4 tons/ha of root dry mass in the degraded pasture, 11.5 tons/ha in the fertilized one and only 5.2 tons/ha in the one-year-old pasture. Roots over 2.0 mm diameter made up 73-81% of total root dry mass. The degraded pasture had lower proportion of fine roots compared to either the fertilized or the new pasture.

Colombia. At Matazul Farm detailed studies of root growth were started using small cylinders of mesh filled with soil buried at different depths in the soil. Root decay studies were also installed. Root washing equipment, an oven and balance from Carimagua were installed in Puerto Lopez at the CORPOICA facility. Analysis of soil samples continued.

At Matazul Farm detailed studies of root growth and decomposition were started using small cylinders of mesh filled with soil buried at different depths in the soil. Decomposition rates of roots of native savanna were compared with *B. dictyoneura, A. pintoi*, and *B. dictyoneura + A. pintoi* in pots recovered over 18 months, covering two wet seasons and one dry season. Native savanna, *B. dictyoneura*, and *B. dictyoneura + A. pintoi* had a rapid loss of mass in the fist 4 weeks compared with *A. pintoi*. Thereafter native savanna continued losing mass faster than the other species. At 24 weeks, the remaining mass of native savanna was less than 1% while the others are between 5 and 18%. *B. dictyoneura* appeared to lose mass at a lower rate than *A. pintoi* alone, while *B. dictyoneura* alone did not lose mass after 16 weeks.

Analysis of samples from Carimagua show little differences between the savanna and pastures of either pure grass or grass legume associations in the soil aggregate fractions less than 2 mm, which represent about 20% of the total soil mass. The implication is that the C accumulation is associated with the aggregate fractions greater than 2 mm, which represent 80% of the whole soil. If the C accumulation in the large aggregates is confirmed, the implications will depend on whether the material is either light fraction (partially or wholly undecomposed material) or primary particulate material.

Venezuela. Two areas were chosen in the experimental fields of the Universidad de los Llanos (UNELLEZ) at Barinas and at Guanare. The soils at both sites are alfisols, because in western Venezuela the oxisols, which occupy the upper parts of the landscape and are droughty and usually very stony, are rarely used for sown pastures. At Barinas a pasture of *Brachiaria brizantha* under rotational grazing is compared with a native savanna managed with periodic cutting and naturalized *Hyparrhenia rufa* pastures of different ages. In Guanare a 13-year-old pasture of *B. humidicola* is compared with small relict areas of native savanna.

At each site soil bulk density was measured in trenches dug to 2 m. Samples were also collected in the introduced pastures and the native savanna at both sites to determine the distribution of C and N in the profile. These are being separated into the various size fractions using the agreed methodologies.

To estimate vertical distribution of roots, samples were taken from the four walls of the trenches used to collect samples for bulk density. The vertical distribution of microbial biomass was also determined using the fumigation-extraction method on samples taken at the start and end of the rainy season in both the introduced pastures and the savanna.

Analysis of samples from both sites showed that both available N and soil microbial biomass were higher in the native savanna than in the introduced grass pastures. These data are consistent with those from Carimagua and suggest changes in the rate of N turnover and possibly that internal remobilization of N is a key difference between the savanna species compared with the introduced grasses.

Two further sites were chosen to supplement the sites at the UNELLEZ stations, Hato Los Esteros and Escuela Agronómica Salesiana. At Hato Los Esteros, grazed native savanna is contrasted with four-year-old *Brachiaria decumbens* pasture, three-year-old *B. brizantha* pasture and naturalized pasture of *Hyparrenia rufa* more than 20 years old. At Escuela Agronómica Salesiana, a *B. decumbens* pasture 14-16 years old is contrasted with a *B. humidicola pasture* 7 years old.

C analysis of soil samples to 140 cm from Hato Los Esteros shows a marked accumulation of carbon in the soil under *H. rufa* compared with the native savanna, a less marked accumulation in the 3-year-old *B. brizantha* pasture and no clear tendency in the 4-year-old *B. decumbens* pasture. At Escuela Agronómica Saleciana the 14-year-old *B. decumbens* pasture has higher soil C contents compared with the 7-year-old pasture in the deeper horizons.

Analysis of 1997 samples for C in the soil solution as well as in the soil microbial biomass indicates an increase with soil depth of the C/N ratios of the microbial biomass and an increase with depth of soluble C. These data indicate that the nitrogen becomes more limiting with depth and so decomposition should be slower at depth in the soil.

Rates of decomposition of the roots of native savanna species with those of *B. brizantha* in a laboratory incubation experiment confirm that roots of introduced grasses decompose faster than roots of the savanna species.

Impact

Data from Venezuela and Brazil are consistent with the original hypothesis of carbon accumulation in the soil under introduced pastures.

Contributors

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Activity 2.5 Determine the effects of soil biota on soil fertility and structure

Purpose:

To determine the effects of soil biota on soil fertility and soil structure and to establish methods of managing macrofauna populations.

Rationale:

Soil biota especially macrofauna, are considered to be the natural plows of the soil via their burrowing activity and effects on the dynamics of organic matter and nutrient cycling. In low-input systems the ability of macrofauna to improve the soil assumes greater importance when compared with high input systems which tend to decrease macrofauna populations. Whilst the beneficial affects of macrofauna have been widely studied, means of manipulating macrofauna populations are less well known. In order to develop guidelines for the encouragement of beneficial macrofauna in low fertile soils it is necessary to understand the ecology of the predominant species under different land use systems. Hence this activity focuses on the increased understanding of macrofauna ecology. In particular the effects of earthworm activities such as casting on soil properties need to be studied in detail in order to assess the magnitude of earthworm effects under different land use systems.

Here we report results from a study of the effects of earthworm casting on soil losses via erosion and water movement.

Effect of earthworm casts on soil erosion and water movement

Methods:

A fallow plot of the Culticore experiment previously sown to maize for 5 years was cultivated by two passes of a heavy harrow plow to 15 cm followed by a chisel plow to 40 cm and finally one pass of a light harrow. Six run-off plots were established of 8 m^2. Three plots were chosen with no earthworm casts and three with casts. A similar set of 6 run-off plots were established in an ungrazed native savanna for comparison. Similar slopes, presence of termites surface microrelief, vegetation cover and superficial soil texture were taken into consideration for the choice of the run-off plots. The plots were enclosed with a metal sheet which directed water and soil run-off into a 60 l tank. A further plastic sheeting was placed to 15 cm depth to control movements of earthworms into and out of the plots.

Results:
In the fallow plots which had been subjected to cultivation the soil loss after 1 month was 1.2 to 2.3 times greater in the presence of earthworm casts than in plots with no casts. Losses from the savanna plots were over 100 times less than in the prepared fallow plots but again plots with casts lost greater amounts of soil than those without casts. In contrast the losses of water in the native savanna was greater without casts. In the fallow there was only a slight tendency for greater mounts of run-off water in plots with casts compared with those without casts. The dominance of tillage effects on the microrelief in the fallow treatment may be responsible for these differences.

A separate study of the rate of surface cast degradation in cultivated treatments of the Culticore revealed that casts had a half-life of some 34-68 days. These results need to be considered in terms of the overall effect of earthworm casting on soil and nutrient dynamics.

Impact:
These results indicate that fresh earthworm casts are susceptible to erosion and such movement of soil needs to be considered in studies of the effects of earthworms on soil losses.

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Activity 2.6 Develop strategies to reduce soil loss and improve soil structure

Highlights

- Free water movement down the profile of a soil in Matazul increased drastically under pasture treatments.
- Improving soil structure by pastures can lead to a better nutrient distribution in depth and to increased in water storage capacity.

Purpose:
To develop a new methodology for the study of drainage water at different depths and with different tillage intensities at the Matazul farm.

Rationale:
The advance of the wetting front and the amount of water that moves into the soil due to gravitational potential, are important properties for the development of better soil management practices that minimize losses of nutrients via leaching. A methodology was designed to measure the amount of water that passes through different soil layers in different soil and crop management treatments.

Method:
Funnels full of clean fine sand and connected to a flask by a hose were installed at different depths: 3, 5, 10, 15, 20 and 30 cm to collect the amount of water that passes through the soil at each depth. The collected water was analyzed ion content. To install the funnels an excavation of a soil block of 140x70x70 cm was made to allow the introduction of the funnels 30 to 50 cm into the walls at the depths already planned.

Results:
The results indicated that the amount of free water that passed through the different layers and was collected in the flasks, was a function of the soil management system (Table 16). Little water was collected in the first three layers of savanna, but a high amount was collected at 15 cm, suggesting that there must be a channel or macropore that produces a path of preferential flow that allowed a higher water movement. This could be the wetting mechanism that is predominant in the natural savannas.

Table 16. Gravitational water collected (ml) at different depths and management systems. Matazul

Depth (cm)	Amount of water collected (ml)				
	Native Savanna	Rice		Pasture	
		8 harrowing	16 harrowing	16 harrowing	32 harrowing
3	3	0	100	480	490
5	2	0	136	480	490
10	4	1	0	480	447
15	490	2	0	440	132
20	1	0	0	40	78
30	0	3	0	0	460

The treatment sown to rice with 8 harrowing passes, did not allow the movement of free water through the soil, possible as a result of surface sealing that impeded the entrance of water. Under 16 harrowing passes more water was able to enter into the soil especially in the first to depths, showing that there was a better rainfall acceptance in this treatment.

Under pastures the amount of free water that entered and moved through the soil profile was extremely high in relation to the other treatments. This indicates that pastures are a very good alternative to improve the amount of macropores (pores for which free water moves) that limit the water entry under savanna conditions. This finding confirms the beneficial use of agropastoral systems in these soils for soil improvement.

Table 17 shows the composition of the water collected at different depths under rice and pastures. There was a tendency for greatest amounts of nutrients in the solutions collected in rice in the first two depths, because the crop was established in the same semester the evaluations were made while the pastures were established the year before. But the main aspect is that pastures are a tool for improving soil structure and influenced the nutrient distributions.

Four aspects deserve attention : a). The methodology used was appropriate and can be used in future research. b). There is a very high variability in the way the water moves into the soil (preferential flows) c). The amount of nutrients that move from one depth to other is a function of the amount of water that moves and d). The capacity of the pastures to allow a better water and nutrient distribution should be used in the improvement of the soils as pastures are creating and maintaining macropores. Future research is needed to improve the methodology and for the study of other soils, crops and management systems.

Table 17. Amount of ions leached at different depths under rice and pasture

Crop	Prof. (cm)	Ppm N	K	Ca	Mg	Al	µs c.e.	pH
	3	8.5	12.0	2.9	0.5	6.0	103.8	5.8
Rice	5	2.8	10.4	6.0	1.0	17.5	90.0	6.0
	3	1.7	4.1	1.7	0.5	2.2	463.0	5.9
	5	2.9	0.6	1.6	0.3	1.4	29.5	6.2
Pastures	10	2.0	1.4	0.8	0.2	0.4	288.0	6.1
	15	2.0	2.6	2.8	0.4	0.6	47.5	6.6
	20	2.7	1.5	2.3	0.4	0.5	56.3	6.7
	30	4.8	3.8	3.7	1.0	1.7	79.0	6.6

Impact.
The development and improvement of this methodology permits studies on the amount of gravitational water that moves into the soil and its chemical composition to be undertaken in the field. This new methodology has further potential in terms of opportunities for research.

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2.7 *Develop methods to improve water infiltration and storage*

2.7.1 *Improvement of some soil physical conditions through tillage*

Highlights:

- Natural soil physical conditions of savanna soil are not adequate for crop production.
- Deep tillage (chisel) at different intensities improved the physical conditions.
- Biological improvement of soils through the use of rice and pasture with legumes improved the physical condition in relation to savanna.

Purpose:

To improve the soil physical conditions of "Los Llanos" through chemical/biological and tillage methods.

Rationale:

Under natural conditions savanna soils do not offer an optimum environment for root growth for crop and pasture production. Therefore, soil improvement is required. In the past years, shallow tillage (0-10 cm depth) was practiced, but proved to be unsustainable for crops and pastures as the soils degraded indicating that new tillage systems should be tested in order to overcome the physical, chemical and biological constraints. A tillage experiment is being carried out at the Matazul farm.

Results:

One pass of a chisel increased the rate of infiltration more than three passes. It appears that three passes are excessive for these soils, causing a collapse of the (Table 18) whole soil volume.. The three biological treatments that included two chisel passes and sowing of rice and pasture, (*Andropogon gayanus, Desmodium ovalifolium* and *Phaseolus pueroides)* resulted in modest increases in water infiltration.

Table 18. Effect of different treatments conducted to build up and arable layer in some physical characteristics. Matazul.

Treatments	Infiltration Rate (cm/hour)	Soil Strength (Kpa)	Bulk Density (Mg/m^3)	Volumetric Moisture Content (%)	Macroporosity
Rotation rice/soybean					
1 chisel passes	68.0a	48.2a	1.43bc	30.9ab	13.5abc
2 chisel passes	41.0b	34.3bc	1.39bc	28.7b	17.6ab
3 chisel passes	29.4bd	26.3c	1.33c	22.7c	24.6a
Rice + Pasture					
A.gayanus	17.7cd	29.7bc	1.43bc	29.5ab	14,9ab
A.g. + P.p. +	13.8de	30.9bc	1.51abc	27.3b	15.3ab
D.o.	12.1de	26.3c	1.61ab	30.3ab	7.5bc
P.p. + D.o.					
Savanna	1.3e	40.1ab	1.71a	33.2a	1.5c

Figures followed by the same letter in the columns indicate non significant differences ($P < 0.05$) by Duncan.

Resistance to rupture (soil strength), was also positively affected by the treatments in relation to savanna. It was reduced by the effect of 1 or 2 chisel passes and by other treatments, showing that it is possible through these treatments to develop a better environment for root growth.

Bulk density decreased in all treatments when compared with the values of the savanna. The decrease was high under chisel treatments. Volumetric moisture content showed some changes in relation to native savanna. In general, it was reduced by the treatments, but macroporosity has increased enormously from 1.5% under savanna condition to 24.6% in three passes of chisel. The increase in aeration porosity (macroporosity) is of great importance for soil management purposes as it regulates the water entry into the soil, which in turn determines the rainfall acceptance.

Impact.
The result are showing that it is possible to improve the physical conditions of the soils and build-up an arable layer, criteria that are considered to be of major importance for these soils.

Contributors: E. Amézquita, E. Barrios, I.M. Rao, R. Thomas, J.I. Sanz, P. Hoyos, D. Molina, L.F. Chavez, A. Alvarez, J. Galvis.

Activity 2.8. Test indicators to assess soil quality

Highlights:
The work is at a preliminary stage and no highlights are presented here

Purpose:
To test and validate soil indicators developed within the project and elsewhere under tropical conditions.

Rationale and approach:
The identification and evaluation of diagnostic measures of soil quality is a dynamic process. We have a set of physical, chemical and biological indicators that we are evaluating in the Andean hillsides. The establishment of improved fallows systems to regenerate soil fertility at San Isidro farm is promoting the development of a gradient of soil qualities through the different treatments and through time that allows to evaluate these and other diagnostic measures for the Hillsides Ecoregion. As a complement to the regenerating systems (i.e. improved fallows) we have established degradative systems through continuous monocultures (cassava, maize, rice) without fertilizer inputs, and a bare fallow as worst case scenarios, in order to assess the sensitivity of the indicators under those conditions. These sets of experiments at San Isidro farm provides us with a suitable spectrum of soil qualities in systems undergoing degradation and recuperation at different rates on the same location.

Inducing Degradation: Cultivation without fertilizer and complete removal of crop and residues as worst case scenarios.

DG-1 Soil degradation by continuous monoculture of cassava, maize and upland rice.

Establishment date: May 1998

Treatments: Cassava (Algodona) monoculture, Maize (Sikuani) monoculture, Rice (Latisdahy x Fosfifa 62-3) monoculture and a bare fallow.

Experimental design: Randomized complete block design with three repetitions. The plot size is 10 m by 6 m. Cassava was planted 0.9 m within and between rows. Maize was planted 0.5 m within and between rows. Rice was planted at the rate of 80 kg/ha with a distance between rows of 0.5 m. Bare plots are weeded and all plant materials removed every 15 days.

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Output 3 Diagnostic and predictive tools developed to combat soil degradation

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

Highlights:

- A set of soil quality indicators has been developed for the some savanna Oxisols
- A questionnaire on SQI's has been developed and is being distributed
- Twenty three scientific articles are in various stages of publication

Purpose:
To develop a set of soil quality indicators (SQI's) as decision support tools to help farmers and other land managers monitor changes in soil health

Rationale:
As farmers intensify land use the risk of land degradation increases as, for example, fallow periods are shortened and the frequency of mechanical disturbances of the soil are increased. Often by the time the land is visibly degraded it is too late or too costly to apply remedial actions. Therefore land users would benefit from the development and use of "early warning indicators" of soil quality or health. In this activity we attempt to develop and document both indigenous SQI's and scientifically based SQI's and to develop a SQI kit for use on-farm and laboratory.

Results:
The BMZ/GTZ project on indicators of sustainable agropastoral systems in the Brazilian cerrados, co-sponsored by the MAS project, terminates in October 1998. A substantial body of work has been described in detail (with methods, approaches etc.) in a separate project report included as an annex with this report. Potential indicators of soil quality for the Oxisols examined in this study include:

- the ratio of free to easily accessible particulate organic matter,
- the quotient of microbial carbon/total organic carbon
- water extractable- and permanganate-extractable organic carbon
- nitrogen management index (permanganate-extractable soil nitrogen)

A total of 23 publications will appear from this project. This level of output surpasses any other project managed by CIAT and is a good example of improved efficiency utilizing an inter- and multi-disciplinary and inter-institutional approach via a consortium.

From this study and that undertaken in the Colombian llanos (Ann. Rep. PE-2, 1997), the project has identified a number of soil quality indicators as shown in table 19.

Table 19. Potential soil quality indicators for savanna Oxisols

Indicator	Study site
Ratio of free to easily accessible particulate organic matter	Brazil
Quotient of microbial carbon/total organic carbon	Brazil
Water extractable- and permanganate-extractable organic carbon	Brazil
Nitrogen management index (permanganate-extractable soil nitrogen)	Brazil
Aggregate size distribution and stability	Colombia
Water infiltration rates	Colombia
Earthworm biomass	Colombia
Earthworm:termite ratio	Colombia

A questionnaire on SQI's has been developed adopting an earlier version that was based on the USDA Soil Quality Test Kit (PE-3 Ann. Rep. 1996?). This is currently being disseminated in Venezuela. Efforts to repeat the process in Colombia have been delayed by the security situation. The questionnaire will also be used in Central America once the regional coordinator has taken up his position (September, 1998).

Impact

The information on soil quality indicators has been disseminated to EMBRAPA-CPAC via the BMZ/GTZ project report. A CIAT publication on this work is in preparation for dissemination to other NARS and collaborators. The results will be used as part of the across-consortia activity in the global SWNM program.

Contributors

W. Zech, R. Westerhof, H. Neufeldt, J. Lilianfein, A. Freibauer, T. Renz, S. Fuhrman, V. Laabs, T. Thiele, R. Gross (all Bayreuth Univ.), L. Vilela, D. Riesck, C. Magno do Rocha Y. Zinn (EMBRAPA-CPAC), P. Lavelle, T. Decaens (Univ. Paris, France), J.J. Jimenez (Univ. Complutense, Spain), M. Ayarza, R. Thomas, E. Barrios, E. Amezquita, J. Sanz (CIAT).

Activity 3.2 Develop a diagnostic kit to assist farmers and extensionists in resource management decision making

Purpose:

To develop and test a diagnostic kit for land users and researchers as an aid to land management decision making.

Rationale:

Land degradation is often only appreciated when it manifests itself as obvious visible signs such as gullies, compacted surfaces and bare ground cover. By this stage the costs of remedial treatments are often prohibitive to resource-poor farmers and other land users. Early warning signals are required that can alert the land manager to detrimental and often unseen changes. Diagnostic kits are becoming available on the commercial markets for temperate agricultural systems. These need to be tested and modified if necessary to tropical conditions not only in terms of the bio-physical context, but also in terms of the socio-economic context where most farmers cannot afford sophisticated test kits. Simple robust methods are required for these conditions.

Results:
To date the activity has centered around identifying those soil quality indicators that are relevant to tropical agroecosystems. These have been reported in 3.1 above. Testing of commercial kits will begin in 1999.

Contributors
W. Zech, R. Westerhof, H. Neufeldt, J. Lilienfein, A. Freibauer, T. Renz, S. Fuhrman, V. Laabs, T. Thiele, R. Gross (all Bayreuth Univ.), L. Vilela, D. Resck, C. Magno do Rocha Y. Zinn (EMBRAPA-CPAC), P. Lavelle, T. Decaens (Univ. Paris, France), J.J. Jimenez (Univ. Complutense, Spain), M. Ayarza, R. Thomas, E. Barrios, E. Amezquita, J. Sanz (CIAT).

Activity 3.3 Compile data bases to feed into simulation models and decision support systems and Activity 3.4 Calibrate simulation models to predict system performance and overcome site specificity.

Highlight:
- A new phosphorus submodel has been tested successfully with maize but was only moderately successfully with soybean using data from the Culticore experiment
- Data has been presented at the American Society of Agronomy

Purpose:
To refine and adapt crop models to tropical conditions.

Rationale:
Crop modeling can be used to extrapolate data from site to site and thereby increase the value of research results. To date most models have been developed for temperate conditions. There is a need however to extend the use of models to tropical agriculture. As CIAT has no in-house expertise in modeling we have developed a collaborative arrangement with Michigan State University which focuses on adapting the DSSAT crop models to tropical conditions especially under low phosphorus-supplying soils.

Results:
Progress has been made on the development and the testing of the phosphorus (P) model. Data sets of P crop response experiments done on maize and soybean were compiled from experiments at the Carimagua research station. The maize data set was sufficient to run the model with the P routines. For the soybean data sets more phenological data is needed for the calibration. Several changes have been were made to the P model as a result of using this data. Two experiments run for three years (1994-1996) both with maize / soybean rotation were collected (2 crops/year). The first experiment, CULTICORE, which is not a P crop response experiment was used mainly to help in the calibration of the model for the maize variety "Sikuani", and the soybean variety "Soyica Altillanura 2" that were used in

both experiments. The second experiment "Fosforo Residual" with treatments of different rates of triple super phosphate application was used in the testing of the P submodel. The model gave reasonable predictions of maize grain and tops yields. It reduced yields for the control treatments when less P was found in the labile pool. The model is predicting higher uptake of P in general by the maize than is actually measured.

The genetic coefficients calibration for the soybean variety "Soyica Altillanura" is not satisfactory. Some of the needed phenological information was not available to insure a good calibration. The 1997 data should be more complete, and would improve the calibration.

At the moment, we are working on simulating the three-year maize / soybean rotation with the data we have. The measured P fractions to initialize the model will be used once before planting in the first year and the model will be run for the three years in sequence. The predicted values of the different pools will be compared with the different measured fractions according to our criteria of putting the different fractions into the corresponding pools. This will help in the evaluation of how well the model is predicting the chemistry of P in the soil. More data on P fractions will be available especially before and after the soybean crop.

Impact:
Two poster papers about the P modeling work will be presented at the American Society of Agronomy meetings this year in Baltimore. One paper would be describing the collaboration between Michigan State University and the International centers regarding the development of the model and the use of the data sets. The second will describe the structure of the P model. The references are:

Daroub, S., Gerakis, A., Ritchie, J. T., Friesen, D.K., Thomas, R., and J. Ryan. Development of a phosphate crop response model based on international data sets. Michigan State Univ., CIAT, and ICARDA.

Gerakis, A., S. Daroub, J.T. Ritchie, D. K. Friesen, and S. H. Chien.
Phosphorus simulation in the CERES models. Michigan State Univ., CIAT, and IFDC.

This activity has increased collaboration between CIAT and ICARDA catalyzed by the Michigan State group and MAS.

A report of this activity also appears under project *SW-2 Activity 4.3 Calibrate, validate and refine crop and pasture models on nutrient dynamics and productivity over the long term.*

Contributors:
D. Friesen, M. Rivera, R. Thomas, A. Oberson, I. Rao (CIAT), S. Daroub, J. Ritchie (Michigan State University, USA)

Activity 3.5 Develop a decision support system to assist in resource management decision making

Purpose:
To develop a range of decision support tools for natural resource management. These will range from simple rule-of-thumb decision guidelines to computerized models.

Rationale:
Decisions regarding the management of natural resources are complex and require an appreciation of both on- and off-site impacts of changes in land use. Efforts are required to simplify the decision making process via the development of a range of decision making tools.

Results:
Progress on this activity has been restricted to the recruitment of a post-doctoral fellow in a shared position with the Tropical Soil Biology and Fertility Program in Nairobi, Kenya as part of the systemwide SWNM program (see report of project SW-2). This position is developing an organic resource database and decision support system for the use of organic materials which are available on- and off-farm. Such information and support tool will allow a better integration of inorganic and organic sources of nutrients.

Impact:
This activity is new but impact is expected in terms of a better use of available nutrient inputs by smallholder farmers.

Contributors:
R. Thomas (CIAT), M. Swift. C. Palm (TSBF) R. Delve (CIAT-TSBF).

Activity 3.6 Test diagnostic tools with NARS and farmers

There has been no activity on this output to date.

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Output 4 Institutional capacity enhanced for strategic research on soil, water and nutrient management

Activity 4.1 Organize and coordinate field days and workshops

Highlight

- Thirteen field days have been held at the site of the Inter-program project in the hillsides of the Cauca valley

Purpose:

To disseminate research results to collaborators, NARS and NGO's

Rationale:

Research results need to be translated into useful adoptable technologies by land users. This activity aims to take our findings directly to our clients and takes us beyond the production of research publications. It forms on important part of our pathways to impact.

Results:

This year 13 field days were held at the site of the Inter-program project in the Cauca valley. Visits have included:
Farmers from Bolívar, Cauca, with Corpoica representatives.
Teachers from Caldono, Pueblo Nuevo, Cauca and Umata representatives.
Representatives of Umatas del Norte del Valle (CIPASLA)
Farmers from Caloto Development Project, Cauca.
Ecology students from Fundación Universitaria Popayan, Cauca (three times).
Part of Organic Agriculture Course (CIPASLA)
Part of Latin American School of Soil Physics (ELAFIS)
Teachers from SENA and ecology students.
Corpotrigo representatives and Nariño farmers
Peruvian NARS representative

A workshop on the carbon sequestration project will be held in late 1998 with project collaborators.
Members of the project participated in a workshop on "encuentro nacional de labranza" held in Villavicencio April 28-30, 1998.

Impact:

Results from the on-farm research in the hillsides are readily transmitted to the local farming community via field days and the collaboration with CIPASLA. The project is able to rapidly respond to the demands of the farmers in the region. We expect information on improved fallows to be developed with farmer participation.

Contributors:

E. Barrios, E. Amezquita, R. Thomas, M. Fisher (CIAT) A. Melendez, C. Trujillo (CIPASLA)

Activity 4.2 Prepare bulletins on agropastoral systems and soil, water and nutrient management projects

Highlight:

- A publication on agropastoral systems is in preparation with contributions from NARS and other collaborators
- A state-of-the-art document on lessons learned from the exploitation of the Brazilian *cerrados* is nearing completion
- A newsletter of the SWNM program has been distributed to collaborators and donors

Purpose:
To synthesize and disseminate research results to collaborators, NARS and NGO's

Rationale:
Research results need to be translated into useful adoptable technologies by land users. This activity aims to take our findings directly to our clients and takes us beyond the production of research publications. It forms on important part of our pathways to impact.

Results:
Members of the PE-2 team have been responsible for writing contributions and collating chapters from collaborators for a publication on agropastoral systems in Latin America. This will be published under the systemwide SWNM program and is co-sponsored by the MAS consortium. Final editing will take place in October 1998 for a publication date of early 1999.

Similarly a publication on the lessons learned from the development of the Brazilian *cerrados* is in the final stages of preparation. This publication was commissioned by the MAS consortium and is be co-authored by PE-2 members and a Brazilian consultant from the University of Lavras.

Impact:
The impact of this activity will be assessed after publication of the articles.

Contributors:
R. Thomas, E. Barrios, I. Rao, E. Amezquita, J. Sanz., M. Ayarza (CIAT)

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

Highlight

- The III ELAFIS (Escuela Latin American de Fisica de Suelos) was held at CIAT in March with 50 participants

Purpose:
To promote and participate in specialized training courses related to priority issues in Soil, Water and Nutrient Management

Rationale:
These training courses are held in response to the training needs identified by our partners and particularly the NARS. They have requested from us training on strategic research methodologies and approaches. This activity also conforms to the aims and objectives of the SWNM program.

Results:
The III ELAFIS was held at CIAT headquarters March 15-28, 1998. A total of 50 participants attended the course with 20 invited specialists giving lectures. The program consisted of formal lectures and two days of field visits. The course was co-sponsored by CLAF (Centro Latinoamericano de Fisica Aplicada), ICTP (International Centre for Theoretical Physics), Universidad Nacional de Colombia, Sede Palmira and COSMOAGRO (a private company which produces foliar fertilizers). The participants requested a similar course on soil biology.

Impact:
This training course gave PE-2 staff an opportunity to discuss and disseminate the philosophy of a need to create an "arable layer" in the soil for sustainable production to a large number of NARS personnel.

Contributors:
E. Amezquita, R. Thomas, I. Rao, M. Fisher (CIAT)

Activity 4.4 Publish research results in refereed journals and other publications

Highlight:

- The project has 50 articles at various stages of publication. These include 34 international journal articles and 6 national/regional journal articles with 10 invited book chapters

Purpose:
To disseminate the research results to the scientific community.

Rationale:
Publication of research results is an essential part of the research and development process. The group strives to publish for the international and regional audiences and consequently spreads its publications amongst English (international) and Spanish (regional) language journals.

Results:
See publication list at the end of the report.

Impact:
The output of publications from PE-2 and MAS collaborators is one of the highest in CIAT. The group's work is being recognized at the regional and international level. An example is the request to contribute chapters to 10 books.

Contributors:
R. Thomas, I. Rao, E. Barrios, E.Amezquita, J. Sanz, M. Ayarza, M. Fisher, W. Trujillo (CIAT), D. Friesen (IFDC)

Activity 4.5 Supervise post-doctoral research, graduate and undergraduate theses

Highlight:
- 50 students are associated with the project

Purpose:
To accomplish our responsibilities for training for the region.

Rationale:
Training is an important feature of the work of the international agricultural research centers. At the same time training also helps advance the research program. The philosophy of the team is to encourage students from developing and developed countries to work together on team research projects in order to maximize experiences and interactions.

Results:
A list of the 50 personnel participating in training and research activities during 1998 is given below.

Table 20. Training supported by PE-2 and MAS

Name	Nationality	Education	Institution	Research theme
J.G. de Cobo	Colombia	M.Sc.	CATIE	Green manure/residue Decomposition
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
A. Oberson	Switzerland	Post-doc	ETH, Zurich	Phosphorus acquisition/cycling
W. Wilcke	Germany	Post-doc	Bayreuth Univ.	Nutrient/water fluxes
J. Lilienfein	Germany	Post-doc	Bayreuth Univ.	Nutrient/water fluxes
S. Phiri	Zambia	Ph.D.	Norway Agric. Univ.	Phosphorus acquisition/cycling
L. Mariani	France	Ph.D.	Univ of Paris/ ORSTOM	Modelling soil fauna Populations
Peter Wenzl	Austria	Ph.D.	Univ. of Vienna	Biochemical and molecular mechanism of tolerance to Al
Nelson Castañeda	Colombia	Ph.D.	Univ. of Gottingen	Genotypic variation in P

				acquisition & utilization in *A. pintoi*
Lutz Collet	German	Ph.D.	University of Hannover	Acid soil tolerance in maize
S.H. Daroub	Lebanon	Post-doc	Michigan State Univ.	Crop modelling
R. Delve	U.K.	Post-doc	TSBF/CIAT	Organic matter database
J.J. Jimenez	Spain	Ph.D.	Univ. Complutense, Madrid	Earthworm dynamics
R. Westerhof	Netherlands	Ph.D.	Bayreuth Univ.	Soil quality indicators
H. Neufeldt	Germany	Ph.D.	Bayreuth Univ.	Soil quality indicators
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
E. Madero	Colombia	Ph. D.	Nacional, Palmira	Soil structure
I. Balcazar	Colombia	B.S.	Univ. Tecnológica Del Llano	Water movement
G. Perea	Colombia	B.S.	Univ. Tecnológica del Llano	Water movement
E. Torres	Colombia	B.Sc.	Univ. del Valle	Rainfall simulator
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	BSc.	Univ. Amazonia	Genotypic differences in P acquisition efficiency of 10 genotypes of *Arachis pintoi*
D.M.Arias	Colombia	BSc.	Nacional, Palmira	Drop impact on soil structure
H. Rivera	Colombia	Ph. D.	CENICAFE	Erodibility of hillsides soils
I. Balcazar	Colombia	BSc.	Nacional, Palmira	Water movement
L. Cobo	Colombia	BSc.	Univ. del Valle	Rainfall simulator
A. Hernández	Colombia	B.Sc.	Universidad del Valle	Cell wall characteristics of Brachiaria species
Y. Conta Diaz H.. Baracaldo	Colombia	B.Sc.	CORPOICA	Root growth and distribution In pastures...
G.P. Botero	Colombia	BSc.	Nacional, Palmira	Water movement
E.M. Quintero	Colombia	B.Sc.	Nacional Palmira	Physicazl and chemical treaments to facilitate the study of soil seed banks.
Y.S. Suárez	Colombia	B.Sc.	Nacional Palmira	Effect of hillside cropping sytems on weed abundance and diversity
L.X. Salamanca	Colombia	B.Sc.	Nacional Palmira	Weed dynamics under

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				Improved fallow systems.
G. Borrero	Colombia	M.Sc.	Nacional, Palmira	Phosphorus cycling
A.M. Patino	Colombia	M.Sc.	Nacional, Palmira	Bio-structure of soils

Impact:
The number of trainees operating within the project is probably the largest within any one project at CIAT.

Contributors:
R. Thomas, E. Amezquita, I. Rao, E. Barrios, J. Sanz, M. Ayarza, M. Fisher (CIAT), D. Friesen (IFDC).

Activity 4.6 Foster research linkages with institutions in the region and advanced or specialized research organizations

Highlight:
- The project has established active research collaborative links with 25 institutions.

Purpose:
To increase the collaborative nature of the projects training and research program.

Rationale:
Projects on natural resource management require an interdisciplinary, holistic approach. No one institute has the capacity to undertake the range of inter-disciplinary activities required in such an approach. Research efficiency can be improved by collaborative efforts that rely on the comparative advantages of the partners.

Results:
Seven collaborative research projects were prepared and submitted to the following donors;
1. COLCIENCIAS - Desarrollo de estrategias para el manaejo sostenible de la Altillanura Colombiana (via CORPOICA) (PE-2 Team)
2. DFID-UK - Potential of *Tithonia diversifolia* to enhance phosphorus mineralization and cycling (R. Thomas/E. Barrios/I. Rao)
3. ACIAR - Concept note on "Managing soil acidification in tropical pasture systems" (R. Thomas/I. Rao)
4. BMZ/GTZ - Improving integrated nutrient management practices on small scale farms in Africa (R. Thomas)
5. CYTED - Concept note on "Harnessing the biological plows of the soil". (R. Thomas)
6. Rockefeller Foundation - Concept note on "Harnessing the biological plows of the soil". (R. Thomas)
7. PRONATTA - Eficiencia de la fertilizacion nitrogenada en pasto estrella (*Cynodon nienfuensis*) en la zona cafetera. (N. Asakawa, M. Rondon, R. Thomas). Project submitted by CORPOICA with PE-2 as collaborators.

Research collaboration is proceeding with the following 25 institutions:
NARS: CORPOICA, EMBRAPA-CPAC, EMBRAPA-CNPAB
NGO's: CIPASLA
Regional Universities: Lavras and Uberlandia, Brazil, Nacional Sede Palmira, CIELAT and UNELLEZ, Venezuela
Specialized research organizations: Universities of Bayreuth and Hohenheim, Germany; University of Bangor, UK; Cornell, Ohio State and Michigan State, USA; University of Paris, France,
IARC's: ORSTOM, CIRAD, France; Maculae Land Use Research Institute, UK; CATIE, Costa Rica; IBSRAM, Thailand; TSBF, Kenya; ICARDA, Syria; ICRISAT, India; IFDC, USA; ICRAF, Kenya.

Impact:
Through these extensive collaborative links the project is increasing its research capacity and strengthening the regional capacity for research on soil, water and nutrient management.

Contributors
R. Thomas, I. Rao, E. Amezquita, E. Barrios, M. Ayarza, J. Sanz, M. Fisher (CIAT), D. Friesen (IFDC).

Publications:

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Invited Book Chapters

1. Amezquita, E., Ashby, J., Knapp, E.B., Thomas, R., Muller-Samman, K., Ravnborg, H., Beltran, J., Sanz, J.I., Rao, I.M. and Barrios, E. 1998. CIAT's strategic research for sustainable land management on the steep hillsides of Latin America. In "Soil erosion at multiple scales: Principles amd methods for assessing causes and impacts". Penning de Vries, F.W.T., Agus, F. & Kerr, J. (eds.) pp. 121-132. CABI/IBSRAM, Wallingford, Oxford, UK.
2. Fisher, M.J. (1999). Crop growth and development - flowering physiology. In: *Pasture Seed Production. Volume II. Tropical Species* (D. Loch and J.E. Ferguson, *eds.*). CAB International, Wallingford. (In press).
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Other Publications

1. Amézquita, E., Preciado G., Arias, D., Thomas, R., Friesen, D., Sanz, J.I., 1998. Soil physical characteristics under different land use systems and duration on the Colombian savannas. 16th World congress of soil science. Montpellier, 1998. (Poster presentation).
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5. Ayarza, M.A., Vilela, L., Pizarro, E. and da Costa, P.H., 1997. Agropastoral systems based on legumes: An alternative for sustainable agriculture in the Brazilian Cerrados. Technical report, CIAT, Cali, Colombia.
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List of donors of Complementary and Special Projects:

Donor/Project	Duration	Total Pledge (US$)
ETHZ, Zurich, Switzerland	1998 – 2001	140,000
Assessing the impact of adapted germplasm on the phosphorus fertility of low phosphorus –supplying tropical soils		
BMZ/GTZ, Germany	1996 – 1998	587,673
Soil Indicators of Sustainable Agropastoral Systems		
DFID – UK	1996 – 1999	303,395
Carbon-nitrogen Relations of Soil Organic Matter from Deep-Rooted Grasses in the South American Tropics		
PRONATTA, Colombia	1996 – 1999	51,480
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		
COLCIENCIAS, Colombia	1996 – 1999	172,800
Sostenibilidad del Recurso Tierra de la Orinoquía		

en Realción a su Uso Actual y Potencial		
DFID – UK Confronting Soil Erosion and Nutrient Depletion in the Humid/Subhumid Tropics	1998 – 1999	156,037
DFID – UK Potential of Tithonia diversifolia to enhance phosphorus mineralization and cycling	1998 - 2000	20,000
BMZ/GTZ A project report on the Combating Nutrient Depletion activities undertaken by partici-pants of the SWNM program in 1997.	1998	65,589
SWNM Managing Acid Soils: Water and Nutrient Fluxes as Indicators of Sustainable Land Use in the Brazilian Savanna.	1996 – 1999	360,000

Over the planned project period 1996-2000 a total of US $1,853,974 in special projects will complement the core funded activities. This excludes SWNM funds for the collaborating consortia.

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