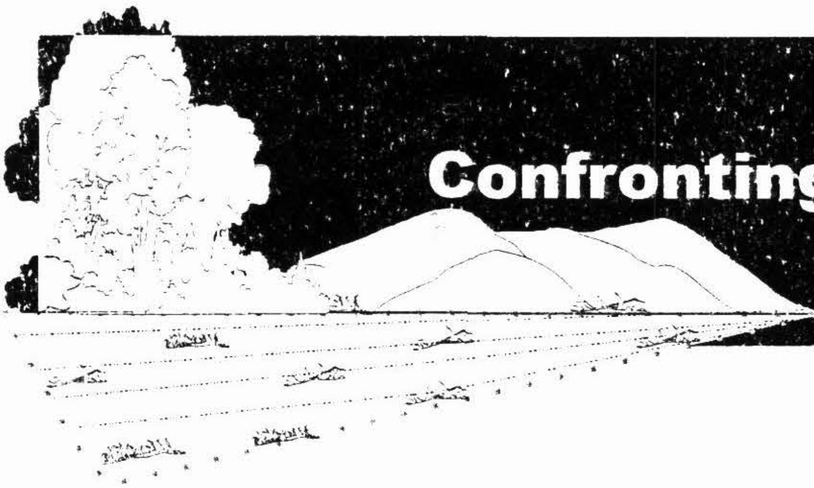

Project PE2: Confronting soil degradation

ANNUAL REPORT 1997

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

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

1. 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 NGOs.

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: CORPOICA; EMBRAPA; IFDC; ICRAF; ORSTOM, CIRAD (France); ETH (Switz.); CIPASLA; Universities of Uberlandia (Brazil), Nacional (Colombia), Paris (France), Bayreuth (Germany), Complutense de Madrid (Spain), Cornell, Ohio State (USA).

CG system linkages: Enhancement & breeding - 15%; Crop Production Systems - 60%; Biodiversity - 5%; Stengthening NARS- 20%; Co-convenor Systemwide Program on soil-water-nutrient management (SWNM), and 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

↓

Output 1 Plant components characterized for edaphic adaptation and efficient production (JIS/EA)	**Output 2** Strategies to protect and improve soil quality (RT/EA)	**Output 3** Diagnostic and predictive tools developed to combat soil degradation (DF)	**Output 4** Institutional capacity enhanced for strategic research on soil, water and nutrient management (RT, JAA)
i) Determine and characterize edaphic and climatic constraints (EA, JIS, DF) ii) Characterize plant components for production potential and nutrient use efficiency (IR, RT, DF, JIS) iii) Determine rooting strategies of crop and forage components (IR) iv) Test compatibility of plant components in different systems (including farmer participation) (JIS, DF) v) Determine spatial and temporal interactions of different components (JIS, DF) vi) Determine impact of systems on production and the resource base (EA, JIS, RT, DF, IR)	i) Determine nutrient release rates of component residues and green manures (RT, DF) ii) Estimate nutrient budges in contrasting systems (DF, RT, JIS) iii) Identify key processes in nutrient cycles to minimize losses and improve use efficiency in systems (DF, RT, JIS) iv) Estimate contribution of different systems to soil organic matter accumulation (MF, RT, EA, IR) v) Determine the effects of soil biota on soil fertility and structure (RT, DF) vi) Develop strategies to reduce soil loss and improve soil structure (EA) vii) Develop methods to improve water infiltration and storage (EA) viii) Test indicators to assess soil quality (RT, DF, EA, IR, JIS)	i) Identify dynamic soil properties and test their suitability as soil quality indicators (RT, DF, EA, JIS) ii) Develop diagnostic kit to assist farmers and extensionists in resource management decision making (EA, DF, RT) iii) Compile data bases to feed into simulation models and decision support systems (DF, EA) iv) Calibrate simulation models to predict system performance and overcome site specificity (DF, RT, IR, EA) v) Develop a decision support system to assist in resource management decision making (RT, DF, IR, EA, JIS) vi) Test diagnostic tools with NARS and farmers (JIS, EA)	i) Organize and coordinate field days and workshops (Team) ii) Prepare bulletins on agro-pastoral systems and soil, water and nutrient mana-gement projects (RT, IR, EA) iii) Promote and participate in specialized training courses, prepare training materials (Team) iv) Publish research results in refereed journals and other publications (Team) v) Supervise postdoctoral research, graduate and undergraduate theses (Team) vi) Foster research linkages with institutions in the region and advanced research organizations (Team)

Initials refer to staff members: JIS =J.I. Sanz, EA = E. Amezquita, DF = D. Friesen, IR = I. Rao, RT = R. Thomas, MF = M. Fisher

3. Highlights

Two articles are reproduced here as highlights for the project. They represent a substantial body of work from this and previous years. The first is a summary of the research completed in Brazil on the development of agropastoral systems. The second is a summary of the work conducted to date on phosphorus acquisition and cycling in systems on low phosphorus available soils.

Individual outputs of the project have highlights presented in a bullet form at the beginning of each progress report.

Agropastoral systems based on legumes: An alternative for sustainable agriculture in the Brazilian cerrados

[M. A. Ayarza*, L. Vilela **, E. A. Pizarro* y P. H. da Costa***]

Summary

Grain, meat and milk production systems in the Brasilian cerrados are currently experiencing increasing economic and environmental problems. This could have a detrimental effect on the natural resource base and on the sustainability of agriculture in the region over the long term if alternative systems are not developed. One option to intensify agricultural production and minimize negative impacts on the soil and water involves the integration of cropping and livestock systems in time and space (agropastoralism)

From 1992 CIAT and EMBRAPA-CPAC have worked together and with other institutions to develop agropastoral systems that have potential to increase the sustainability of production systems in the cerrados. The strategy involves the development of systems based on forage legumes adapted to low and high inputs and the quantification of their impact on productivity and on the soil. Most of these activities have been done on farms in the Uberlandia region of Minas Gerais.

The use of *Stylosanthes guianensis* cv. Mineirão in a rice-pasture system with low inputs resulted in a 50% increase in animal production when compared with a control without the legume. However the use of this legume in high input annual cropping systems was not successful.

Arachis pintoi BRA-031143 was better adapted in terms of competition with crops and forage grasses in high input systems. This legume has high potential for use in crop rotations (ley farming) or as a permanent ground cover in direct sowing. However chemical or mechanical methods are needed to control problems of competition with crops.

The results of a crop-livestock case study confirmed the synergistic effect on production and soil quality. Soil fertility was increased during the cropping cycle and soil aggregation and soil organic matter were increased under the pasture phase. More detailed studies indicated that organic matter underwent a process of physical protection under pastures. This process was especially significant with sandy soils.

Surveys from three watersheds in Uberlandia showed that crop-livestock integration is gaining acceptance amongst grain producers.

I. INTRODUCTION

In less than 30 years the cerrados region was converted into the most important agricultural frontier region in Brazil. Of the 204 million hectares that make up this ecosystem 47 million ha are under agriculture and it has been estimated that a further 89 million ha have similar potential (Macedo, 1994).

This rapid transformation is due to the technological advances made in soil management, the selection of cultivars adapted to the soil conditions and climate of the cerrados and to the state's investment in infrastructure and development programs.

Growth in agriculture in the region had positive impacts on wealth and employment with some negative environmental impacts. Soil erosion and compaction increased under annual crops (Ayarza et al., 1993). Agrochemical use rose sharply in order to control weeds, pests and diseases. Pastures degraded to the extent that more than 50% of the pastures sown in the cerrados show problems of loss of vigour, weed invasion and disease (Macedo, 1995).

Alternative systems are being developed in order to reduce these negative impacts. traditional soil preparation practices are being changed for minimum tillage practices where crops are sown into crop residues or into ground covers controlled with herbicides. At the same time soybean monocropping is being replaced by crop rotations. This reduces the incidence of weed and pest and disease infestation. In grazing systems grasses with resistance to spittle bug (*Deois flavopicta*) and crops are being used to recuperate degraded pastures (Klutchousky, 1995).

One of the best strategies to intensify agricultural production sustainably and reverse problems of degradation involves the integration of crop-livestock systems in time and space (agropastoralism). This is based on the fact that there is a beneficial synergistic effect on productivity and on the soil when annual and perennial species are combined (Spain, 1990; Lal, 1991). Available nutrients are used more efficiently and soil chemical, physical and biological properties are improved. In addition economic risk is decreased compared with crop or livestock enterprises alone.

For 4 years CIAT and EMBRAPA-CPAC have worked together with other institutions to develop agropastoral systems for the Brazilian cerrados. Specific objectives of the project were, 1) to develop agropastoral systems based on multiple purpose legumes, 2) evaluate the productivity of the systems on-farm, 3) quantify the impact of integrated crop-livestock systems on production and on soil quality, and 4) characterize the dynamics of the production systems and their adoption.
Here we describe the main results and discuss the potential use of agropastoral systems in the context of the current production systems.

2. Methodology

Most of the work was done on-farm in the Uberlandia region, Minas Gerais (19° S 48' W). Most of the agroecological classes of the cerrados are found in this region (Jones et al., 1992) which has been undergoing a rapid process of intensification of soil use during recent years (Oliveira Schneider, 1996). The soils are deep, well structured but with low fertility and high phosphorus fixation capacity. They are classified according to the Brazilian system as latossols vermelho-amarelo and vermelho-escuro (Anionic Acrustox and Typic

Haplustox after the USA system). Mean annual rainfall is around 1600 mm concentrated between November and March. There is a severe dry season between June and September when relative humidity falls to 15%.

The project focused on the development of agropastoral systems based on legumes with potential to adapt to both grazing systems of low inputs, and to cropping systems of high inputs as components of rotations and permanent ground covers. Studies from other tropical regions indicate that legumes are a key component for increased sustainability of production systems (Boddey et al., 1996; McCown et al., 1993; Thomas et al., 1995).

Stylosanthes guianensis cv. Mineirão and *Arachis pintoi* BRA-031143 were evaluated as potential plant components. These two legumes are adapted to the climatic and soil conditions of the cerrados and have a large production potential (Pizarro y Rincón, 1994; E MBRAPA/CPAC, 1993).

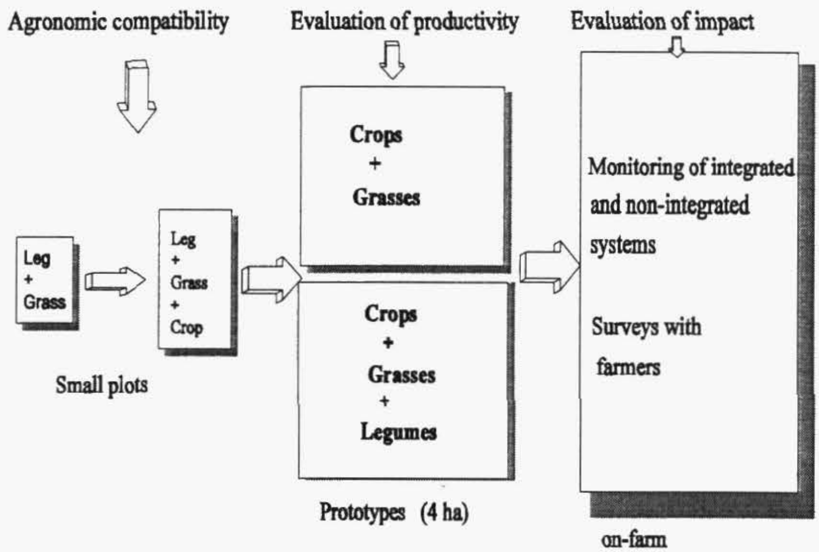

Figure 1. Sequence of activities in the development of improved agropastoral systems.

A schematic representation of the process involved is shown in Figure 1. Compatibility studies of *Stylosanthes guianensis* cv. Mineirão and *Arachis pintoi* BRA-031143 were done in small plots under cutting with forage grasses. In other studies legume establishment was examined with crops and grasses on sandy soils with two levels of fertility. The potential use of *Stylosanthes* and *Arachis* as ground covers was evaluated in pure stands.

The impact of the legumes on production was evaluated in 4 ha prototypes on farm either in pastures with low inputs, or in annual cropping systems with high inputs on clay and sandy soils. Table 1 shows the soil characteristics of each system used. The experimental design included a comparison between a crop plus a grass-only pasture system and a crop plus grass pasture plus a legume cocktail, each with two repetitions.

Table 1. Chemical and physical characteristics of 0-20 cm soil from selected areas used for prototypes in Uberlandia, Brazil.

Production System	Clay (%)	OM (%)	PH H_2O	P (ppm)	Ca + Mg	K	Al	Aggregates % > 2mm
					------------	meq/100g	----------	
Pastures (LI)	57	3.7	5.1	0.9	0.5	0.07	0.5	77
Pastures (LI)	17	0.7	5.3	1.1	0.4	0.13	0.6	73
Crops (HI)	57	3.4	6.2	34	4.9	0.12	0.0	50
Crops (HI)	13	0.7	6.3	26	2.4	0.25	0.0	46

LI = Low input; HI = High input
Means of 20 samples/ha

The crops and forage grasses used varied with the production system and fertility level applied. Pastures with low inputs were sown with upland rice and *Brachiaria decumbens* and *Brachiaria ruzizienzis* . The high input systems were sown with maize and *Panicum maximum* cv. Vencedor. All prototypes sown with legumes used a cocktail including *S. guianensis* cv. Mineirão, *Neonotonia wightii* cv. Tinaroo and *Calopogonium muconoides*. The latter two legumes are used commercially and were included as controls. *A. pintoi* BRA-031143 was not sown in the high input systems because of a lack of seed. The fertilization of the high input systems included 1 t/ha of lime, 70 kg/ha P_2O_5, 35 kg/ha K_2O and 12 kg/ha N applied at sowing. After 60 days 20 kg N/ha and 60 kg/ha K_2O were also applied. For the low input systems only P was applied at 20 kg/ha de P_2O_5 together with the legume seed. Fertilization of maize followed the recommendations given to farmers.

The evaluation of the prototype systems included grain and animal production. Biomass production and botanical composition of the pastures were measured three times per year. Soil samples were taken at various depths to evaluate changes in aggregate stability, soil organic matter and availability of nitrogen. A degraded pasture was included as a control in the comparison of low input systems.

Seed multiplication plots of *S. guianensis* and *A. pintoi* BRA-031143 were set up in farmer's fields and visits to the prototype system sites were used to promote the systems.

The impact of integrated crop-livestock systems on productivity and on the soil was quantified in a case study on the Santa Terezinha farm in Uberlandia. This farm has sandy soils and a 10 year history of crop-pasture integration. Information on the use of soils, crop and animal productivity was available. In addition changes in chemical and physical properties of the soil in areas used for crops and pastures were monitored. This work was complemented by a detailed study on soil organic matter and soil aggregation (see Output 3 activity i).

The dynamics of grain production systems and technological changes occurring over time were studied in three watersheds situated in three municipals: Rio Uberabinha (Uberlandia), Ribeirrao Santa Juliana (Sta juliana) and Rio Bagagem (Irai de Minas). This work was achieved by the use of surveys conducted on farms and were complemented by remote sensing studies.

3. RESULTS

3. 1. Agronomic compatibility of *S. guianensis* cv. Mineirão and *A. pintoi* BR-031143 with grasses and annual crops.

The aggressiveness of forage grasses and associated crops influence legume establishment in systems where they are simultaneoulsy sown. In an experiment with 19 forage grass ecotypes *S.guianensis* cv. Mineirão grew better with ecotypes of *Paspalum* and *Brachairia brizantha* in comparison with *P. maximum* and *B. decumbens*. However there were differences amongst ecotypes of the same genus. Differences in compatibility of *S. guianensis* with ecotypes of *B. brizantha* were inversely related with the dry matter production of the grasses (r^2 = - 0.83). With ecotypes of *P. maximum* and *B. decumbens*, the negative effect of the grasses was related to other characteristics such as shading, root production and nutrient uptake. *Stylosanthes* is a genus very which is sensitive to shading (Rodriguez et al., 1993) and to competition from the grasses for N, Ca and P (Rao et al., 1995).

In other experiments the compatibility of various ecotypes of *A. pintoi, Centrosema macrocarpum, Centrosema brasilianum* and *Calopogonium mucunoides* was compared when own in association with *B. decumbens* CIAT 16488. Most legumes disappeared, except *Arachis,* mainly as a result of poor adaptation and diseases. All *Arachis* ecotypes grew well with the grass and retained their leaves during part of the dry season (Pizarro et al., 1996). There were large differences in dry matter production between the commercial cultivar Amarillo and accession BRA-031143 which is considered promising for the cerrados (Fig. 2).

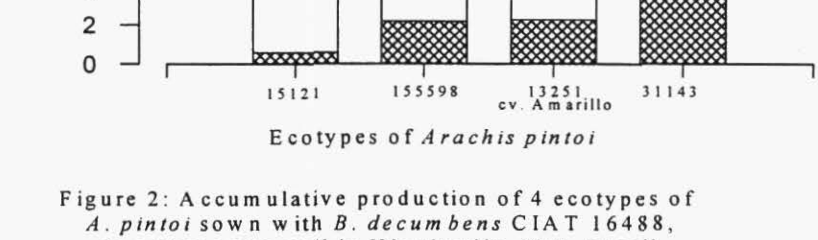

Figure 2: Accumulative production of 4 ecotypes of *A. pintoi* sown with *B. decumbens* CIAT 16488, in a clay soam soil in Uberlandia, MG, Brasil.

Sowing *P. maximum* cv. Vencedor and *B. ruziziencis* simultaneously with rice and *S. guianensis* cv. Mineirão significantly reduced rice production and the establishment of the legumes when compared with *P. atratum* BRA-009610 (Table 2). Competition was greater with the higher level of fertilization. *Stylosanthes* practically disappeared when sown together with *P. maximum* cv. Vencedor and maize in a high input system (Table 3). Maize yields were little affected by the grasses (14% reduction in yield). Competition from the grasses was significantly reduced if they were sown 30 days after the crops and forage legumes (Tables 2 and 3). Dry matter production of *A. pintoi* BRA-031143 was very low in both high and low input systems but did establish better with high inputs after the harvest of the maize.

Table 2. Effect of three grasses on production of rice and DM of *Stylosanthes guianensis* cv. Mineirão and *A. pintoi* BRA-031143 grown on sandy soils in Uberlandia.

Species[1]	*Sown simultaneously*			30 days*		
	Grass	Rice	Mineirão	Grass	Rice	Minerirão
	kg/ha			kg/ha		
P atratum	4808	1106 a	1375 a	628	2189 a	1829 a
B. brizantha	7299	1208 a	558 b	714	2556 a	957 a
P. maximum	7458	194 b	274 c	1417	2156 a	1389 a
	Grass	Rice	Arachis	Grass	Rice	*Arachis*
P. atratum	5677	1014 a	169 a	1988	2445 a	21 a
B. brizantha	6187	1023 a	137 a	1612	2570 a	43 a
P. maximum	7166	314 b	74 a	2733	2203	60 a
Monoculture		2662			2437	

* Grass sown 30 days after sowing the crop and legume
[1] (Paspalum atratum BR-009610, Brachiaria brizantha cv. Marandu, Panicum maximum cv. Vencedor)
- Means of 3 repetitions

Table 3. Grain and forage production in a maize-pasture system with two sowing dates for the grass on a sandy soil in Uberlandia.

Sowing System	Grass[1]	Mineirão	Arachis	Maize
	DM(kg/ha)			Kg/ha
Monculture maize	-	-	-	6364 a
Maize + Legumes	-	1814 a*	569 a	6400 a
Maize + Legumes + *P. atratum* (s)	4700	144 b	221 b	6500 a
Maize + Legumes + *P. maximum* (s)	6200	11 c	96 c	5586 b
Maize + Legumes + *P. atratum* (30 d)	1200	1078 b	618 a	6484 a
Maize + Legumes + *P. maximum* (30 d)	1500	723 c	545 b	6594 a

* Values followed by the same letter in each column are not significantly different (Turkey P<0.05)
[1] Grass = *P. atratum* BR-009610, *P. maximum* cv. Vencedor
Mineirão = *Stylosanthes guianensis* cv. Mineirão
Arachis pintoi BRA-031143
(s) = Sown together, (30 d) = grass sown 30 days after the crop and legume
Means of 3 repetitions

3. 2. Potential of *Stylosanthes* and *Arachis* as permanent ground covers in annual cropping systems

Ground covers of *S. guianensis* cv. Mineirão and *A. pintoi* BRA-031143 had different effects on the growth and production of maize. In a preliminary experiment on a sandy soil *Stylosanthes* had little effect on grain production but *A. pintoi* severely inhibited the growth of maize.The maize plants grew slowly and showed nutrient deficiency symptoms. This was associated with the large root biomass production by *A. pintoi* in the 0 -10 cm soil depth and a vigorous re-growth of the legume at the start of the rains. Later experiments showed that the competition from *A. pintoi* BRA-031143 could be reduced temporarily by the application of 3.5 l/ha of Round-up plus 1% urea or with a pass of a subsoiler before sowing the maize (Fig. 3). Other more intensive mechanical methods such as a harrow or plow also reduced the competition from the legume but stimulated weed infestation (Table 4). Exploratory work with a range of herbicides showed that there are various alternatives to control ***Arachis***. In all studies ***Arachis*** eventually completely covered the ground. In contrast *Stylosanthes* ground cover disappeared after the maize harvest.

3. 3. Productivity of agropastoral systems

As observed in plot experiments *S. guianensis* cv. Mineirão adapted well to low input systems on sandy and clayey soils. At rice harvest there were 3-4 plants m^2 of *Stylosanthes*. Other legumes were also observed but at low densities. Rice yields in these systems were very low due to a dry period and competition from the grasses. In the high input systems the legumes disappeared as a result of competition for light from *P. maximum* cv. Vencedor and maíze. Maize production and grass establishment were however excellent.

After 3 years under pastures, animal production in the low input prototypes with legumes was 50% greater than that under crop-pastures without legumes (Table 5). This difference

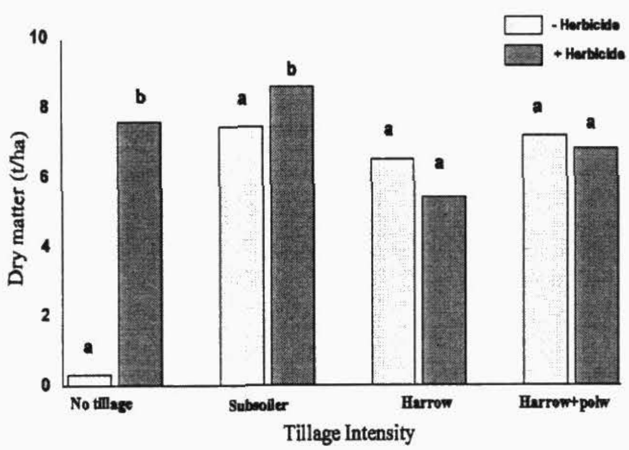

Figure 3. Maize production in a ground cover of A. pintoi controlled with various mechanical and chemical methods in a sandy loam soil in Uberlândia, MG, Brazil. Values followed by the same letter are not significantly different (Tukey $p < 0.05$)

increased to 80% after a maintenance application of 20 kg/ha P_2O_5 and 40 kg/ha of K_2O. The better animal production from systems with legumes was associated with higher carrying capacities, greater individual animal live weight gains and a better quality diet. The differences were marked during the dry season as a result of the capacity of *S. guianensis* cv. Mineirão to maintain green material on offer. The proportion of the legume remained stable during the evaluation ranging from 30 to 60% of the total biomass depending on the season. Animal performance on the crop-grass pastures was similar to that of a degraded pasture on a sandy soil that was used as a control.

Table 4. Effect of tillage intensity and herbicide use on DM production of *A. pintoi* BRA-031143 and weeds.

	- Herbicide		+ Herbicide	
	------------------------------- DM (kg/ha) ------------------------------ ---			
Tillage Intensity	Arachis	Weed	Arachis	Weed
No-tillage	10895 a*	427 a	602 b	463 a
Subsoiler	4050 b	745 a	86 a	2168 b
Harrow	2280 c	3366 b	2773 c	7775 c
Plow + harrow	2008 c	3373 b	1581 c	8219 c

* Values followed by the same letter in each column are not significantly different (Turkey P< 0.05)

Animal production from the high input prototype on a clay soil was two times greater than that on a sandy soil. This was due in part to a greater availability of nitrogen for the grass on the clay soil (1.29 mg N g clay soil vs. 0.61 mg N g sandy soil). The effect of the low availability of N in the sandy soil was confirmed by the linear response of *P. maximun* cv. Centenario to N fertilizer (Fig. 4). Nitrogen limitation was revealed over time by an increasing proprtion of perennial soybean *(Neonotonia wightii)* in the pasture and the better animal production in the prototype with legumes (Table 5). At the end of the measurement period this legume comprised 40% of the biomass on offer.

The results obtained in prototypes including *S.gui*anensis cv. Mineirão y *A. pintoi* BRA-031143 have stimulated an interest by the farmers of the region in seed production of these two legumes. In two years some 8 ha of *Stylosanthes* and 3. 5 has of *Arachis* have been sown and 122 kg and 235 kg of seed have been obtained respectively.

Table 5. Animal live weight gain from agropastoral prototypes sown in two productive systems and two soil types in Uberlandia.

Production System	Input use	Soil type	Prototype	Animal prod. Kg/ha/year	Increase (%)
Pastures	Low	Sandy	Crop + Grass	160	-
Pastures	Low	Sandy	Crop + Grass + Leg	254	58
Pastures	Low	Clayey	Crop + Grass	230	-
Pastures	Low	Clayey	Crop + Grass + Leg	354	54
Crops	High	Sandy	Crop + Grass	236	-
Crops	High	Sandy	Crop + Grass + Leg	267	10
Crops	High	Clayey	Pure grass	503	-

- Mean of 3 years

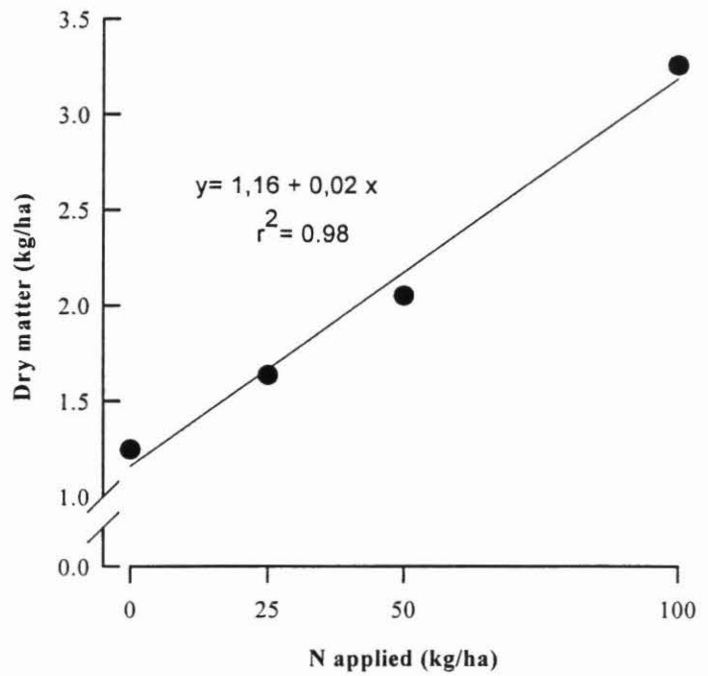

Figure 4. Response of a 4 year old pasture of *P. maximum* cv. Centenário to the application of N fertilizer.

3.4 Impact of crop-livestock systems on production and on the soil

With the introduction of agricultural activity in 1983 the original grazing enterprise on the farm Santa Terezinha was transformed into an integrated system where crops and pastures are rotated in time and space. By 1992 all the original pastures of *B. decumbens* cv. Basilisk had been replaced with *P. maximum* sown simultaneously with maize after a cycle of 3-4 years of crops only (Table 6). From 1992 the percentage of the farm area in pastures has been maintained at 40%. In spite of the reduction in pasture area the animal numbers have been increased (Table 6). This has occured with an increase in the net margins and an increase in the number of calves per ha when compared with the traditional system (Table 7)

The new integrated system has also improved the soil. During the crop cycles the fertility of the soil increased as a result of the use of fertilizers and amendments (Table 8). Soil organic matter has increased by 30% under pastures compared with areas under crops for 4 years. Soil aggregation has also improved (Fig. 5). Lilienfein (1996) showed that there was an enrichment of C, N and P in macroaggregates in soils under pastures (see Output 3 activity i). Further studies are being done to evaluate the effect of the legumes on soil properties. Preliminary results indicate that there is an increase in the populations of mesofauna in the litter layer and soil (see Output 2 activity v).

Table 6. Changes in areas under pasture over time on the Sta. Terezinha MG, Brazil as a consequence of the introduction of crop-pasture rotations.

Year	Systems: Cerrado/Pastures (ha)	Systems: Crops/Pastures (ha)	Total area	No.of animals	Carrying capacity (an/ha)
1983	1014	0	1014	1094	1.1
1984	970	0	970	1069	1.1
1985	858	61	919	1025	1.1
1986	647	80	727	804	1.1
1987	521	176	697	862	1.2
1988	293	296	589	821	1.9
1989	205	377	582	846	1.4
1990	115	493	608	892	1.4
1991	15	632	647	891	1.4
1992	0	412	412	1150	1.8

Source: Ayarza et al. (1993)

Table 7. Economic efficiency of calf production in 3 grazing systems with different degrees of intensification in the Uberlandia region.

Parameters	Traditional	Improved	Crop-pastures
% renovated/year	1	10	25
Pasture age (years)	15-20	10	5
Has/cow	1.85	1.3	0.96
Calves/ha	2.8	5.7	6.6
Net gain (US $)	43	95	110
Area in pastures	1728	2110	416
Total net gain (US $)	74304	200450	45760

Source: Fisher et al., 1995

3.5 Adoption potential of agropastoral systems

Results of the characterization study of 3 watersheds show that crops occupy around 72% of the total farm area. The rest is pastures and reserve areas where mechanization is not possible (Smith et al., 1997). About one half of the farmers questioned have livestock for meat and milkproduction. During the wet season the animals remain on the pastures and in the dry season they are confined and fed silage and concentrates produced generally from the crops within the farm.

This type of integration has allowed for the use of areas not suitable for agriculture and has increased the income from meat and milk. The farmers perceive that livestock activity is complementary rather than substitutive for their principal activity of grain production. The rotation of crops and pastures is still a relatively unused practice by grain producers. Only some 6% have sown pastures of high productivity in cropping areas. The majority have pastures in areas unsuitable for mechanization where crop production is difficult.

Table 8. Changes in chemical properties in a sandy Oxisol on the Sta. Terezinha farm in Uberlandia after 4 years of continuous cropping.

Parameters	Depth	Native Cerrado	Crops
PH	0-10	5.4	6.3
	10-20	5.2	5.9
	20-30	5.2	5.6
	30-40	5.2	5.0
Sat. Bases (%)	0-10	19.1	82.7
	10-20	22.6	84.6
	20-30	21.9	69.5
	30-40	17.7	52.0
P (ppm)	0-10	1.6	24.8
	10-20	0.6	2.0
	20-30	0.4	1.0
	30-40	0.3	0.0

Means of 4 bulked samples

4. GENERAL DISCUSSION

One of the requirements for a sustainable technology that could be rapidly adopted by farmers is the generation of production benefits and soil improvement in the short and long term that require little structural changes in the production systems (Spencer, 1991). An possible example is the introduction of *S. guianensis* cv. Mineirão into livestock systems with low input use. Seed requirements are relatively small some, 700 - 1,500 g /ha for establishment, with no extra labor for soil preparation and little fertilizer use. It is known that Stylosanthes legumes are very efficient in associating with mycorrhiza and obtaining a high rate of P uptake per unit of root (Rao et al., 1997) although the exact mechanisms for this are not known. These characteristics together with the capacity to provide green herbage during the dry season give this legume clear advantages over other species for the improvement of production during critical periods.

In spite of these attributes of *Stylosanthes* there is a need to select the grass and accompanying crop to avoid problems of light and nutrient competition. Grasses have a more profuse root system than legumes which allows them to better explore the soil for water and nutrient absorption (Rao et al., 1996). In better soil fertility conditions the survival of *S. guianensis* cv. Mineirão is less due to the greater capacity of the accompanying grasses and crops to respond to increased fertility.

The greater productivity of pastures associated with *S. guianensis* cv. Mineirão is related to the supply of N from the legume to the soil-plant system. Cadisch et al., (1993) and Thomas et al., (1997) have shown that around 80% of the *Stylosanthes*' N is derived from biological fixation. Some of this N is consumed by the animals and some is recycled via excreta and plant litter decomposition (Thomas, 1992). These processes can increase the levels of mineral-N in the soil (Cadisch et al., 1993; Freibauer, 1996) and thereby N availability for the grasses. This was confirmed in these studies by greater N concentrations in the tissues of grasses associated with *S. guianensis* cv. Mineirão compared with that in pure grass swards (data not presented). The increase in pasture production after P and K fertilization could also be related to a better availability of N. On the other hand the small differences in animal production between pure grass pastures in the crop-pasture systems and the control degraded pasture on sandy soils indicates that the recovery of pastures via crops is of short duration and that it is necessary to include a source of N to maintain the increased pasture productivity.

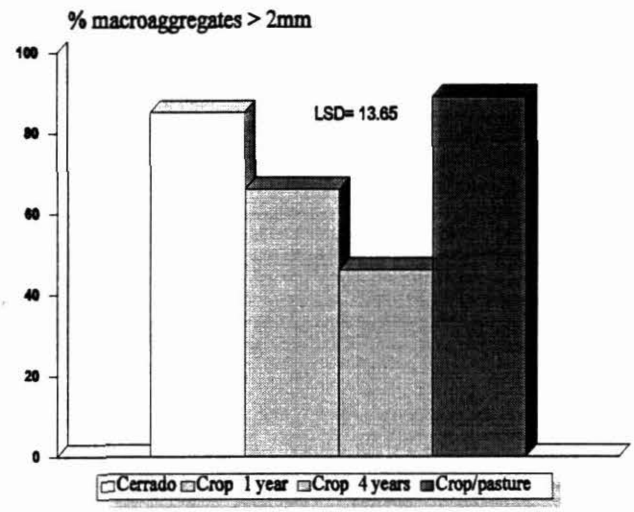

Figure 5. Effect of soil management on the proportion of macroaggregates in a sandy loam in Uberlandia, MG, Brazil.

The behaviour of *A. pintoi* BRA-031143 contrasts with that of *S. guianensis* cv. Mineirão. *Arachis* is a perennial legume with prostrate growth habit and various mechanisms of persistence (Fisher y Cruz, 1994). Although growth is initially slow it produces more roots than other legumes and has a better nutrient absorption efficiency (Rao et al., 1996). Also it tolerates temporary shade relatively well. These characteristics together with an excellent nutritive quality and capacity to cover the soil suggests that it is a plant better adapted to systems of more intensive management and higher inputs. Once established *Arachis* can persist in mixtures with grasses as aggressive as *P. maximum* cv. Vencedor and can contribute to the maintenance of animal production in rotation systems with crops in sandy soils. Although this effect could not be demonstrated in this project because of a lack of seed, the legume's persistence was noted in plots under grazing in the prototype experiments.

The use of *A. pintoi* as a permanent ground cover has been reported in plantations of coffee (Staver, 1996), banana (Perez, 1996; Granstedt and Rodrigues, 1996) and oranges (Perez-Jimenez et al., 1996) in Central America. These studies illustrate the advantages and disadvantages of *A. pintoi*. Weed control and protection of the soil against the impact of rain drops and a reduction in the incidence of nematodes are some mentioned advantages. The slow establishment, eventual competition with crops and high costs of establishment are mentioned disadvantages. There is little information about its potential as a permanent ground cover with annual crops.

In this study the incidence of weeds was greatly reduced once *A. pintoi* was established. However it is necessary to control competition from *A. pintoi* to obtain good yields of crops such as maize. There is a need to minimize the initial competition with the crop but also a complete ground cover needs to be established by the end of the crop cycle. The speed of complete ground cover establishment and incidence of weeds is influenced by the type of control applied to the ground cover. Methods that destroy the ground cover and disturb the soil stimulate weed seed germination. The results obtained with a subsoiler indicate that this system of vertical preparation of the soil damages the roots of *A. pintoi* but does not destroy the ground cover. This practice reduces the root competition and improves physical conditions of the soil for the crop.

Various experiments are being done to determine the potential use of this ground cover with other crops together with a study of the dynamics of the cover, its effects on N availabiltiy and on weeds over time. Data from Australia have shown that clover (*Trifolium subterraneum*) can acidify the soil when used in rotations with crops and pastures (Coventry et al., 1987) and this effect needs to be monitored in other systems.

The results from monitoring crop-livestock systems confirmed the beneficial effect of integration on soil quality and system productivity. However in spite of its great potential the integrated systems are not widely used. This is due in part, to the changes needed in infrastructure and administration of the systems in order to manage both sets of activities which are generally done separately by different farmers (grazers and crop farmers). Thus there is a need for a change of attitude and perspectives of both grain producers and cattlemen to undertake both activities (Spain et al., 1996). According to the surveys however this change is occurring. Producers are perceiving the economic benefits of integration but the activities are maintained on separate areas of their farms. Adoption of rotation systems of crops and pastures is likely to take time but appears to be an option for increasing the sustainability of agricultural systems on fragile soils. The inclusion of forage species as ground covers in direct sowing systems has a large potential by protecting the soil, adding value to the cover and permiting its use as a part of the rotation with crops. The identification of other grass and legume species adapted to the soil conditions and management system is needed

5. CONCLUSIONS

The project results have demonstrated that agropastoral systems have potential to increase productivity and improve soil properties while reducing the risks of degradation. The impact of these systems is greatest when *Stylosanthes guianensis* cv. Mineirão and *Arachis pintoi* BRA-031143 are included.

S. guianensis cv. Mineirão is a legume adapted to low fertility soils that can be easily established in rice-pasture systems to renovate degraded pastures with low input use. In addition to improving the diet of the grazing animal it can increase the availability of N in the soil-plant system and allow a better pasture establishment.

In contrast *Arachis pintoi* BRA-031143, is a legume better adapted to more intensive production systems with higher input use. It is relatively tolerant to competition for light and nutrients and has a good ability to cover the ground once established. These attributes are appropriate for rotational use with crops and as a ground cover for direct planting systems.

The integration of crop and livestock activities on farm is a relatively recent innovation by producers in the cerrados. Those producers that are using the systems see the economic and environmental advantages of this technology. The widespread adoption of these systems depends on the ability of both grain producers and cattlemen to adapt to the structural changes. Researchers for their part, need to increase the component options of crops and pastures and identify an adequate management system in order to maximize the synergistic effects on production and on soil quality.

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Phosphorus acquisition and cycling in crop and pasture systems in low fertility tropical soils

D. K. Friesen[1,2], I. M. Rao[1], R. J. Thomas[1], A. Oberson[1,3] and J. I. Sanz[1]
[1]Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia; [2]International Fertilizer Development Center, Muscle Shoals, AL, USA; [3]Swiss Federal Institute of Technology, Zürich, Switzerland.

Key words: litter decomposition, Oxisols, phosphorus fractionation, root distribution, root length, savannas

Abstract
Soil-plant processes which enhance P acquisition and cycling in low-P Oxisols were investigated in a crop rotations and ley pasture systems experiment on the Colombian eastern plains. Comparison of rooting patterns indicated that, despite low available P at depth, there are important differences in root size and distribution among native savanna, introduced forage and crop species which affect their ability to acquire P from these soils. Differences in crop/forage residue decomposition and P release rates suggest that managing the interaction of residue with soil may help slow P fixation reactions. Despite these differences, soil P fractionation measurements indicate that applied P moves preferentially into labile inorganic P pools, and then only slowly via biomass production and microbes into organic P pools under both pastures and crop rotations.

Introduction
Highly weathered tropical soils (Oxisols, Ultisols) are characterized by low total and available phosphorus (P) content, and a high P retention capacity. P inputs are essential to increase and sustain agricultural production but are often unaffordable or uneconomical for resource poor farmers. Moreover, P applied to soil enters into reactions which gradually render it unavailable to crops. Since P acquisition by plants rarely exceeds 20% of the total fertilizer P applied, the scope for improving P efficiency is immense. The key is to increase P recovery from less accessible forms using crop and forage cultivars that more efficiently take up P, and to integrate these P efficient cultivars into crop-pasture production systems

to more effectively cycle applied P.

During the past 20 years superior tropical crop and forage germplasm adapted to low P supplying soils has been identified (Lynch and Beebe, 1995; Pellet and El-Sharkawy, 1993; Rao et al., 1993) but the plant traits and mechanisms that contribute to greater P acquisition and/or utilization in these genotypes are poorly understood. Systems could benefit from greater P acquisition by enhanced P cycling through residues. Following the concept of 'synchrony' of nutrient release and crop demand in systems (Swift, 1984), P cycling could be enhanced by intercepting P released from residues before it moves into less labile pools. Understanding cycling processes would enable us to design systems and management interventions which minimize undesirable P flows out of the cycle (through "fixation" reactions) and maximize P flows through dynamic pools which can be accessed by plant roots and mycorrhizae. We hypothesize that crop and forage cultivars that are more P-efficient would be able to absorb P from soil solution at much lower concentrations, mobilize less-available P forms and cycle the acquired P to less-efficient components in cropping systems. In this paper we present results demonstrating differences in rooting strategies among crop and forage species and their ability to acquire P from infertile Oxisols, differences in P release from residues derived from this germplasm, and examine differences in the dynamics and cycling of P among inorganic and organic pools in contrasting production systems on infertile Oxisols of the eastern plains of Colombia.

Materials and methods

Studies were carried out at the CIAT-CORPOICA Experiment Station, Carimagua (4°30'N, 71°19'W and 150 m.a.s.l.), on the eastern plains of Colombia. Rainfall averages 2240 mm annually, falling mainly from late March to mid-December. Mean annual temperature is 27°C. Soils are well-drained silty clay Oxisols (tropeptic haplustox, isohyperthermic).
Measurements were made in selected treatments of an experiment established in 1993 to investigate sustainable crop rotation and ley farming systems for the acid-soil savannas. In a split-plot design with 4 replications, 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 nutrient cycling, carbon inputs and soil organic matter loss, and soil physical condition. In addition to cereal monocultures, system components rotated with rice and maize include (respectively) grain legumes (cowpeas or soybeans), green manures (GM) and "improved" pasture leys (*Brachiaria humidicola* CIAT 679 + *Arachis pintoi* CIAT 17434 + *Stylosanthis capitata* CIAT 10280 + *Centrosema acutifolium* CIAT 5277 [*Bh*-legume]; or *Panicum maximum* CIAT 6871 cv. Centenario + *A. pintoi* + *Pueraria phaseoloides* CIAT 9900 (Kudzu)). Native savanna (NS) plots are maintained for baseline comparisons. Triple superphosphate fertilizer at 60, 80, 40 and 40 kg P ha^{-1} is applied to each rice, maize, grain legume and GM crop, respectively. Pastures were sown under cereals and relied on that initial P input plus biennial maintenance applications (20 kg P ha^{-1}). Other nutrients were applied at adequate levels.

Root length distribution (0-80 cm soil depth) was estimated in maize monoculture in July 1994 (during grain filling), and in NS and *Bh*-legume pasture in November 1994 (1.5 years after establishment). A coring method was used in which 10 soil cores were collected from each plot, bulked by depth, washed free of soil, scanned for length, dried and weighed (Rao et al., 1997a; Vepraskas and Hoyt, 1988). Bray-2 available P (Olsen and Sommers, 1982) and exchangeable cations and aluminum (Al) (Thomas, 1982) were determined in soil subsampled from root cores.

Differences in vertical root length distribution among treatments were estimated using the model of Gale and Grigal (1987), $Y = 1 - \beta^d$, in which Y is the cumulative root length fraction (between 0 and 1) from the soil surface to depth d (cm), and ß (the only parameter estimated) is the index of root length distribution. Higher ß values correspond to greater proportions of root length at depth.

P acquisition was estimated using total biomass (dry weight basis) measured from harvested quadrats together with P concentration determined in dried, ground subsamples of maize grain and shoot residues at maturity, and savanna and *Bh*-legume pasture above-ground biomass sampled when roots were sampled. Only one (late-rainy season) sampling was used for the pastures.

The decomposition of crop residues, GMs and forage litter collected from the field plots was studied using standard litter bag techniques (Thomas and Asakawa, 1993). Nylon bags containing approximately 10 g dry weight of different 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. Litter bags were arranged in 3 to 4 replicate sets of six bags each. At each sampling date, one of each set of each plant material was removed, washed, dried and analyzed for dry matter and nutrient content (Thomas and Asakawa, 1993). Decomposition rate and half-life were calculated using the exponential decay model, $X = X_0 H \exp(-kt)$, where X is the relative amount of dry matter or P remaining, X_0 is the initial amount, k is the rate constant for decay or release and t is time.

P dynamics and partitioning in soil were studied in the rice monocrop, rice-GM, *Bh*-legume pasture and NS treatments. Soil samples (0-10cm) composited from 10 randomly located 8 cm diameter cores per plot were taken on an approximately bi-weekly basis from March 1995 through March 1996, air-dried, sieved and fractionated partially (labile P pools only) or (for selected sampling dates) completely according to the modified Hedley procedure (Tiessen and Moir, 1993). This procedure attempts to quantify increasingly labile or stable forms of inorganic (Pi) and organic P (Po) by applying the following increasingly aggressive extractants: H_2O with anion exchange resin, 0.5 *M* $NaHCO_3$ (Bic-P), 0.1 *M* NaOH, 1.0 *M* HCl, and hot concentrated HCl (HCl_{hc}). Residual P in the remaining soil is determined by digestion with perchloric acid.

Results

P acquisition by crops and forages

Root length per unit soil surface area decreased with increasing soil depth (Fig. 1a, b, c). About 75% of root length of maize was found in the top 0-10 cm soil layer whereas NS and *Bh*-legume pastures had 38% and 42% of their total root length, respectively, in this soil layer. Mean cumulative root length fractions and estimated ß-values (Fig. 2) confirm that NS and *Bh*-legume pastures had a greater proportion of roots at depth (that is, were more deep-rooted) than maize. Moreover, total root length (Fig. 1) and biomass (475, 954 and 453 kg ha^{-1}, respectively) of the NS and *Bh*-legume pastures were greater than of maize.

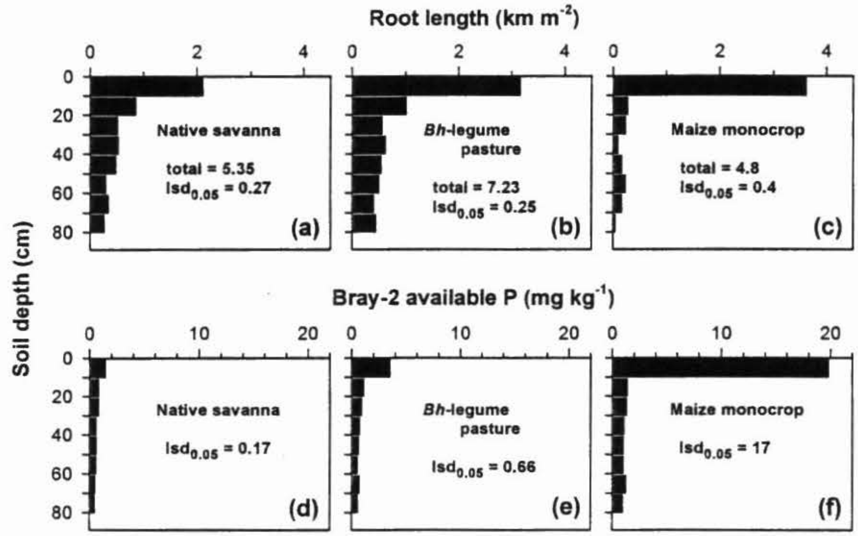

Fig. 1. Root length distribution (a, b, c) by soil depth as related to (Bray-2) P availability (d, e, f) in a silty clay loam Oxzisol under native savanna, *B. humidocola*-legume pasture and maize monoculture.

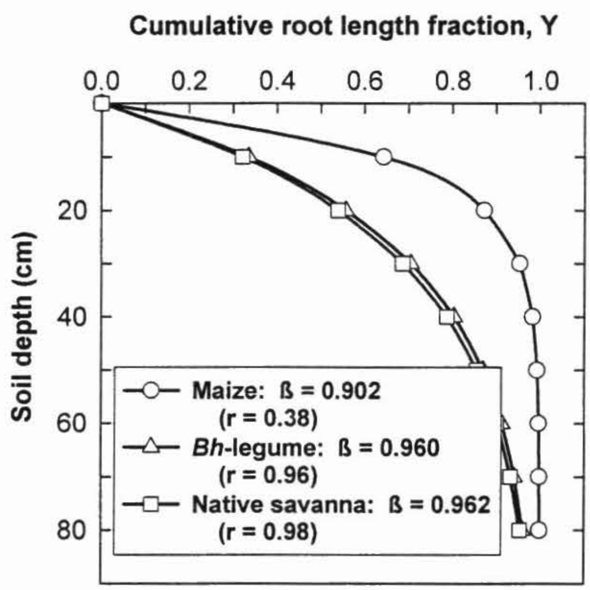

Fig. 2. Vertical root length distribution (cumulative fraction between 0 and 1) for native savanna, *B. humidicola*-legume pasture and maize monoculture as a function of soil depth where ß is the distribution coefficient. (See text for definition of model and parameters).

P release from crop residues and forage litter

Rates of decomposition of rice straw residues, cowpea GM, forage grass (*B. humidicola*) and a forage legume (*S. capitata*), distributed on the soil surface, were related to their C:N ratios, but were both greater and less than apparent rates of P release (Fig. 3). While this suggests, for the latter, possible P immobilization, the C:N and C:P ratios of the GM do not support this interpretation. Other controlling factors as yet unidentified may have been responsible for the greater apparent stability of P in the GM residues. Nevertheless, the actual amounts of P released from the GM residues were much greater than from the rice, forage grass or legume residues, principally because of the greater initial P concentrations (Fig. 3). Half-lives of legumes (GM and forage legume) were generally shorter than grass or rice residues. Mixing of forage litters with different decomposition rates (the grass and the legume) did not result in any synergistic or inhibitory effects on decomposition or nutrient release; rates of the mixtures were equal to the mean of the rates of individual components (data not shown).

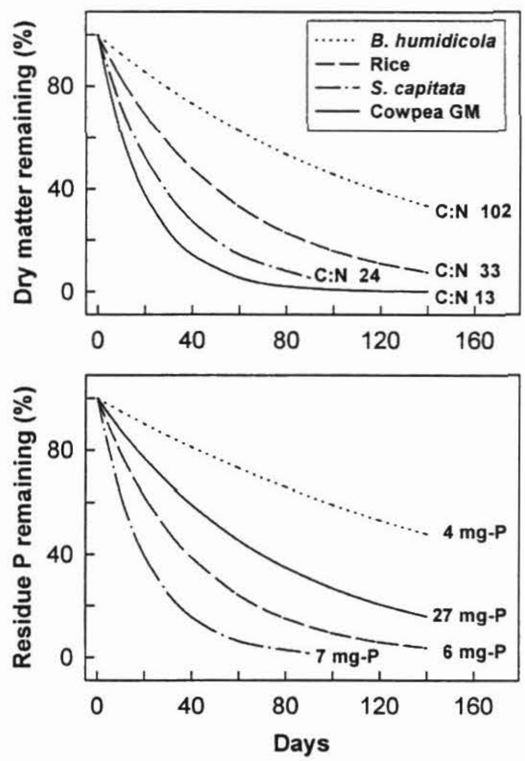

Fig. 3. Relative amounts of dry matter and phosphorus remaining in residues of *B. humidicola* , rice straw, *S. capitata* and cowpeas GM during incubation of litter bags placed on the soil surface. Curves are fitted exponential decay functions (see text); values in figures are initial C: N ratios and P contents of residues.

Burial of residues in the soil markedly stimulated decomposition and nutrient release. The decomposition rate of cowpea GM, for example, was increased more than two-fold and half-life declined from 63 days to 14 days. The effect on rice residues was less dramatic with the half-life declining from 64 days to 37 days. P release rates were similarly increased by incorporation.

P cycling in contrasting systems

In general in all systems, the labile Pi fractions (resin-Pi, Bic-Pi and NaOH-Pi) were most sensitive to fertilizer P inputs (Fig. 4). Po fractions were generally stable throughout the year with significant variations occurring only in the monocrop rice and rice-GM systems as short pulses in Bic-Po concentrations. The first followed the pulse in Pi pools due to fertilization in April and the second followed the incorporation of GM in October (both corresponding to a slight and simultaneous decline in Bic-Pi). NaOH-Po concentrations moved within a narrow range during the year and no significant differences in short-term P dynamics among systems were observed.

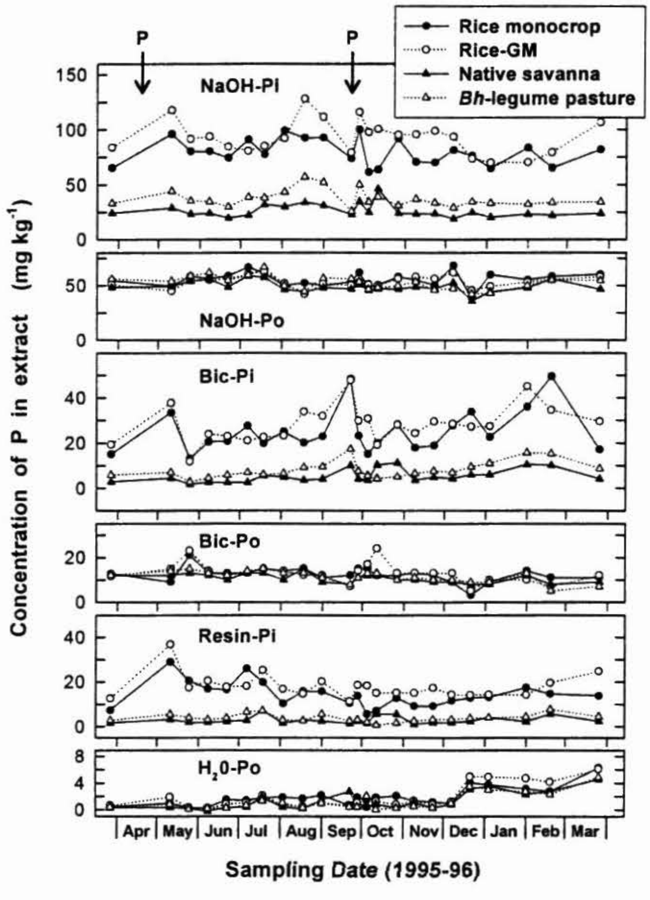

Fig. 4. Dynamics of P during one year (March 1995-March 1996) in labile inorganic and organic fractions (defined by the modified Hedley procedure) under four production systems including native savanna. The letter P and arrow indicated dates of P fertilizer application and sowing of crops.

Overall effects of systems on P partitioning during the initial 3-years followed trends similar to the seasonal dynamics with most applied P flowing into labile Pi fractions (Table 1). The only labile Po pools significantly affected were those extracted by NaOH. There was also significant but comparatively less movement of P into the more recalcitrant forms extracted by stronger acidic reagents (in particular, HCl_{hc} as well as residue-Pt). In relative terms (percent of total P), increases were observed in the resin-Pi, Bic-Pi and NaOH-Pi fractions while NaOH-Po and residue-Pt declined relative to the NS system.

Table 1. Distribution of P in various fractions in different production systems with and without P application on a silty clay Oxisol three years after establishment on native savanna at Carimagua.[a]

System	Resin-H_2O Pi	Resin-H_2O Po	Bicarbonate Pi	Bicarbonate Po	NaOH Pi	NaOH Po	HCl 1M Pi	HCl hc Pi	HCl hc Po	Residue-Pt	Total P
					(milligrams of P per kilogram of soil)						
Native savanna	4a	4	6a	8a	20a	44a	0	33A	7	54a	181a
Bh-legume pasture	4a	3	11ab	9ab	33a	43a	1	40A	9	59bc	212a
Rice monocrop	13b	4	23bc	9b	65b	60b	1	49B	9	56ab	289b
Rice-GM	14b	5	27c	10b	70b	49ab	4	51B	8	62c	300b
					(percent of total P)						
Native savanna	2a	2	3a	4a	11a	24a	0	18	4a	30a	100
Bh-legume pasture	2a	1	5ab	4a	16a	20ab	1	19	4a	28a	100
Rice monocrop	4b	1	8bc	3b	22b	21ab	0	17	3b	20b	100
Rice-GM	5b	2	9c	3b	23b	16b	1	17	3b	21b	100

[a]values within a column followed by the same letter (or no letter) do not differ significantly ($p < 0.05$) according to Duncan's test.

Discussion

Soil-as-a-source, roots, biomass, litter/residues and soil-as-a-sink are the major components through which P and other nutrients cycle in natural and agricultural ecosystems. Processes within and interactions between these components determine the efficiency of P cycling or loss. P acquisition by plants depends on root system size and distribution, P uptake kinetics and P mobilizing capacity (Barber, 1984). Whereas deep-rootedness is advantageous in the recovery of nutrients which move to depth in soil, P is generally concentrated in the surface soil layer and is very immobile in highly weathered tropical soils. Consequently, a shallow rooted crop with greater root length density may be more efficient at P recovery. Maize root growth and distribution in the present study was diminished in subsoil layers by low P availability and high Al toxicity, even though this variety (Sikuani 3) is apparently adapted to highly acidic soils (Pandey et al., 1994). Despite having a smaller proportion of roots in the surface layer, the overall size of the forage root systems in comparison to maize allowed the pasture to explore a much greater volume of soil, particularly subsoil layers. Consequently, P uptake by the *Bh*-legume pasture (underestimated since it is based on a single biomass sampling of the pasture and does not consider animal consumption or senescing forage tissue) was 4-5 times greater than maize in relation to the available P content (Bray-2) in the surface soil (3.1 *versus* 0.70 kg P kg^{-1} Bray-P). The substantially greater root growth of *Bh*-legume pasture into the acidic, very low P subsoil layers reflects the greater capacity of forages to mobilize and take up P from soils (Rao et al., 1997b).

Acquired P in crop residues and forage litter re-enters the cycle when residues decompose in soil. Since P loss from systems occurs mainly through processes in the soil, minimizing P interaction with soil is an important management tool for increasing P cycling. Residue quality and management is a component of this strategy. We have seen in the present study considerable differences in decomposition and P release rates among residue/litter types, as might be expected from their initial compositions in terms of %N, %P and amounts of lignin (e.g. Thomas & Asakawa, 1993). Differences in release rates may be of lesser importance in pastures where active roots are always present to recover P released from decaying litter. In systems involving crops, however, the crop root system may not be sufficiently developed to recover P released from the preceding crop's residues. For rice, the P release pattern of surface applied residues suggests that <60% will be available to the following cowpea crop (or alternative components) in a rotational system. For rice monoculture, complete release within 4 months implies unimpeded interaction with soil for perhaps 6 months before the next crop root system is sufficiently developed to acquire it. Clearly, residue incorporation will aggravate the problem by stimulating decomposition through increased soil-microbe-litter contact.

P maintained in organic pools may be better protected from loss through fixation than P flowing through inorganic pools in soil. P enters organic pools by crop assimilation and the subsequent decay of derived residues and roots, or through immobilization by soil microbes. Thus, systems which acquire more P and produce more residues may be expected to have more influence on soil Po pools. In this study, there is some evidence of Pi immobilization into the Bic-Po fraction following fertilization as well as pulses of Po into the Bic-Po fraction which coincided with root senescence at harvest and GM incorporation. However, all fluxes into Po fractions were very transient suggesting that the pools they represent are all highly labile. In fact, the changes in the relative pool sizes observed over the course of this study suggest that P flowed preferentially into labile Pi pools and then more slowly into Po pools.

These observations differ from earlier ones in an adjacent 16-year-old grazing experiment in which P status in fertilized *B. decumbens* CIAT 606/Kudzu pastures was compared with native savanna (Oberson et al., 1995). As above, both NaOH-Pi and -Po fractions as well as HCl_{hc}-Pi were significant sinks for P fertilizer applied to the improved pasture. However, in relative terms, partitioning of the applied P in soil under *B. decumbens* pasture was similar to the distribution of P in the virgin soil under savanna. This suggests that, in the longer term (in this case, 16 years vs 3 years), P may be redistributed from labile inorganic to less labile organic pools through cycling processes (Rao et al., 1997a). Forage plants with their large and efficient root systems must play an important role in this process. The results of these studies together imply that (a) the residence time of P in the most labile organic pools is very short and that, consequently, P cycling through them is very rapid, and (b) the residual effectiveness of P inputs is high with low rates of "fixation" into the more stable P forms. This observation is supported by the high residual value in P fertilizer measured in associated experiments underway at the same site (D. Friesen, *unpublished data*). The effectiveness of the different systems in acquisition and cycling P will continue to be monitored in these long term experiments.

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4. PROGRESS REPORT

OUTPUT 1. PLANT COMPONENTS CHARACTERIZED FOR EDAPHIC ADAPTATION AND ENHANCED PRODUCTIVITY

Introduction

Characterizing and selecting plant components for use in production systems has been a traditional activity within the centre. This work continues here in output 1 and follows the approach of the new soil research paradigm whereby germplasm is adapted to adverse soil conditions (see also Output 2). New efforts are under way to select perennial nitrogen-fixing species which can contribute N to the soil and bring other benefits such as a deep rooting habit. This activity comprises part of the search for nutrient use efficiency required for limited input systems along with studies on root morphology and functioning and nutrient requirements of adapted plants.

Highlights

- Defined lime, magnesium and potassium and requirements for acid-soil tolerant varieties of rice, maize, cowpea and soybeans in rotational production systems on medium-textured Oxisols
- Quantified the residual effectiveness and maintenance requirements of lime applications to medium-textured savanna Oxisols
- Showed that crop potassium requirements on medium-textured savanna Oxisols were less than 50% of current recommended levels of application
- Determined that the balanced nutrition of annual crops in rotations was not significantly affected by antagonistic interactions although efficient use of nutrients depends on the removal of other nutritional constraints.
- Evaluation of nodulation and growth of 17 sp of shrub/trees legumes identified *Enterolobium* sp. and *Piptademia* sp. as fastest growers. Both species could benefit from further rhizobia strain selection studies
- Chicken manure increased nodulation of most green manures tested
- Calopogonim spp. responded greatly to manure; Mucuna spp. did not respond to manure
- Showed that the presence of the legume (*Pueraria phaseoloides*) in association with the grass (*Brachiaria decumbens*) could improve the acquisition of nutrients (N, P, K and Ca) from low fertility soils.
- Showed that increase in stocking rate could stimulate fine root production and increase partitioning of nutrient s to roots.
- Showed that the size of the field-grown upland rice root system was greater than that of the maize.
- Showed that the elephant grass with its large root system can serve as an effective grass barrier to reduce soil erosion in Andean hillsides
- Showed that the root growth and distribution of field-grown maize was greater when it was rotated with soybean as a grain crop in the Colombian Llanos.
- Harrowing increases soil compaction in surface soil layers

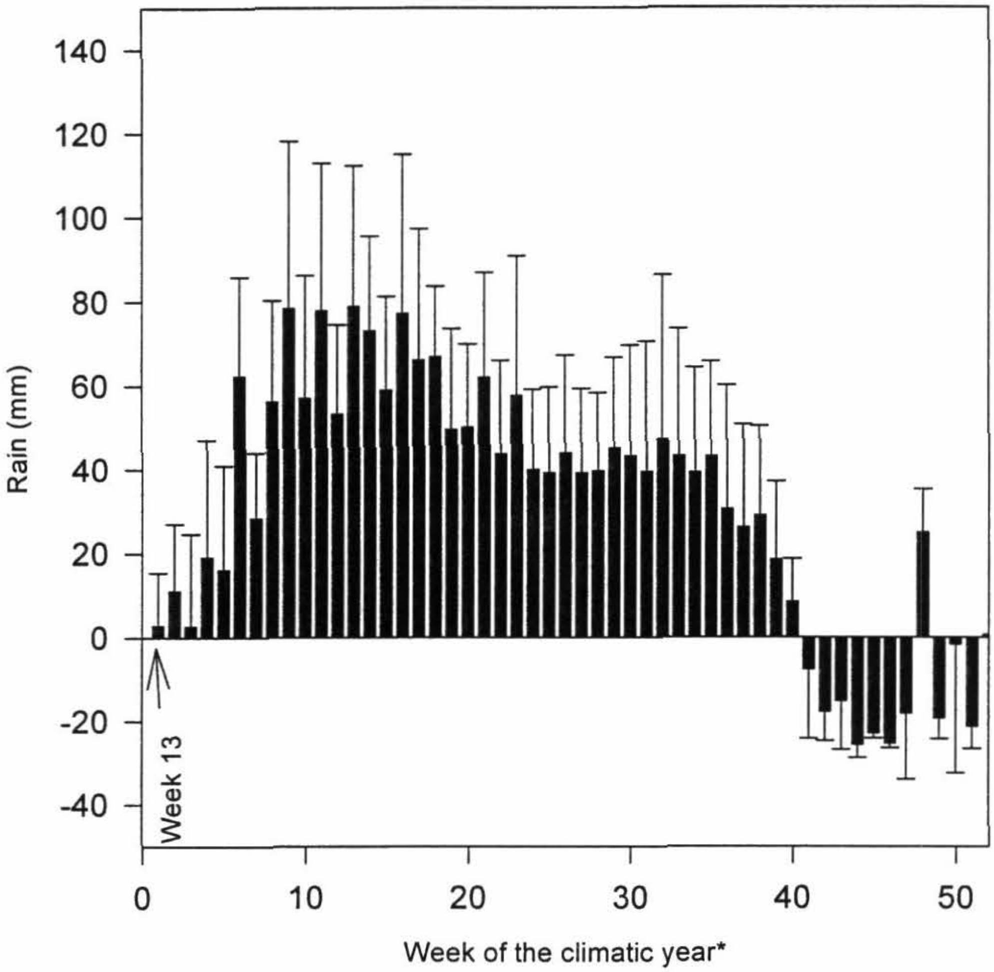
Output 1 – ***Activity i) Compile and collate climatic data and analyze them in an agronomic base.***

Hydric balance of Sta Rosa (Llanos Piedmont)

The atmospheric hydric balance together with the physical characteristics of the soil surface, determine the amount of water that can enter the soil and affect its water storage capacity and run-off yields. The atmospheric hydric balance (precipitation - evaporation *0.75) of Sta Rosa, located at the Piedmont of the Llanos, is shown in fig. 1 within confidence limits of 95%. From the figure it is clear that there are two well defined seasons. One, the wet season, starts in the 13^{th} week of the year (beginning of March, first bar in the figure) and ends in December and a dry season that starts in December and ends in the first week of March. To construct the figure week 13 was taken as the first week of the climatic year; considering that by that time the soil is dry and will accept water with the beginning of the rainy season.

Considering the wetting process of the soil, there will be enough water to moisten it from the 5^{th} week (first bar in the figure, week 18 in the calendar) to the end of the rainy season. However, it will be the sorptivity and the infiltration rates that regulate the water entry into the soil and both of these parameters are usually low. Additionally, if there is some slope, much of this water could be lost by runoff. It is convenient to determine rainfall acceptance capacity of the different soils and management systems influenced by the climatic conditions of the Santa Rosa station.
[E. Amézquita, D. Peña, L. F. Chavez]

Fig 1. Hydric balance of Sta. Rosa. Piedemont. Confidence limits 95%



* Starting on week 13

Output 1 - ***Activity i) Nutritional constraints and requirements of crop components in annual rotations of medium textured Oxisols***

Highlights

- Defined lime, magnesium and potassium and requirements for acid-soil tolerant varieties of rice, maize, cowpea and soybeans in rotational production systems on medium-textured Oxisols
- Quantified the residual effectiveness and maintenance requirements of lime applications to medium-textured savanna Oxisols
- Showed that crop potassium requirements on medium-textured savanna Oxisols were less than 50% of current recommended levels of application
- Determined that the balanced nutrition of annual crops in rotations was not significantly affected by antagonistic interactions although efficient use of nutrients depends on the removal of other nutritional constraints.

Intensified agricultural production on the Oxisols which dominate the tropical savannas of South America is constrained principally and initially by deficiencies in most major and many minor nutrient elements. Retention of mobile nutrients is poor due to the very low, pH-dependent cation exchange capacities of these soils and the high incidence of rainfall which they usually receive. On the other hand, nutrients such as phosphorus are retained very strongly through surface reactions with iron and aluminum oxides which can rapidly reduce their availability.

New crop cultivars developed by CIAT and its partners are more adapted to the edaphic constraints of highly infertile and acidic Oxisols but their nutritional requirements are poorly defined. In 1993, CIAT initiated a long-term production systems experiment on Oxisols on the Colombian savannas at Carimagua incorporating adapted crop components in various rotations. Simultaneously, satellite experiments were established to

- define the nutritional constraints (lime [Ca], Mg, K and P) of these components and determine their balanced requirements for efficient utilization of inputs
- quantify the dynamics of nutrient cations, and Al and pH, in soil profiles and the interaction of amendments on nutrient fluxes and fate.
- characterize the fate of P applications (uptake by crop, removal in products, immobilization in organic matter, reversion to less soluble inorganic phases).
- determine the residual effectiveness of nutrient inputs and requisite maintenance rates for optimal crop growth.
- Develop and modify models of P dynamics and residual value in highly weathered soils.

These experiments included:

- cation balance experiments involving levels of calcitic lime, magnesium and potassium in an incomplete factorial
- phosphorus residual value experiments comparing rates of annually applied and residual TSP

These experiments were established at two sites on silty clay loams (tropeptic haplustox) at Carimagua and Matazul. Maize (cv. Sikuani CV110)-soybean (cv. Soyica altillanura 2) rotations were planted at Carimagua whereas rice (cv. Sabana 6)-cowpea (cv. ICA Cabecita negra) rotations were sown at Matazul. Cation balance experiments have been concluded at Carimagua (1993-96) and Matazul (1993-1995) and results are summarized in Figure 2

Soil acidity constraints and lime response

Levels of Al saturation in the unbroken native savanna soils at Carimagua and Matazul were 85-90%. The different crop species displayed varying degrees of tolerance to the severely acid soil conditions (Fig. 2 a-d). "Sabana 6" rice consistently produced well even without lime and did not respond to additions greater than 150 kg/ha. Cowpea, grown in rotation with Sabana 6 rice, was less tolerant of acid soil but nevertheless did well with the minimum inputs applied to the rice. Both the acid-soil tolerant maize variety ("Sikuani V110") developed by CIMMYT and the CORPOICA soybean line ("Soyica altillanura 2") required substantial inputs of lime to realize their full yield potential. Moreover, responses to the residual lime applications increased over the 3-4 year period. Declining response corresponded to loss of exchangeable Ca and increasing exchangeable Al saturation, especially at the lower lime rates (see below). Although not measured, declining labile organic matter levels and their potential to complex toxic Al in soil solution may also have contributed. Regular maintenance application of lime combined with methods for conserving organic matter are therefore indicated for sustained yields of these more susceptible rotations.

Potassium constraints and requirements

Three to four years of data derived from repeated annual applications suggest that K deficiency in annual crops is not as severe as previously assumed. Results at both sites indicate maintenance rates of approximately 40-50 kg K/ha applied in three equal splits to the rice or maize crop in the rotation (Fig. 2 e-h). These K requirements are substantially less than the levels of fertilization (typically, 100 kg K/ha/year) adopted in the systems trials at Carimagua and Matazul. Furthermore, this rate generally provided sufficient residual effectiveness to support the subsequent grain legume crop in the rotation without further additions. In some cases (e.g., soybeans after maize), the strong K responses in the first year declined over the three years as soil K fertility was built up by K applications. These observations are consistent with the presence of small amounts of K fixing Al-interlayer vermiculite clays in these Oxisols which both to reduce fertilizer requirements and losses by leaching.

Magnesium constraints

Severe magnesium deficiency, previously recognized in rice in agropastoral systems trials at Matazul, was confirmed in both rice and cowpea in the rotations experiment where responses were observed up to the maximum 60 kg Mg/ha applied (Fig. 2 i-l). Magnesium response in maize and soybean at Carimagua was either absent or weak but increased over the 3-year period. Whereas Mg deficiency may be addressed with moderate inputs of dolomite lime applied to the more acid-soil sensitive crops such as maize and soybeans, the low rates applied to rice and cowpeas may be insufficient and require supplementation with a soluble Mg source.

Cation balance

Statistical analyses revealed no significant interactions among lime (Ca), Mg and K in the growth and yield of any of the crops on the two soils. That is, deficiencies of Mg or K were not induced or exacerbated by increasing levels of calcitic lime, as might be expected with a severe nutrient imbalance. Although soil analyses indicate improved retention of Mg and K on soil cation exchange sites, liming did not significantly improve response to given levels of applied Mg or K (see below).
[D. Friesen, C.G. Meléndez, D. Molino, M. Rivera]

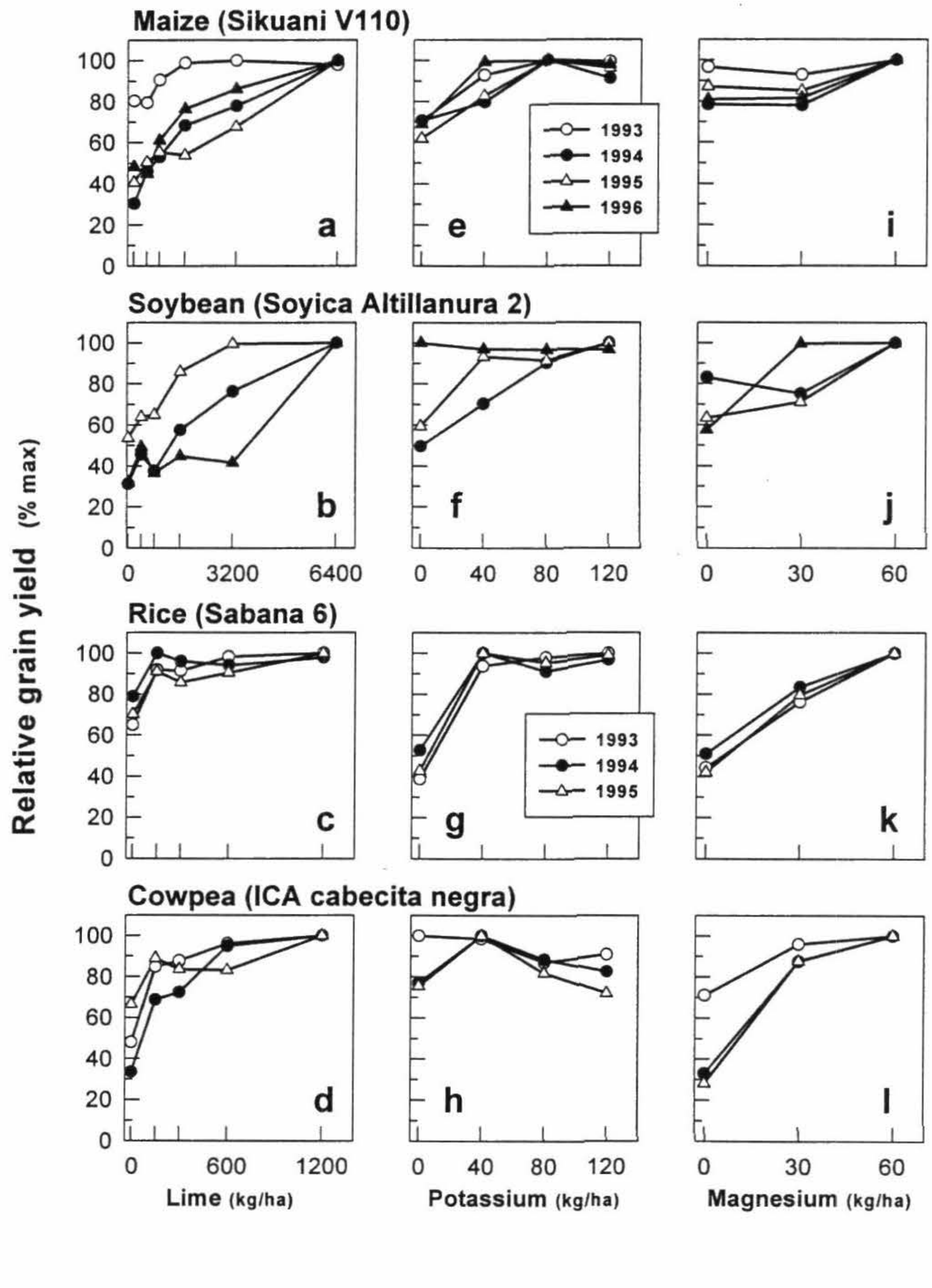


Figure 2. Nutrient constraints and requirements of acid-soil tolerant cultivars in rotational systems on Colombian savanna Oxisols over 3-4 years. (lime as calcite applied at establishment; K and Mg applied annually.)

Output 1 ***Activity ii) Characterize plant components for production potential and nutrient use efficiency***

Highlights

- Evaluation of nodulation and growth of 17 spp. of shrub/trees legumes identified *Enterolobium* sp. and *Piptademia* sp. as fastest growers. Both species could benefit rom further rhizobia strain selection studies.

Evaluation of herbaceous and shrubby/tree legumes for multiple uses in the hillsides and savannas of Colombia

The multiple use of herbaceous and shrub/tree legumes is a relatively new area for CIAT as previously species were evaluated for forage only. There is an increasing demand for legume ground covers, green manures, shrubs and trees in both the hillside and savanna agroecosystems for multiple purposes including shade for animals, fencing and other wood products, soil conservation and erosion barriers. A nitrogen-fixing tree brings the added benefit of serving as a source of N input into the system. Knowledge of nitrogen fixing capacity and ability to nodulate in different soils is scarce. Evaluation studies were therefore initiated in Pescador-Cauca (hillsides) and Carimagua (savannas).

Evaluations at Carimagua

Seventeen legume species were chosen from different sources including the gallery forests in the savanna and the Genetic Resources Unit at CIAT. The legumes were sown in a nursery with 3 treatments; + inoculation with a mixture of rhizobia strains
isolated from the same sub-family, no inoculation, and + N fertilizer at 150 kg N/ha.

The seedlings were transplanted into the field Table 1 shows the plant heights obtained after a 6-month period. The results can be grouped into four categories;

1. Species that showed no differences amongst the 3 treatments and which grew very slowly without demonstrating nutrient deficiencies or insect and pest damage: *Copaifera sp.*

II. Species that nodulate with native species and grew equally well as those receiving N fertilizer i.e. do not require inoculation: *Pithecellobium sp.* 31 and 54, *Hymeanea sp.*

III. Species that responded to inoculation, outgrowing the uninoculated treatment and growing as well as the +N fertilizer treatment: *Calliandra calothyrsus, Enterolobium sp.*

IV. Species that require further rhizobia selection as they grew better or equal to the uninoculated treatment but grew less than the +N fertilizer treatment: *Erythrina sp., Dioclea spp., Cassia grandis, Piptadenia sp., Pterocarpus sp., Coumarouna sp, Inga sp., Ormosia sp.*

The fastest growing species (> 1 m height in 6 months) were *Enterolobium sp.* and *Piptadenia sp.* Intermediate species growing to a height 50 to 100 cm included *C. calothyrsus, Inga sp., Coumarouna sp., Cassia grandis,* and *Pithecellobium sp.* 31. Slow growing species included *Ormosia sp., Erythrina sp., Pterocarpus sp. Dioclea sp., Pithecellobium sp.* 54, *Hymeneae sp.*, and *Copaifera sp.*

A *Tamarindus sp.* failed to grow and was discarded.
[N. Asakawa, I. Corrales, G. Ocampo, M. Rondon, R. Thomas]

Table 1. Shrub/tree heights in cm, 6 months after transplantation to the field at Carimagua.

Species	- Inoculation	+ Inoculation	+ N fertilizer
Group I			
Copaifera sp.	11.3	13.4	14.2
Group II			
Hymenaea sp.	23.0	11.9	21.2
Pithecellobium 31	55.5	15.5	53.0
Pithecellobium 54	23.1	15.5	17.6
Group III			
Enterolobium sp.	119.9	150.7	150.8
Calliandra Calothyrsus	35.6	82.1	78.2
Group IV			
Erythrina sp.	24.2	15.8	40.9
Dioclea sp.	3.7	-1.8	2.7
Dioclea sp. 40	14.3	16.0	30.0
Cassia grandis	29.7	16.4	55.2
Pterocarpus sp.	32.9	35.0	44.1
Piptadenia sp.	86.7	98.5	139.5
Loumarouna sp.	27.5	22.2	59.5
Inga sp.	39.0	42.8	69.0
Ormosia sp.	10.9	23.7	45.8

Evaluations of legume ground covers, green manures and shrubs/trees at Pescador-Cauca

Highlights

- Chicken manure increased nodulation of most green manures tested
- Callopogonim spp. responded greatly to manure; Mucuna spp. did not respond to manure

The hillside environment suffers from problems of erosion and nutrient depletion. There is increasing interest in plants that rapidly cover the ground and those that can serve as a green manure following the successful use and adoption of *Mucuna* in Southern Brazil and Central America. Adoption studies from elsewhere indicate that farmers require fast growing species that rapidly complete ground cover, have relatively little interference with a grain or other cash crop, reduce weed competition, survive through dry periods and are easy to manage in terms of labor. In addition seed supplies may be a limiting factor.

There is little information on which legumes are suitable with the choice restricted mainly to *Mucuna pruriensis*. There are no clear guidelines on the amounts of biomass produced or on what target levels should be set. In addition there is little or no information on the amounts of nitrogen fixed, if there is a need to inoculate with rhizobia or what is the fate of the fixed nitrogen in the system.

Here we report results of an initial study to determine the inoculation requirements of species under glasshouse conditions. The species selected were mainly those under field trials in Brazil.

Soil was collected from the Pescador-Cauca valley hillsides site (pH 6.1, 15.8% OM, 8 ppm P, 4275 total N) and placed in black plastic polypropylene bags. The species list and rhizobia strains used are shown in Table 2.

Table 2. Species and rhizobium strains used.

Species	CIAT rhizobium strain
Herbaceous	
Calopogonium mucunoides CIAT 8113	543+770+4575+4197
C. mucunoides CIAT 17851	1223
Canavalia brasiliensis CIAT 17009	429+453
C. ensiformis CIAT 715	273+4461
Crotalaria juncea CIAT 21709	234+3666+4461
Mucuna pruriensis CIAT 21686	3864+29+180
Shrubs/trees	
Calliandra calothyrsus CIAT 20400	4910
Indigofera constricta	5071
*Flemingia con*gesta	4099

Plants were evaluated with 5 treatments and 3 replications per treatment:

1. No inoculation
2. With inoculation
3. With N fertilizer

4. With inoculation and with chicken manure
5. No inoculation with chicken manure

Chicken manure was included as this is commonly used by farmers in the region for trees and crops. The approximate rate used is 6 tons/ha equivalent. Treatments 1 to 3 received no other fertilizer except 3, which received 60 kg N/ha in the form of urea-N. Chicken manure contains 3.13% N, 1.98% P and 3.67 % K and was applied at rates equivalent to 188 kg N/ha, 119 kg P/ha and 220 kg K/ha. Plants were inoculated with rhizobia as a liquid inoculant on transplanting from germinating paper to the plastic bags. Plants for which there was no previous information on inoculation requirements received a mixture of strains (Table 3) others received the recommended strain.

Nodule numbers, size and distribution were noted 6 and 12 weeks after sowing. Dry weights of roots and aboveground material were also measured while total N was measured in tops only.

Results and conclusions

Results were similar after 6 or 12 weeks and only the latter are presented here.

Calopogonium mucunoides CIAT 8113 and CIAT 17851

There was little nodulation with or without inoculation or plant growth in +/- inoculation or +N fertilizer treatments of either ecotype (Table 3). Addition of chicken manure however had a dramatic effect on plant growth and nodulation even in the absence of inoculated strains. The effect of inoculation with chicken manure was slightly greater with CIAT 8113 compared with CIAT 17851.

Canavalia brasiliensis and *Canavalia ensiformis*

C. ensiformis outperformed C. brasilensis for most treatments (Table 3) Chicken manure increased plant growth and nodulation especially with C. ensiformis with inoculation compared with the other treatments. It is of interest to note that the N applied in chicken manure had little effect on nodulation compared with the urea fertilizer treatment. Nodulation with chicken manure only (- inoculation) was better than inoculation without manure for C. brasiliensis. Greatest nodulation was observed with both ecotypes receiving inoculation plus chicken manure.

Crotalaria juncea

Chicken manure also increased nodulation compared with the other treatments with greatest growth occurring with the inoculated plus chicken manure treatment (Table 3).

Mucuna pruriens

The two ecotypes, CIAT 21883 and CIAT 21686, behaved differently from the other plant species tested. Chicken manure had a negative effect on plant growth both total N and dry weight per plant (the latter not shown here). The native rhizobia present appears to be effective with this plant (- inoculation compared with + inoculation or + N fertilizer). Also of note was the increase in nodulation in CIAT 21686 with inoculation plus chicken manure. This effect was not observed with CIAT 21883.

Calliandra calothyrsus

Best growth was obtained with inoculation plus chicken manure; nodulation was also greater with this treatment. Growth was poor in the absence of or presence of N-fertilizer suggesting a severe limitation of another nutrient, which is supplied with chicken manure.

Flemingia congesta

Growth only occurred with chicken manure. Inoculation with chicken manure greatly increased nodulation (Table 3).

Indigofera constricta

Chicken manure plus inoculation increased nodulation four fold compared with the other treatments. Little or no growth occurred in the absence of chicken manure.

Conclusions

1. With the exception of *Mucuna pruriens* chicken manure increased biomass and nitrogen production in all species tested.

2. The normal need-to-inoculate treatments (treatments 1 to 3) indicate that some factor(s) other than N is limiting growth, which is supplied in chicken manure.

3. The N sources in chicken manure do not appear to be detrimental to nodulation. This is in contrast to the normal observation that N-fertilizer, predominantly nitrate-N, is inhibitory to nodulation in legumes.

4. Native strains of rhizobia in the soil used do not appear to be effective with *Crotalaria juncea, Canavalia ensiformis, Indigofera constricta,* and *Flemingia congesta*. Further strain selection is required. The other species tested are effectively inoculated with native strains.

Further studies

The role of chicken manure and identification of available nutrient sources needs to be investigated and in particular the form of N, which does not appear to inhibit nodulation, needs to be further characterized. Ammonium-N is likely to be the most readily available form of N from manure and its uptake and transformation into other N sources needs to be quantified. The results obtained are similar to those reported in Brazil for the establishment of legume trees on severely degraded soils where cow manure was the principal amendment used and where phosphorus was the principal limiting nutrient (Franco et al., 1994).
[N. Asakawa, G. Ocampo, R. Thomas]

Table 3 Effect of inoculation and chicken manure on nodulation and plant-N.

Species	Treatment	% N	mg N.pl^{-1}	No. of nodules pl^{-1}
Calopogonium mucunoides CIAT 8113	- Inoculation	2.77	19.09 b	0
	+ Inoculation	2.69	27.06 b	0
	+ Nitrogen	3.15	16.67 b	0
	+ Inoc + Manure	3.13	421.35 a	946
	- Inoc + Manure	3.08	371.93 a	359
C. mucunoides CIAT 17851	- Inoculation	2.70	16.98 b	0
	+ Inoculation	2.68	25.84 b	21
	+ Nitrogen	3.64	28.92 b	0
	+ Inoc + Manure	2.98	402.17 a	518
	- Inoc + Manure	3.64	390.53 a	394
Mucuna pruriens CIAT 21883	- Inoculation	2.61	463.23 a	29
	+ Inoculation	2.04	134.93 b	55
	+ Nitrogen	2.44	451.01 a	41
	+ Inoc + Manure	2.20	116.00 b	45
	- Inoc + Manure	1.38	70.24 b	11
M. pruriens CIAT 21686	- Inoculation	2.50	510.00 a	12
	+ Inoculation	1.71	123.42 b	15
	+ Nitrogen	2.53	608.30 a	20
	+ Inoc + Manure	1.63	128.70 b	72
	- Inoc + Manure	1.80	101.35 b	7
Canavalia ensiformis CIAT 715	- Inoculation	2.17	185.68 b	44
	+ Inoculation	1.81	164.30 b	210
	+ Nitrogen	2.21	254.22 b	18
	+ Inoc + Manure	2.61	857.09 a	375
	- Inoc + Manure	3.14	202.90 b	134
C. brasiliensis CIAT 17009	- Inoculation	1.95	125.53 b	52
	+ Inoculation	2.21	127.22 b	43
	+ Nitrogen	2.06	114.08 b	9
	+ Inoc + Manure	2.91	644.08 a	282
	- Inoc + Manure	3.84	651.09 a	156
Calliandra calothyrsus CIAT 20400	- Inoculation	2.38	18.63 b	0
	+ Inoculation	2.19	19.55 b	0
	+ Nitrogen	2.98	30.73 b	0
	+ Inoc + Manure	2.95	232.06 a	67
	- Inoc + Manure	2.58	175.70 a	30
Crotalaria juncea CIAT 21709	- Inoculation	2.74	39.27 b	3
	+ Inoculation	2.47	32.85 b	23
	+ Nitrogen	4.10	28.32 b	0
	+ Inoc + Manure	2.44	273.20 a	185
	- Inoc + Maure	3.18	25.16 b	79
Flemingia congesta	- Inoculation	3.80	4.81 c	0
	+ Inoculation	3.61	9.10 c	1
	+ Nitrogen	4.26	5.51 c	0
	+ Inoc + Manure	3.93	201.41 a	105
	- Inoc + Manure	3.86	66.19 b	3
Indigofera constricta	- Inoculation	4.28	4.91 b	0
	+ Inoculation	3.97	9.71 b	2
	+ Nitrogen	5.41	8.69 b	0
	+ Inoc + Manure	3.23	133.66 a	38
	- Inoc + Manure	4.66	36.76 b	2

Values followed by the same letter are not significantly different (Duncan $p<0.05$).

Output 1 - ***Activity ii: Characterize components for production potential and nutrient use efficiency***

Determine differences in plant growth and nutrient use efficiency among native and introduced pasture systems

Determine differences in shoot and root attributes among native and introduced pasture systems in the Llanos

Highlights

- Showed that the presence of the legume (*Pueraria phaseoloides*) in association with the grass (*Brachiaria decumbens*) could improve the acquisition of nutrients (N, P, K and Ca) from low fertility soils.

A field study was conducted to determine the differences in plant attributes that contribute to nutrient acquisition and utilization in native and introduced (16 year-old) grass alone (*Brachiaria decumbens* cv. Basilisk) and grass + legume (*Pueraria phaseoloides* cv. Kudzu) pasture systems in a clay loam Oxisol at Carimagua, Colombia. The introduced pastures were fertilized every two years (kg/ha: 10 P, 13 K, 10 Mg and 16 S) and have been under continuous grazing with seasonal adjustment of stocking rate (2 hd/ha in the wet season and 1 hd/ha in the dry season). The native savanna pastures received no fertilizer application and have been under grazing at 0.2 hd/ha stocking rate. Differences in shoot and root attributes of these native and introduced pastures were determined at the end of the rainy season.

Forage on offer was much greater in grass + legume pasture than that of the grass alone pasture (Table 4). The legume proportion in the association was 35% of the total. The root to shoot ratio of the grass alone pasture was greater than that of the grass + legume association. But the presence of the legume in an association not only contributed to N supply to the grass but also markedly improved the acquisition of nutrients, particularly Ca, K and P. Results on partitioning of nutrients to roots indicated that the amount of N partitioned to roots in grass + legume association was 7.56 kg/ha, compared to the value of 4.16 kg/ha of the grass alone pasture. These results indicate that the presence of legume in an association improves the cycling of nutrients in pastures via greater acquisition and utilization of nutrients. The utilization efficiency of nutrients by native savanna pastures was greater than that of introduced pastures.
[I. M. Rao, C. Plazas and J. Ricaurte]

Table 4. Differences in plant attributes among native and introduced grass alone (*Brachiaria decumbens*) and grass + legume (*Pueraria phaseoloides*) pastures in a clay loam Oxisol site at Carimagua.

Plant atrtributes	Pasture			LSD
	Native savanna	Grass alone	Grass+Legume	$P = 0.05$
Forage yield (kg/ha)	5239	3528	7592 (35)*	1984
Root biomass (kg/ha)	738	840	986	NS
Root: Shoot (g/g)	0.14	0.24	0.13	0.07
Root length (km/m^2)	4.32	4.03	3.97	NS
Shoot N uptake (kg/ha)	33.1	26.7	85.1	7.7
Shoot P uptake (kg/ha)	1.92	3.21	4.42	1.46
Shoot K uptake (kg/ha)	20.8	15.4	41.2	16.2
Shoot Ca uptake (kg/ha)	11.4	15.9	59.5	9.5
N use efficiency (g/g)	145	114	82	
P use efficiency (g/g)	2403	990	1545	
N partitioned to roots (kg/ha)	2.97	4.16	7.56	1.21
P partitioned to roots (kg/ha)	0.26	0.34	0.47	0.13

% of legume biomass in an association

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

In the Amazonian piedmont of Caqueta, Colombia, a field study is in progress in collaboration with CORPOICA-Macagual and the University of Amazonia. The objective of this investigation is to determine root growth and distribution and to test relationships among root growth, shoot growth and nutrient acquisition in native and introduced grass only and legume-based pastures during rainy season. Over grazing, subsoil compaction and low nutrient supply are three major factors leading to degradation of native and introduced pastures in the Caqueta region. Widespread adoption and utilization of introduced legume-based pastures in different production systems in this region will depend upon their rooting patterns that contribute to rapid establishment and efficient extraction and utilization of nutrients for growth. Pasture treatments selected for the study included: degraded native pasture, 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 nuntrient acquisition are being monitored under grazing.
[**Y. Conta Diaz, H. J. Baracaldo, G. Ruiz, C. J. Escobar, I. M. Rao and C. E. Lascano**].

Determine the influence of stocking rate on shoot and root attributes of introduced pasture systems in the savannas

Highligths

- Showed that increase in stocking rate could stimulate fine root production and increase partitioning of nutrients to roots.

A field study was conducted to determine the influence of stocking rate on plant attributes of introduced pastures that contribute to nutrient acquisition and utilization of *B.*

humidicola CIAT 679 (10 year-old) alone and *B. humidicola* + *Arachis pintoi* CIAT 17434 (6 year-old) association in a clay loam Oxisol at Carimagua, Colombia. Both pastures were grazed at three stocking rates (2, 3 and 4 hd/ha) using a flexible alternate system. The availability of *A. pintoi* on-offer in the rainy season increased over time (500 to 600 kg/ha after 4 years of grazing). Increase in stocking rate decreased the amount of forage on-offer of both pastures and the legume content in the association (Table 5). But increase in stocking rate stimulated root growth, particularly fine roots. Shoot nutrient uptake was lower with high stocking rate because of greater partitioning of nutrients to roots.
[I. M. Rao, C. Plazas and J. Ricaurte]

Table 5. Influence of stocking rate on shoot and root attributes of introduced grass alone (*B. humidicola* CIAT 679) grass + legume (*B. humidicola* + *Arachis pintoi* CIAT 17434) pastures in a clay loam Oxisol site at Carimagua, Colombia.

Plant attributes	Pasture	Stocking rate (hd/ha)			LSD
		2	3	4	$P = 0.05$
Forage yield (kg/ha)	Bh	8597	7006	5572	1652
	Bh + Ap	8904 (17)	4696 (13)	4792 (9)	2148(NS)
Root length (km/m^2)	Bh	5.88	9.73	10.6	2.79
	Bh + Ap	3.25	4.19	8.58	1.73
Sepecific root length (m/g)	Bh	54.1	58.5	77.1	22.3
	Bh + Ap	53.1	71.7	67.9	NS
Shoot N uptake (k/ha)	Bh	50.2	41.3	31.6	14.6
	Bh + Ap	97.5	50.0	38.9	30.3
Shoot P uptake	Bh	4.53	5.15	4.11	NS
	Bh + Ap	8.64	3.21	2.99	1.94
Shoot Ca uptake	Bh	19.3	18.8	12.3	5.4
	Bh + Ap	53.1	23.7	19.4	17.2
N partitioned to roots (kg/ha)	Bh	6.57	8.29	8.72	NS
	Bh + Ap	4.99	7.67	8.17	NS
Ca partitioned to roots (kg/ha)	Bh	1.09	2.21	1.85	0.77
	Bh + Ap	0.88	1.70	1.99	0.65

* % of legume biomass in association
Bh = *Brachiaria humdicola*; Ap = *Archis pintoi*.

Determine differences in plant attributes among cropping systems

Determine differences in shoot and root attributes of system components in the savannas

Highlights

- Showed that the size of the field-grown upland rice root system was greater than that of the maize.

Shoot and root attributes of field-grown upland rice (cv. Sabana 6) and maize (Sikuani V110) were determined during grain filling in a clay loam Oxisol at Carimagua (Table 6). Upland rice root production was not affected by either monoculture or by rotation with cowpea cv. ICA Cabecita negra (as grain crop) or forage cowpea cv. ICA Menegua (as green manure). But root production of maize was greater when rotated with soybean cv. Soyica Altillanura 2 (as a grain crop compared to soybean as green manure (GM). The amount of N partitioned to roots was greater in upland rice than maize in different systems.

The grain yield of upland rice and maize at harvest was not much affected by monocropping.
[**I. M. Rao, D. K. Friesen, C. G. Melendez and J. Ricaurte**].

Table 6. Differences in shoot and root attributes of upland rice and maize in upland rice-systems (monoculture, rotation with cowpea for grain, rotation with forage cowpea as green manure) and maize-systems (monoculture, rotation with soyabean for grain, soyabean as green manure) in a clay loam Oxisol at Carimagua.

Systems	**Plant attributes**						
	Grain yield (t/ha)	Shoot biomass (kg/ha)	Shoot N uptake (kg/ha)	Shoot P uptake (kg/ha)	Root biomass (kg/ha)	Root length (km/m$^{2)}$	N partitioned to roots (kg/ha)
Upland-rice-systems:							
Rice monoculture	3.22	3459	53.6	4.76	766	6.42	8.99
Rice – Cowpea (G)	2.52	4323	63.8	6.58	834	6.51	8.40
Rice – Cowpea (GM)	3.23	3261	47.8	4.64	846	639	9.96
Maize – systems:							
Maize monoculture	3.37	3795	41.7	6.36	310	2.78	2.77
Maize - Soyabean (G)	3.52	3236	33.5	4.83	637	3.60	6.87
Maize - Soyabean (GM)	4.23	3437	37.7	5.41	360	2.80	3.78

G = for grain; GM = as green manure

Determine differences in shoot and root attributes of system components in the Andean Hillsides

Highlights

- Showed that the elephant grass with its large root system can serve as an effective grass barrier to reduce soil erosion in Andean hillsides

Rooting characteristics of crop and forage components of crop-livestock systems in hillsides could have important effects on both nutrient acquisition and cycling, and on reducing 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 natural resource base. 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 (25-43%). Four treatments, cassava (*Manihot esculenta* cv. algodona) monocrop, cassava + cover legumes (*Centrosema acutifolium* CIAT 5277 and *Arachis pintoi* CIAT 17434), elephant grass (*Pennisetum purpureum* cv. Mott) pasture and imperial grass (*Axonopus scoparius*) pasture, 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.

Root biomass of cassava + cover legumes was 44% greater than that of cassava monocrop treatment. The presence of cover legumes not only reduced soil erosion but also improved potassium acquisition by cassava crop. Among the two grasses, elephant grass had greater root biomass (9.3 t/ha) than the imperial grass (4.2 t/ha). The greater root length density (per unit soil volume) of the former has contributed to significantly superior acquisition of nitrogen, phosphorus, potassium and calcium from soil. In addition, the abundance of very fine roots in elephant grass pastures in the top soil layers reduced the loss of soil from steep slopes. These results indicate that (i) the presence of cover legumes can improve nutrient acquisition by cassava crop; and (ii) elephant grass can be used as an effective grass barrier to reduce soil erosion in Andean hillsides.
[Qi Zhiping, I. M. Rao, J. Ricaurte, E. Amezquita, J. I. Sanz and P. C. Kerridge]

Output 1 - ***Activity iii) Determine rooting strategies of crop and forage components***

Differences in rooting ability of upland rice and maize grown as monoculture or in rotation with grain legumes or green manures

Highlights

- Showed that the root growth and distribution of field-grown maize was greater when it was rotated with soybean as a grain crop in the Colombian Llanos.

Knowledge of root distribution of field-grown crops is essential for designing improved crop/soil management pracices and for modelling nutrient and water uptake by crops. Crop growth and yield are controlled by the development and function of the root system. There is a lack of information on root distribution of upland rice and maize when rotated with legume crops. The objective of this study was to determine the influence of crop rotation on root length distribution of these two crops during grain filling when grown in a clay loam Oxisol.

Root length distribution (0-80 cm soil depth) was determined using core method. Roots from soil cores were washed free of soil using a hydropneumatic elutriation system. Root samples were scanned for length on a root-length scanner. Root length per unit soil surface area was calculated from total root length of a sample up to 80 cm soil depth and the surface area of the soil from which roots were collected. Differences in root length distribution by soil depth are shown in Fig. 3. Root length of upland rice cv. Sabana 6 and maize cv. Sikuani V110 decreased with the increase in soil depth (Fig. 3). But the ability to root in subsoil was markedly greater with upland rice than with maize. More than 55% of root length of maize was distributed in the top 0 to 10 cm soil depth. Root growth and distribution of field-grown maize was greater when it was rotated with soybean as a grain crop. Differences in subsoil rooting ability between upland rice and maize may be related to their ability to tolerate high levels of aluminum in subsoil layers. The ability of maize to root in subsoil layers could be improved by building an arable layer via cultivation and nutrient management.
[I. M. Rao, D. K. Friesen, C. G. Melendez and J. Ricaurte].

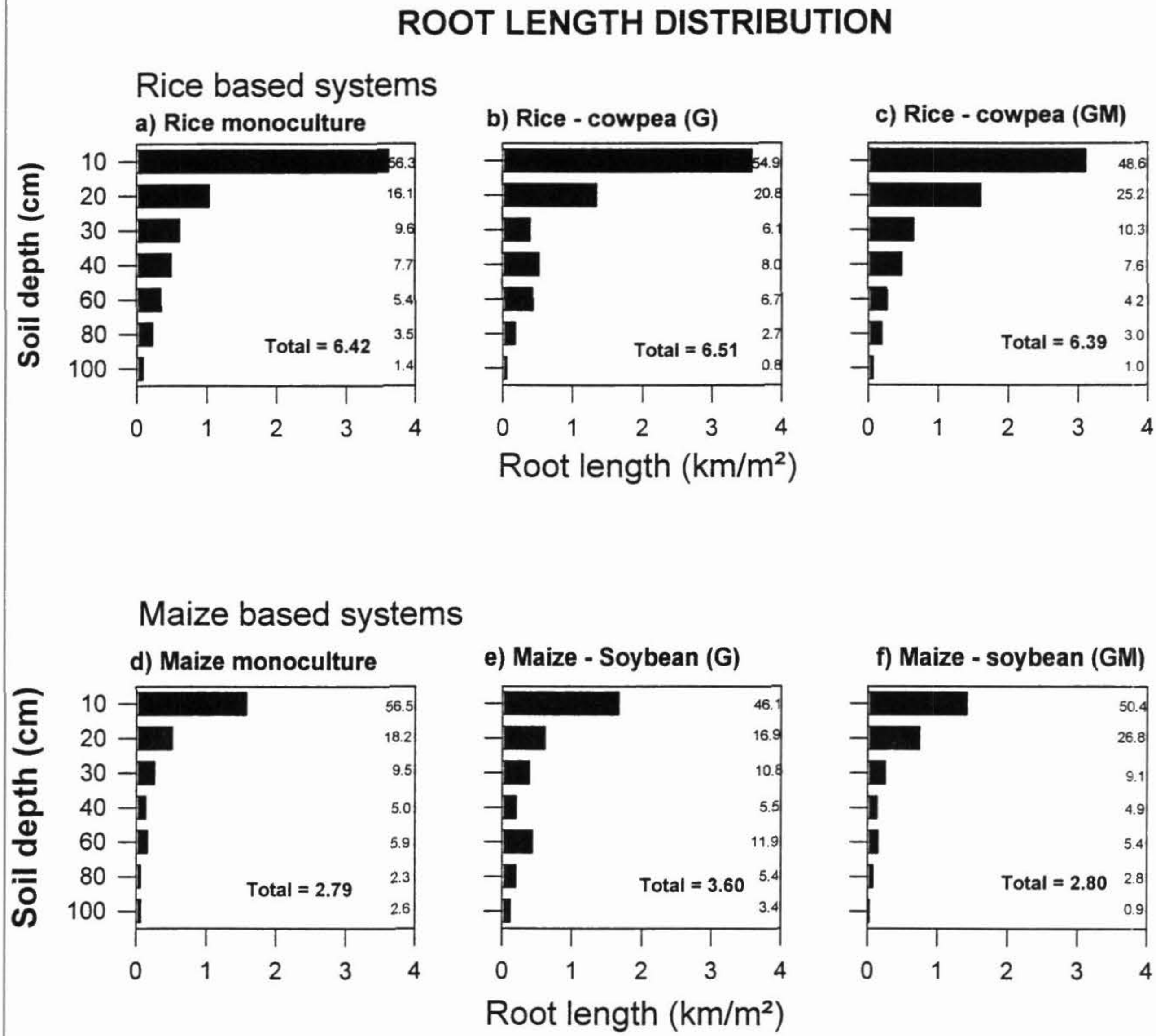


Figure 3. Differences in root length distribution of upland rice and maize by soil depth in upland rice-systems (monoculture, rotation with cowpea for grain, rotation with forage cowpea as gren manure) and maize-systems (monoculture, rotation with soybean for grain, soybean as green manure) in a clay loam Oxisol at Carimagua. Numbers to the right of graphs are the proportion (%) of total root length values at each depth.

Output 1 – ***Activity vi) Determine impact of systems on production and the resource base.***

Effects through time.of the intensive use of machinery on soil physical properties and in crop productivity

A field experiment on the influence of increasing number of harrowing passes on soil physical conditions is being conducted. The experiment started in 1995. The following number of harrowing passes have been applied to date: 0, 6, 12 and 24. The influence of the intensity of harrowing on bulk density is showing in table 7. The number of passes has affected bulk density. It is lower under the treatments than under native savanna in the first 0-5 cm. At 5-10 cm there are little changes but below 10 cm the use of the harrow has increased bulk density. This behavior is showing that when machinery is used on this soil it reduces bulk density where the discs are acting and increases it below the depths of discs causing compaction and therefore negatively affecting pore continuity.

Table 7. Influence of different number of harrowing passes on bulk density ($g.cm^{-3}$) at different depths.

Native savanna		N° of harrowing passes		
Depth (cm)	0	6	12	24
0-5	1.41	1.36	1.28	1.37
5-10	1.33	1.40	1.37	1.33
10-20	1.23	1.42	1.38	1.46
20-30	1.41	1.45	1.36	1.45
30-50	1.46	1.56	1.46	1.48
50-70	1.38	1.56	1.43	1.45

For the behaviour of bulk density in native savanna, one important aspect is the presence of a high value (1.41 $g.cm^{-3}$) in the top 0-5 cm, followed by lower values to a depth of 20 cm: 1.33 and 1.23 $g.cm^{-3}$ respectively. This means that the first layer exhibits less total porosity than the others and is regulating the entry of water and the flux of air into the profile. Therefore, for crop and pasture production this constraint must be avoided by an adequate tillage improves the top soil condition and reduces the risks of compaction at depth.

The effect of the number of harrowing passes on the volumetric moisture content is shown in table 8. Some changes can be observed. There is a reduction in moisture content in the first 0-5 and 5-10 cm as the number of passes increases, which agrees with the behavior of bulk density. Below these depths little changes are observed, however, under 12 and 24 passes there is a reduction in the moisture content in the 30-50 and 50-70 cm layers, which could mean that these treatments are affecting the water movement into the profile. In others words, they are affecting the rainfall acceptance capacity of the soil.
[E. Amézquita, I. Valenzuela, G. Perea, D. Molina, P. Hoyos]

Table 8. Changes in volumetric moisture content (%) as a response to increasing number of harrowing passes

	N^{O} of harrowing passes			
Depth (cm)	0	6	12	24
0-5	29.43	25.85	27.21	26.62
5-10	30.34	26.26	27.93	19.97
10-20	26.11	27.76	27.37	25.52
20-30	26.95	28.76	25.92	25.48
30-50	26.44	29.53	25.66	24.90
50-70	28.07	26.20	25.67	22.5

Effect of size of aggregates and N addition on the growth of Brachiaria decumbens in an Oxisol of "Los Llanos".

One of the effects of increasing land preparation is a constant reduction in the aggregate sizes, which by repacking, due to action of rains and gravity, produce different soil physical conditions and as a consequence changes in total porosity and pore size distribution, affecting the flow of water and nutrients.

A greenhouse experiment to check how different aggregate sizes could affect the growth of Brachiaria in the presence of N established at CIAT headquarters. Three aggregate sizes >4; 4-2 and <2 mm classes and three N levels: 0, 75, 150 Kg/ha were tested. 12 Kg pots were used.

Result showed that *Brachiaria* response was more strongly influenced by the size of the aggregates (Table 9). This means that any land preparation practice should by planned, to take into account a drastic reduction in the size of the aggregates which will produce less biomass and reduce productivity. N absortion was a function of aggregate size, therefore, any excess in soil preparation will negatively affect the uptake of this element. N remaining in the soil was higher in larger aggregates indicating that they could protect it against leaching.

Some physical characteristics of the pots having different aggregate size are shown in table 10. Bulk density was higher, when the equivalent cylindrical diameter of the aggregates was smaller than 2 mm, affecting therefore, the value of total porosity. Air permeability of core samples equilibrated to 75 cm of suction, was very sensitive to the changes in aggregate size. This function of aggregate size could be used to assess the state of degradation of soil structure.

[A. Melendez, E. Amézquita, J. I. Sanz]

Table 9. Biomass production and N absorption by Brachiaria growing in different aggregate sizes.

Aggregate size (mm)	Dry weight (g)	N absorption (g/pot)	N in soil (g/g)
>4	21.0 a	0.39 a	37.5 a
4-2	12.7 b	0.31 b	27.0 b
<2	5.0 c	0.13 c	17.6 c
C.V.	25.3	14.0	14.7

Table 10. Some physical properties under different aggregate size.

Aggregates	Bulk density (g/cc)	Total porosity (%)	Air permeability at 75 cm suction (cm/day)
>4 mm	1.069	59.03	261.96
4-2 mm	1.020	60.90	130.98
<2 mm	1.212	53.54	87.67

OUTPUT 2. STRATEGIES TO PROTECT AND IMPROVE SOIL QUALITY

Introduction and summary

Over 51% of croplands and 14% of pasture land in Latin America are experiencing land degradation of various forms. First estimates indicate the water erosion and loss of nutrients are the major causes of degradation resulting from overgrazing and improper agricultural practices. The objectives of this output are to develop strategies to prevent and/or reverse land degradation. The approaches involve the new paradigm of soil research i.e. rely more on biological processes by adapting germplasm to adverse soil conditions, (see output 1) enhancing soil biological activity and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use. We are attempting to develop a framework for integrated nutrient management whereby available on-farm resources such as organic material and soil biota are combined with judicial inputs of fertilizers to improve productivity and ensure the maintenance of soil quality. At the same time it has become apparent during the project that soil physical processes have a major impact on loss of productivity and soil quality in the llanos of Colombia and the project has developed the concept of the establishment and maintenance of an arable layer for tropical soils.

The report includes data from the long-term experiment on crops and crop-pasture rotations established in the llanos of Colombia (Culticore experiment).

Highlights

- Residue decomposition rates and N and P release patterns were determined for rice, maize, cowpea and soybeans.
- Soil organic N levels can remain balanced in maize-based systems despite large leaching losses. Rice-based systems result in a drain on soil organic N.
- Recycling of N, P and K was greater when rice and maize were rotated with legumes, especially in green manures, than when grown in monocultures
- Current indicators of P and K fertility are poorly sensitive to recycled nutrients, and that identification of new alternatives were required
- Additions of organic phosphorus were undetectable in labile organic P pools and, by implication, is cycled very rapidly through them
- The accumulation of P in organic pools under pastures is a slow process extending over several years
- The rate of reversion of P to more recalcitrant forms in Colombian savanna Oxisols proceeds much slower than expected, accounting for the unexpectedly high residual value of P fertilizer applications
- Lime applications had no influence on subsoil acidity or nutrient retention on medium-textured savanna Oxisols
- Leached nutrient cations were not retained in the subsoil but moved rapidly through soil profiles probably as companion cations to rapidly leaching nitrates
- Lime applications greater than 1 t ha^{-1} have substantial longer term effects on heavier textured savanna Oxisols, sufficient to sustain production of more acid-soil sensitive crops periods of 3-5 years or more
- The presence of the legume in introduced pastures improved the availability of N and Ca in soil as a result of increased shoot uptake and recycling processes.

- Medium stocking rates improve the legume (*Arachis pintoi*) root proportion and carbon sequestration in soil by the introduced pasture of *Brachiaria humidicola*.
- External funding obtained from the UK DIFD.
- Partners in Brazil and Venezuela select sites and initiate sampling and analyses.
- Meetings of the partners held in Mérida, Venezuela in Febrauary and in CIAT in October to agree common methodologies.
- Litter production in Brazil appears to be much higher than previously reported.
- Rate of pasture regrowth may be a sensitive indicator of degradation.
- Grass/legume pastures markedly increase soil fauna biomass in the savannas of Colombia and Brazil and in the forest margins of Peru.

Output 2 - ***Activity i) Determine nutrient release patterns of component residues and green manures***

Decomposition of crop residues and green manures in the Culticore experiment

Highlights

- Residue decomposition rates and N and P release patterns were determined for rice, maize, cowpea and soybeans.

Tables 11 and 12 summarize the data obtained from a series of litter bag decomposition studies when rice or maize residues, collected after harvesting the grain, and green manure material, collected before incorporation into the soil, are left to decompose either on the soil surface or after burial at 5 cm depth in the soil. Table 11 shows the initial compositions of the material used in the litter bags. The experiments were initiated after the normal harvesting period i.e., at the end of the wet season (Sept-Nov) and beginning of the dry season (Nov-Dec).

Table 12 includes the decomposition half-lives in terms of dry weight, total N and P, all estimated by fitting a single exponential model to the data.

For rice residues the mean half-life was 91 days and 127 days for maize when left on the soil surface and 40 and 53 days respectively when incorporated into the soil. Green manures had much faster rates of decomposition as expected from their initial compositions. The mean half-lives of cowpea residues were 43 and 18 days for surface and incorporated material respectively. Similar values for soybean green manure material were 57 and 25 days.

Half-lives of nitrogen and phosphorus were similar for any particular surface applied residue but incorporated matter sometimes had longer half lives for phosphorus than nitrogen.

Extensive data sets exist on the correlations between decomposition parameters such as half lives and the initial composition parameters including %C, % N, % P and % lignin and various combinations and elemental ratios. These are not included here but will appear in a publication.

[I. Corrales, N. Asakawa, R. Thomas]

Table 11. Initial composition of crop residues

Incorporated material	Initiation date	% N	% P	% lignin	C/N	C/P	L/N	L/P
Rice-residue	Dec. 20/93	0.94	0.07	6.49	44.18	577	7.08	93
	Sept. 15/94	1.17	0.08	8.95	33.43	487	7.65	112
	Sept. 26/95	0.67	0.03	5.80	62.50	1389	8.71	193
Maize-residue	Sept. 16/95	0.75	0.06	11.20	56.57	708	14.97	187
	Sept. 26/97	1.02	0.09	8.27	45.57	479	8.87	92
Cowpea green manure	April 14/93	2.80	0.20	14.70			5.23	72
	Dec. 09/94	3.02	0.32	11.16	13.09	124	3.70	35
	Nov. 27/95	2.89	0.19	11.65	19.88	215	5.45	61
Soybean green manure	Dec. 09/94	2.12	0.24	10.24	17.85	158	4.83	43
	Dec. 19/95	2.65	0.15	6.84	16.06	282	2.62	46

Table 12. Half-lives of crop residues

Half-life in days							
		Surface applied			Incorporated (5 cm)		
Incorporated material	Date	DM	**N**	**P**	DM	**N**	**P**
Rice-residue	Dec. 20/93	88	30	28	47	26	27
	Sept. 15/94	64	29	29	37	30	29
	Sept. 26/95	120	179	Ind	36	61	116
Maize-residue	Sept. 16/94	128	26	31	53	27	18
	Sept. 26/95	125	60	69	53	42	35
Cowpea green-manure	April 14/93	32	22	35			
	Dec. 09/94	63	53	53	14	10	22
	Nov. 27/95	35	22	35	19	14	26
Soybean green-manure	Dec. 09/94	65	46	69	21	18	38
	Dec. 19/95	49	25	46	30	17	34

Half-lives estimated from a fit of a single exponential decay function

Output 2 - ***Activity ii) estimate nutrient budgets in contrasting systems***

Highlights

- Soil organic N levels can remain balanced in maize-based systems despite large leaching losses. Rice-based systems result in a drain on soil organic N.

Nitrogen budgets in crop rotations

Nitrogen budgets have been estimated for rice and maize monocropping and rice-cowpea green manure and maize-cowpea green manure sequential rotations in satellite experiments to the Culticore experiment.

^{15}N labelled material was used as a marker for nitrogen in these studies. Labelled ammonium sulphate fertilizer was supplied to crops at similar levels to those used in the Culticore experiment (for details see Tropical Lowlands Ann. Report 1995). Green manure crops were also labelled with ammonium sulphate fertilizer and the fate of the labelled organic matter was followed into subsequent crops after incorporation of the green manure. Label was measured in the bulk soil organic nitrogen profile down to 40 cm depth.

Rice monocropping

Figure 4 shows the nitrogen balance when a rice crop is grown with 80 kg N/ha fertilizer-N. The rice contains 106 kg N/ha in the total biomass. Of this 49 kg N is harvested in the grain leaving 57 kg N/ha returned to the soil as unharvested above-ground residues. Labelled fertilizer studies revealed that the rice only recovers 34% of that applied i.e., some 27 kg fertilizer-N from 80 applied. The remaining N must come from soil sources, i.e. some 79 kg-N. Data from rice residue decomposition studies indicate that of the 57 kg N in residues returned to the soil, some 20% or 11 kg N will remain in the soil. The rest is relatively rapidly mineralized (half life 48 days when incorporated) and is assumed to contribute little or no N to the subsequent rice crop. From labelling studies a further 25% of the fertilizer enters the soil organic matter pool i.e. some 20 kg N/ha. The net loss of fertilizer-N is equal to 80 - (27 + 20) = 33 kg N or 41% of that applied.

The additions to the soil are then 11 kg from resides + 20 kg from fertilizer = 31 kg N/ha. However to support another rice crop some 79 kg N/ha needs to be supplied from soil organic matter assuming the recovery of fertilizer is only 34%. Taking the returns from the previous rice residues and the fertilizer recovered, there is a net drain on the soil organic nitrogen sources in the medium to long term of 79-31 = 48 kg N/ha/rice crop.

Rice rotated with cowpea as a green manure

A rice crop receiving 80 Kg N/ha and following green manure incorporation produced a total plant biomass of 112 kg N/ha (Fig. 5). In this experiment the recovery of the fertilizer-N was some 26% or 21 kg N/ha. Around 28% or 32 kg N of the N incorporated via the green manure was recovered in the rice crop. A remaining 59 kg N is then estimated by difference to come from organic soil nitrogen sources (112- [21 + 32]).

The rice crop consisted of 50 kg N in the grain which was removed from the system at harvest and the remaining residue contained 62 kg N/ha which was incorporated into the soil. Estimates from rice residue decomposition studies indicate that some 20% of this or 12 kg N will enter the soil organic matter pool. Labelling of the fertilizer indicated that some 23% or 19 kg N/ha entered the soil organic matter pool. If a subsequent crop of rice requires 59 kg N /ha from the soil organic matter as estimated above then the net drain on the SOM pool will be 59- {12 + 19) or 28 kg N/ha.

The amount of fertilizer-N lost from the system is 80 - (21 + 19) = 40 kg N or 50% which is a little more than that lost in the rice monocrop system.

Maize monocrop

A maize crop containing 71 kg N/ha in the total biomass was produced with the addition of 120 kg fertilizer-N/ha (Fig. 6). Some 34% or 41 kg fertilizer-N was recovered in the crop and 21% of the fertilizer-N or 25 kg N entered the SOM pool. As there were no other N inputs around 30 kg N was supplied from the SOM pools (71 - 41). The grain harvested contained 50 kg N/ha with a further 21 kg N /ha in the maize residues which were returned to the soil. Decomposition studies indicated that some 20% of the residue or 4 kg N/ha entered the SOM pool. The N balance in the soil then for subsequent maize cropping at the same level of production and recoveries of fertilizer and maize residues will be 30 - (4 + 25) = 1 kg N/ha. Some 54 kg or 45% of the fertilizer applied was lost from the system (120 - [41 + 25]).

Maize rotated with cowpea as green manure

Maize following a green manure of cowpea produced a total biomass of 95 kg N/ha. Of the 120 kg N fertilizer applied some 40% or 48 kg N/ha was recovered by the crop (Fig. 7). Of the green manure-N applied some 14% or 14 kg N was recovered in the maize crop. The amount from the SOM pool is then 95 - (48 +14) = 33 kg N/ha.

Sixty seven kg N in the maize crop was harvested as grain leaving some 28 kg N /ha as residues. Applying a 20% recovery of this residue by a subsequent maize crop would be equivalent to an input of 6 kg N/ha. Twenty two % or 26 kg N of the fertilizer-N entered the SOM pool. Therefore the net drain on the SOM pool in this system would be 33 - (6 + 26) = 1 kg N/ha.

Of the 120 kg N fertilizer added, 48 kg N was recovered directly and a further 26 entered the SOM pool leaving 46 kg N or 38% lost from the system.

Summary

These results indicated that the maize-based systems are in balance in terms of the N cycle but the both rice-based systems are draining the SOM pool of nitrogen. The yields of rice grain were similar with or without the green manures in these satellite experiments. Other data from the main experiment have indicated a yield benefit from green manures of around 0.7 t/ha. Differences in the amounts of green manure produced may account for this discrepancy.

Greatest recovery of fertilizer N was observed in the maize-green manure treatment (40%) with the recoveries in the other treatments ranging from 26-34%. Results from other experiments using labelled urea-N fertilizer rather than ammonium sulphate used here, were in the range 34-46% (Project 10 Ann. Report, 1996). However greatest amounts of N fertilizer were unaccounted for, presumed lost, in the maize systems compared with the rice-based systems. These results are in agreement with those reported previously for the main plot experiments (Project 10 Ann. Report 1996).

The small benefits in terms of grain yield following incorporation of green manure, the high levels of soil nitrate measured after green manure incorporation and the relatively poor rates of nitrogen fixation by cowpeas (Ann Report Project 10 , 1996), all indicate a poor efficiency of the grain crop-cowpea green manure system. Previous data (Project 10 Ann. Report, 1996) showed that the amounts of nitrogen derived from fixation in the green manures, cowpea and soybean, were low. This implies that the growth of a green manure crop is a further net drain on the soil organic nitrogen reserves which were not taken into account in the estimations of nitrogen balances presented here.
[M. Rondón, I. Corrales, N. Asakawa, R. Thomas]

Fig. 4. N balance in rice monocrops

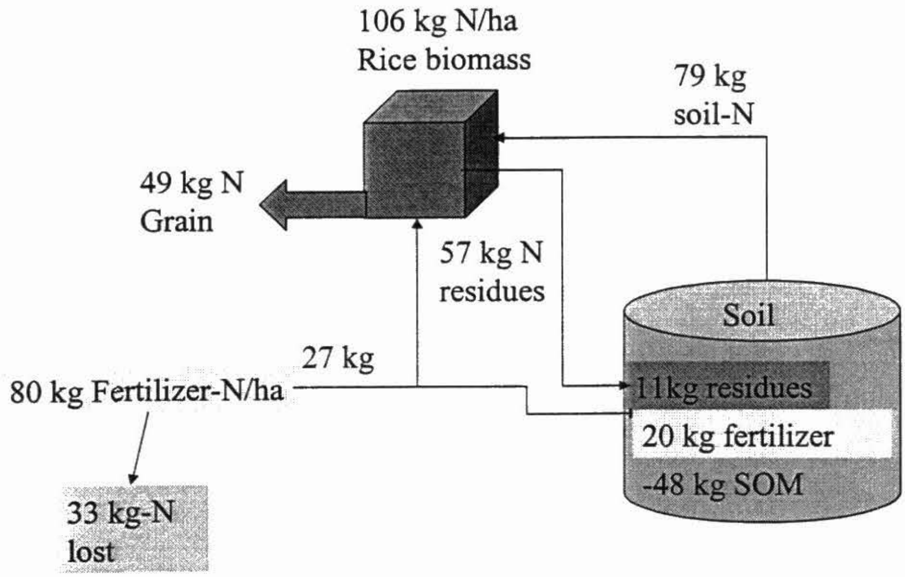


Fig. 5. N balance in rice cowpea rotation

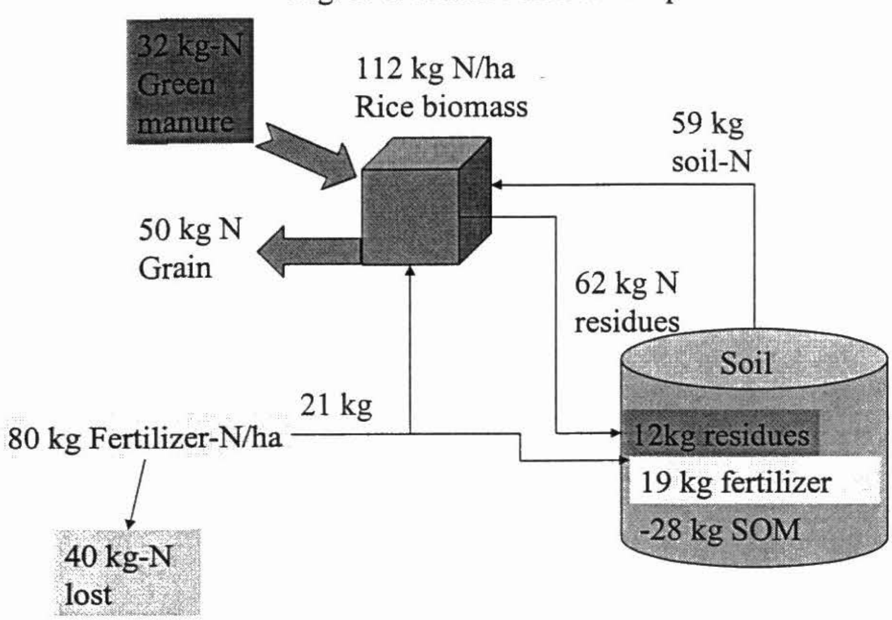


Fig. 4. N balance in maize monocrop

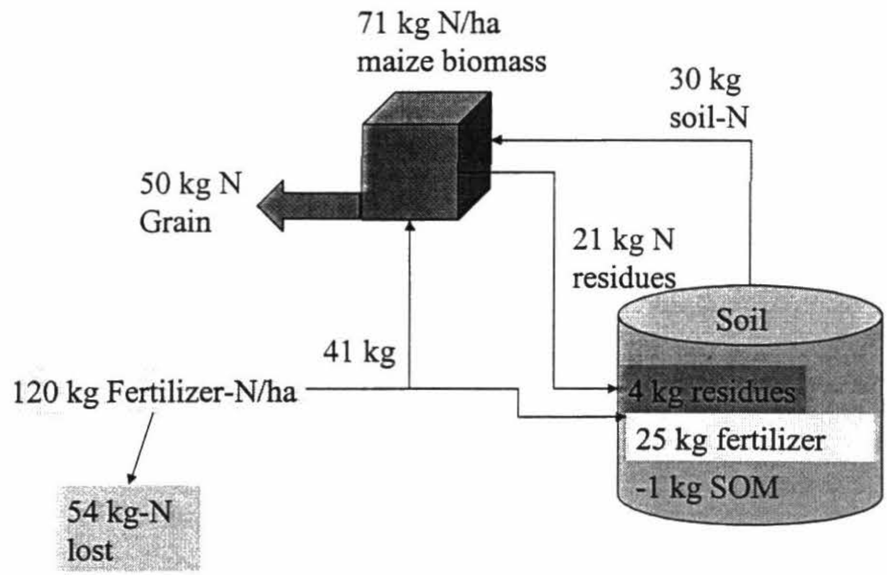
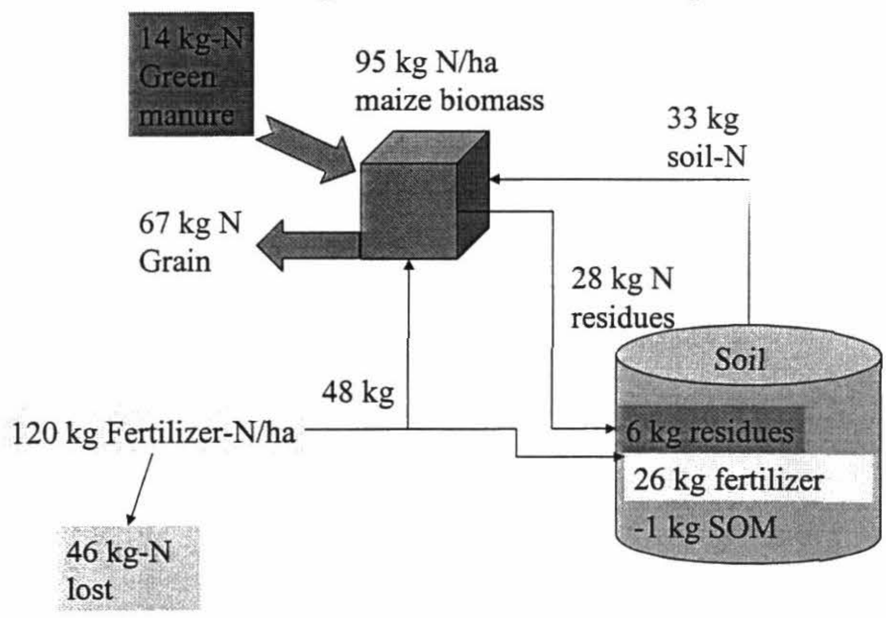


Fig. 7. N balance in maize-cowpea rotation



Output 2. Activity ii) Estimate nutrient budgets in contrasting systems.

Budgets of N, P and K in monocropped cereals and rotations with grain legumes and green manures (Culticore)

Highlights

- Showed that recycling of N, P and K was greater when rice and maize were rotated with legumes, especially in green manures, than when grown in monocultures
- Showed that current indicators of P and K fertility are poorly sensitive to recycled nutrients, and that identification of new alternatives are required

A central hypothesis to our work on systems maintains that nutrient cycling is improved in systems which incorporate components that are more efficient in nutrient acquisition than others. Efficient acquirers will cycle nutrients to less efficient components in the system. To examine this hypothesis, we have estimated and compared the uptake and recycling of macronutrients (N, P and K) in rice and maize monocultures and rotations which incorporate a grain legume or a green manure after the cereal in the long-term systems experiment at Carimagua. Rice-based systems were established in May, 1993, on an Oxisol taken out of native savanna grassland. Maize-based systems were sown in April, 1994. Each rice crop received 80 kg-N ha^{-1}, 60 kg-P ha^{-1} and 100 kg-K ha^{-1} whereas each maize crop received 120 kg-N ha^{-1}, 80 kg-P ha^{-1} and 100 kg-K ha^{-1}. Legumes (cowpeas or soybeans, for grain or green manure) received 20 kg-N ha^{-1}, 40 kg-P ha^{-1} and 60 kg-K ha^{-1} annually. Grain and biomass production (excluding roots) in the different systems since establishment is summarized in Figure 8. Apart from an initial decline in rice yields during the first 3 years, attributable to increasing weeds competition, no consistent trends in production during the 3-4 years of cultivation is evident in any of the systems. Nor have the higher biomass returns in the rotational systems produced marked effects in succeeding cereal grain yields.

Nutrient budgets together with indicators of changing soil fertility are presented in Figures 9 and 10. As expected, incorporation of a second crop into the system after the cereal greatly enhanced total nutrient uptake. In relation to biomass production, legumes were considerably more efficient in acquiring nutrients than the cereals. Although all acquired nutrients were recycled when legume green manures were plowed in, available nutrient pools (except for N) did not reflect the inputs of recycled nutrients (compare cereal-grain legume with cereal-green manure rotations). Biological N_2 fixation considerably augmented biomass N inputs in legume rotations which contributed in increased available (mineral) soil N levels. (These accumulations have been previously reported.) Uptake and recycling of N in rotations therefore approached or exceeded the levels of N applied in fertilizer although previously reported results of N fertilizer balance studies using 15N tracers indicated that actual recovery of fertilizer-derived N by the crop was poor. Fertilizer N applications together with recycled N derived from legumes resulted in large accumulations of mineral N in the soil profiles beneath these systems, a considerable proportion of which was found at depths greater than 40 cm (compare mineral N contents in 0-40 cm and 0-80 cm profiles; Figures 9 and 10). Especially for more acid soil sensitive germplasm, these accumulations may be inaccessible to other crops growing in the sequence.

Acquisition and recycling of K was also high in relation to K inputs from fertilizer. Legumes, especially cowpeas, were particularly efficient in acquiring K and recycling it back to the soil. In rotational systems, K uptake generally exceeded K applied from fertilizer despite the initially low level (< 0.1 meq/100 g) of exchangeable K in the soil. These observations together with the observation of weak growth response to K applications (see above) suggest that crops acquire K from ('fixed') sources not measured by our current methods. However, despite widely disparate amounts of K recycled in the different systems, trends in exchangeable K levels did not differ significantly among systems. This further suggests the need to re-evaluate current K fertility indicators for these soils.

In contrast to N and K, acquisition and recycling of P in all systems was very low in comparison to fertilizer inputs. P recovery was generally less than about 25% of P applied. Among the component crops, cowpea was most effective at recycling P although (as with K) increased P returns in residues/green manure litter had no measurable impact on available P measured by the Bray-2 method (see following discussion on "P dynamics in ..." Culticore systems [Output 2; activity iii]). In general, the very poor recovery of P from soil indicates considerable scope to improve the efficiency of P inputs on high P-sorbing soils. Differences among crop species in the systems studied here indicate that there is potential to improve P acquisition in systems, which is the essential first step to improved P cycling.
[M. Rivera, M. Rodríguez, C.G. Meléndez, D. Friesen]

Output 2 - ***Activity iii) Identify key processes in nutrient cycles to minimize losses and improve use efficiency in systems.***

Phosphorus dynamics in monocultures and rotations on an Oxisol (Culticore)

Highlights

- Showed that additions of organic phosphorus was undetectable in labile organic P pools and, by implication, is cycled very rapidly through them
- Showed that the accumulation of P in organic pools under pastures is a slow process extending over several years
- Showed that the rate of reversion of P to more recalcitrant forms in Colombian savanna Oxisols proceeds much slower than expected, accounting for the unexpectedly high residual value of P fertilizer applications

Phosphorus is the most limiting nutrient for increased and sustainable production on savanna Oxisols. Yet this nutrient is strongly sorbed on oxidic clay mineral surfaces and gradually reverts to less plant-available forms. Systems, or components of systems, which are more efficient in acquiring soil P from less available pools could enhance the cycling of P to less efficient components in the system. We used contrasting production systems based on upland rice in the long-term experiment established at Carimagua in 1993 (Culticore) to study the dynamics of P in labile and stable P pools in soil. Phosphorus pools in soils sampled (0-10 cm depth) annually or biannually at the beginning of the rainy season were fractionated using the modified technique of Hedley et al (1982) (Tiessen and Moir, 1993). This method sequentially applies increasingly aggressive extracting solutions to soil to successively remove increasingly stable P forms. The extractants are made with resin/H_2O, 0.5 *M* $NaHCO_3$, 0.1 *M* NaOH, 1 *M* HCl, and hot concentrated HCl. Residual P is finally determined by digestion with perchloric acid. Both inorganic and organic P in determined at each extraction step. Results are summarized in Figure 11.

Phosphorus pools changed very little with time under native savanna, which was burned approximately annually but never grazed during the experimental period. Phosphorus under the *Brachiaria humidicola*-legume pasture (established under rice with 60 kg-P/ha in 1993, and fertilized with 20 kg-P/ha in 1995) was also relatively stable. P inputs principally influenced the NaOH-Pi fraction. This fraction is relatively more stable than P extracted by resin or bicarbonate solution. These latter labile fractions increased marginally over levels in native savanna. In contrast, labile (resin and bicarbonate) Pi increased substantially under annual cropping systems (rice monoculture and rice-green manure), which received regular fertilizer P inputs. Nevertheless, the secondary (NaOH) Pi fraction was again the most strongly influenced by P inputs. In all systems receiving inputs, labile and secondary fractions stabilized or even declined marginally after three years despite, in the annual cropping systems, continuing P inputs. Reasons for these apparent losses have not as yet been determined, although mixing of 0-10 cm surface soil with the subsurface (10-20 cm) layer is a probable explanation.

In none of the systems was there significant movement of P into or out of organic P fractions, although there is some minor tendency for P movement into the NaOH-Po and HClhc-Po fractions. Previously reported analyses of P fractions in soils under 15-year-old *Brachiaria decumbens*/Kudzu pastures indicated that applied P was partitioned among inorganic and organic P pools in similar proportions as that found under native unfertilized savanna. These results consequently indicate that organic P pools build very slowly in soil, even under systems such as pastures which conserve and sequester carbon. Thus, the considerable Po inputs which these systems receive in the form of recycled crop residues and forage/green manure litter (see below) must be largely mineralized to Pi forms which cycle through the systems and are slowly immobilized into Po forms or slowly revert to less available Pi forms. However, the rate of reversion to more recalcitrant forms (extracted by acid in the Hedley scheme) was undetectable during the four years of observation in any of the systems. The implication, borne out in our results from P fertilizer residual value experiments on the same soils, is that soluble P applications to Oxisols on the Colombian savannas remain available for periods of time which are much longer than expected for "high P-fixing" soils. The present results suggest, therefore, that all systems under study were equally efficient (or inefficient) in cycling P in the short-term.
[G. Borrero, C.G. Meléndez, M. Rodríguez, D. Friesen]

Dynamics of exchangeable Ca, Mg and K in Oxisols under cereal-grain legume rotations (Lime-Mg-K balance experiments)

Highlights

- Showed that lime applications had no influence on subsoil acidity or nutrient retention on medium-textured savanna Oxisols
- Showed that leached nutrient cations were not retained in the subsoil but moved rapidly through soil profiles probably as companion cations to rapidly leaching nitrates

- Showed that lime applications greater than 1 t ha^{-1} have substantial longer term effects on heavier textured savanna Oxisols, sufficient to sustain production of more acid-soil sensitive crops periods of 3-5 years or more

Due to the predominance of low activity clays (kaolinites, iron and aluminum oxides), highly weathered soils such as Oxisols have a very low cation exchange capacity (CEC) which is also dependent on pH and the ionic activity of the soil solution. Lime applications affect the soil CEC by (a) increasing soil pH and (b) displacing and precipitating exchangeable Al from permanent charge sites. Increased surface charge density may increase retention of fertilizer cations such as Mg and K in addition to Ca derived from lime. However, these effects are expected to be rather transitory under conditions which acidify the soil (acidifying fertilizers, decomposing crop/green manure residues, etc.) and reduce soil solution concentration (high rainfall and leaching). In satellite experiments described above, selected treatments were monitored on an annual basis to determine (a) the interacting effects of calcitic lime, Mg and K on the retention and dynamics of nutrient cations in the soil profile, and (b) the residual effectiveness of lime applications on medium textured savanna Oxisols.

The dynamics of exchangeable cations in the surface 0-10 cm soil layer during 3 and 4 years after liming are shown in Figure 12. Liming effects were immediate (measurable) within one season (4 months) of application although applied calcite was not fully recovered as exchangeable Ca at the first sampling, presumably due to incomplete reaction of coarser particles. Nevertheless, the effects of lime commenced to diminish almost immediately after the first season of cropping: at application rates of < 600-800 kg/ha, exchangeable Al saturation and exchangeable Ca concentration returned to original levels within 3 years of liming. Lime applications >1 t/ha maintained low exchangeable Al and high exchangeable Ca for longer periods of time as coarser particles continued to react and dissolve under the acidifying conditions of cultivation and N fertilization. Although trends were somewhat inconsistent and variable, exchangeable Mg+K tended to increase with time during the experiment. Lime levels had no apparent influence on these trends which must therefore be related solely to the buildup of residues of K and Mg fertilization.

Although the dynamics of exchangeable cations in the surface soil indicate loss of Ca but increased retention of Mg and K, soil profiles presented in Figures 13 and 14 suggest a rather low rate of movement of lime and cations below the layer of incorporation in Oxisols at Carimagua and Matazul. Concentrations of exchangeable cations in subsoil layers below 20 cm depth were not significantly greater than those found in the unamended soil. The pattern of cation flux through these soil profiles must therefore follow a different model from that which we have observed previously for nitrate leaching where flow could be described by a chromatographic model. Cation fluxes more closely resemble those expected for a slowly soluble source under conditions of slow percolation, although this concept remains to be verified. The case of K is further complicated by the possibility of fixation in Al-interlayer vermiculites which are present in small but significant quantities in these soils. In this case, actual fluxes need to be quantified using tracer techniques.
[M. Rivera, D. Molina, C.G. Meléndez, D. Friesen]

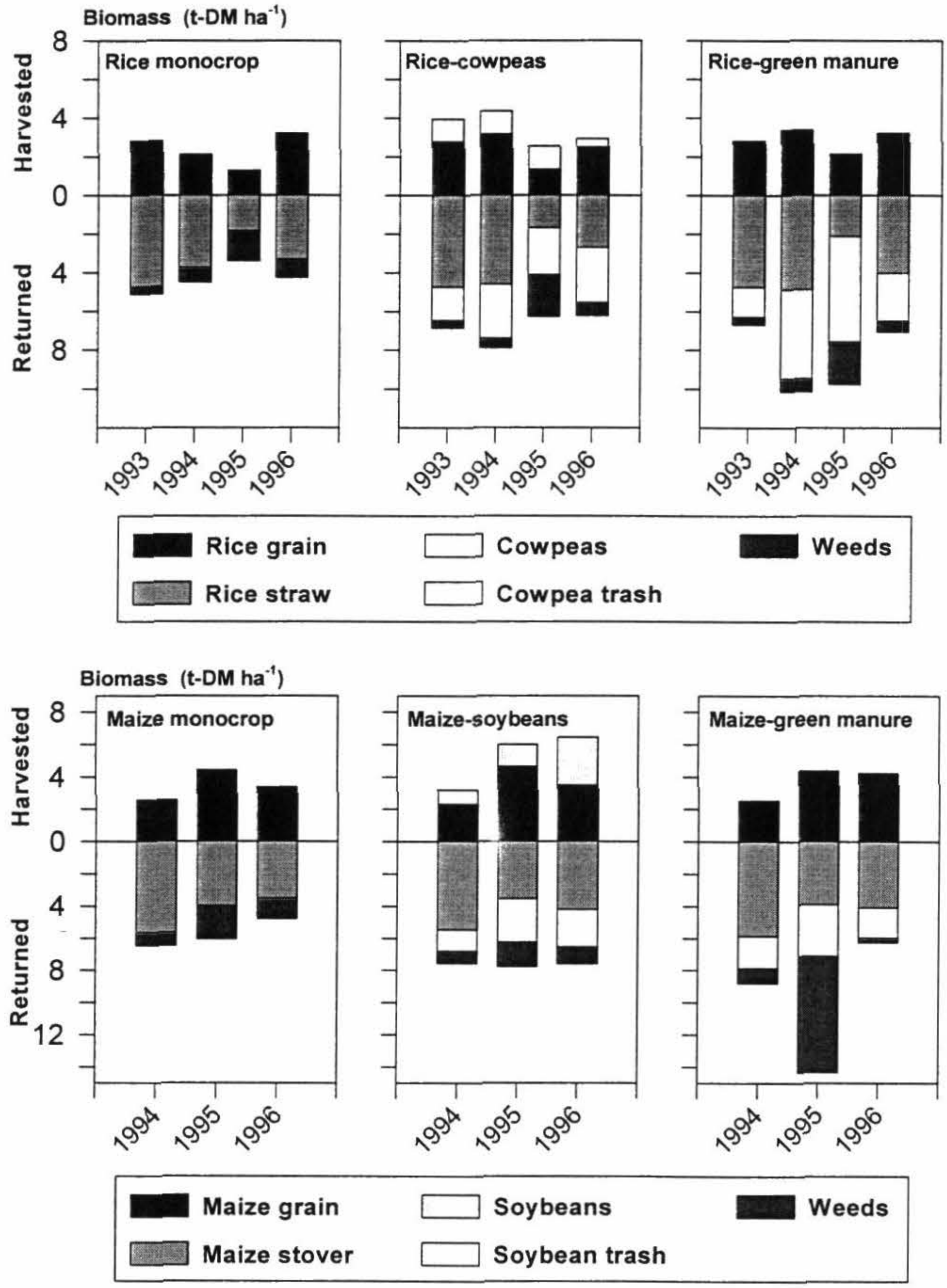


Figure 8. Production of grain (harvested biomass) and trash (biomass returned to soil) in monoculture and rotational cropping systems on a medium-textured Oxisol at Carimagua during 3-4 years of cultivation (Culticore experiment).

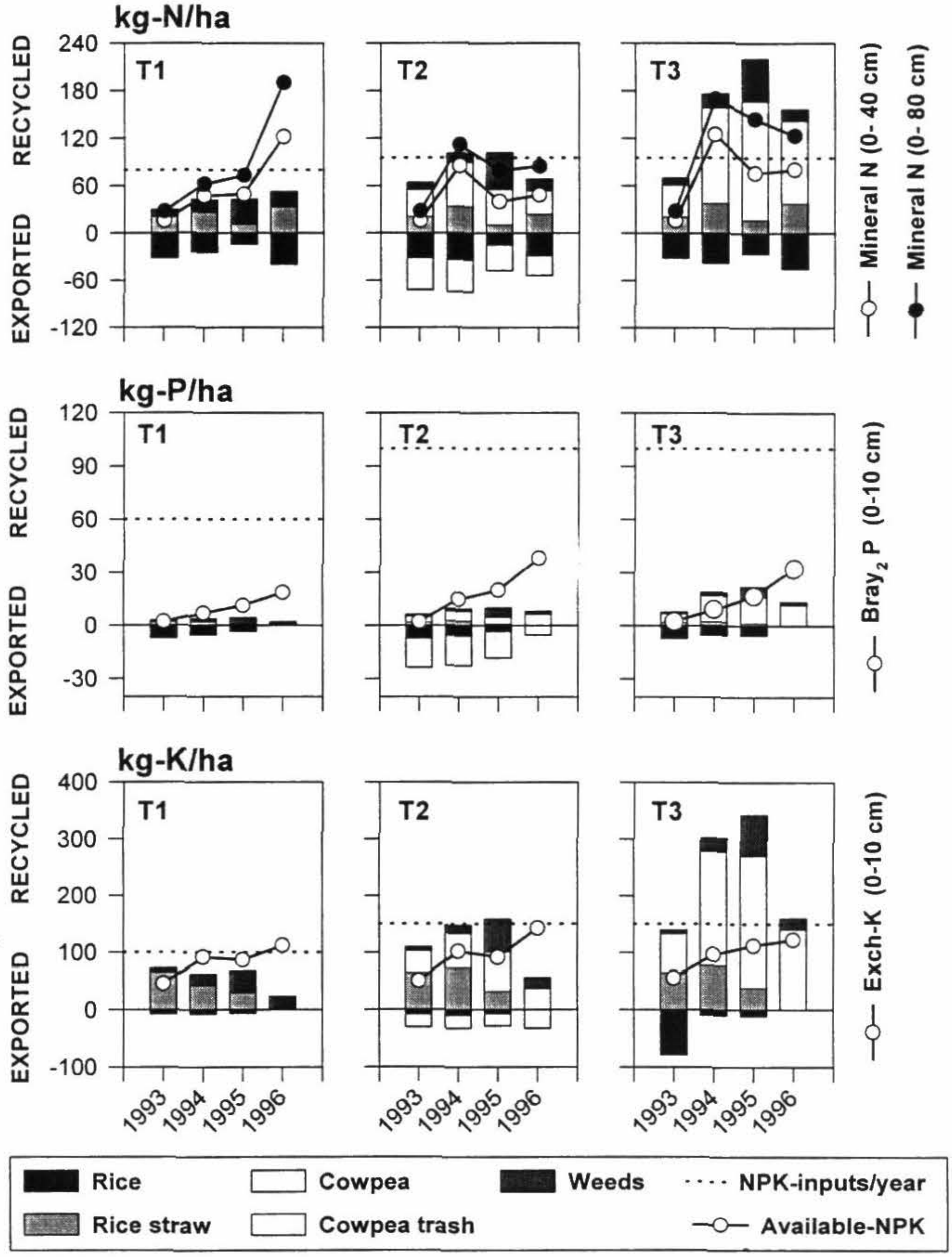


Figure 9. Nutrient balances and soil fertility indicators under rice monoculture (T1), rice-cowpeas (T2) and rice-cowpea green manure (T3) rotations during 4 years of cultivation on an Oxisol at Carimagua (Culticore experiment).

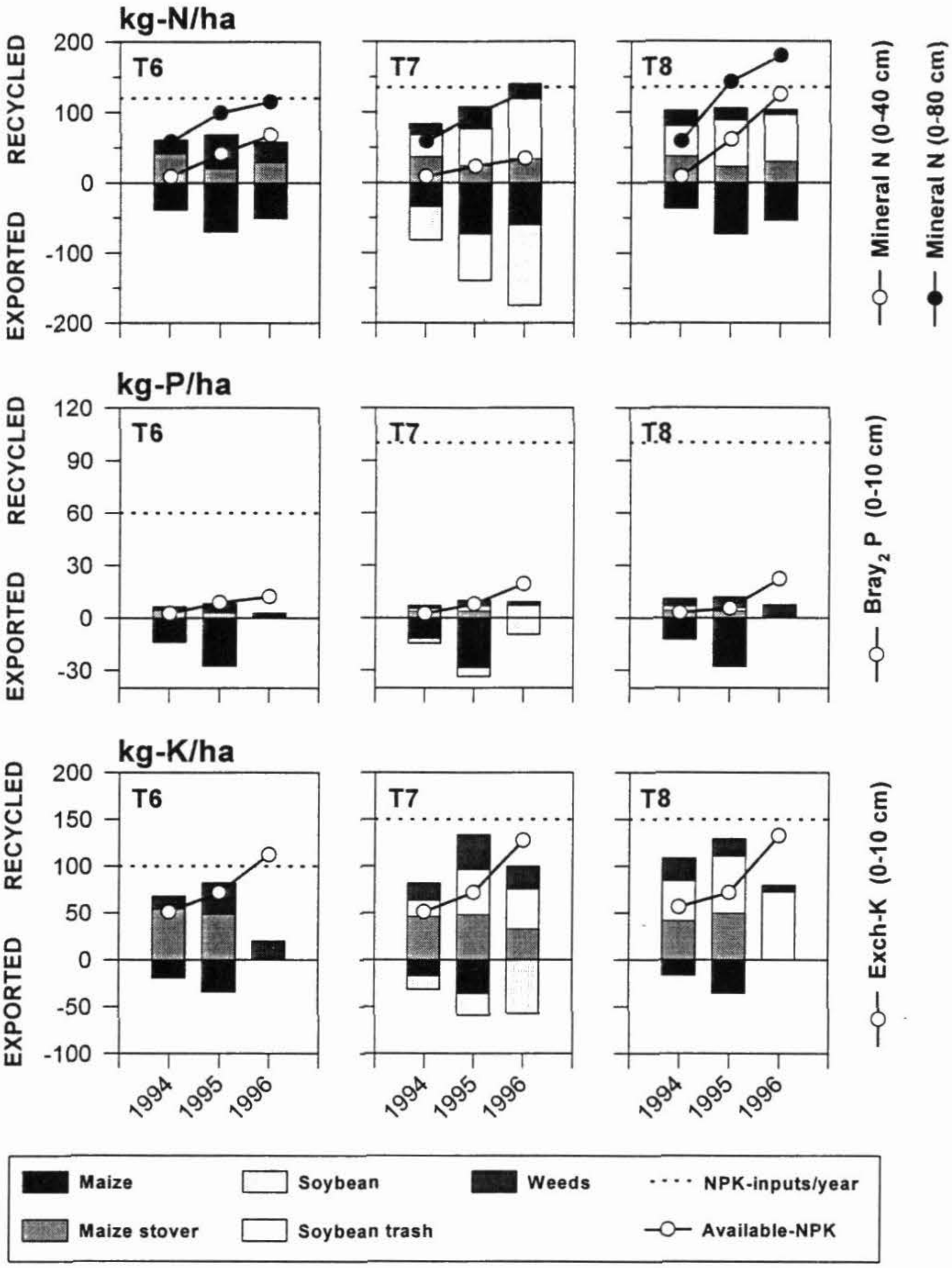


Figure 10. Nutrient balances and soil fertility indicators under maize monoculture (T6), maize-soybeans (T7) and maize-soybean green manure (T8) rotations during 4 years of cultivation on an Oxisol at Carimagua (Culticore experiment).

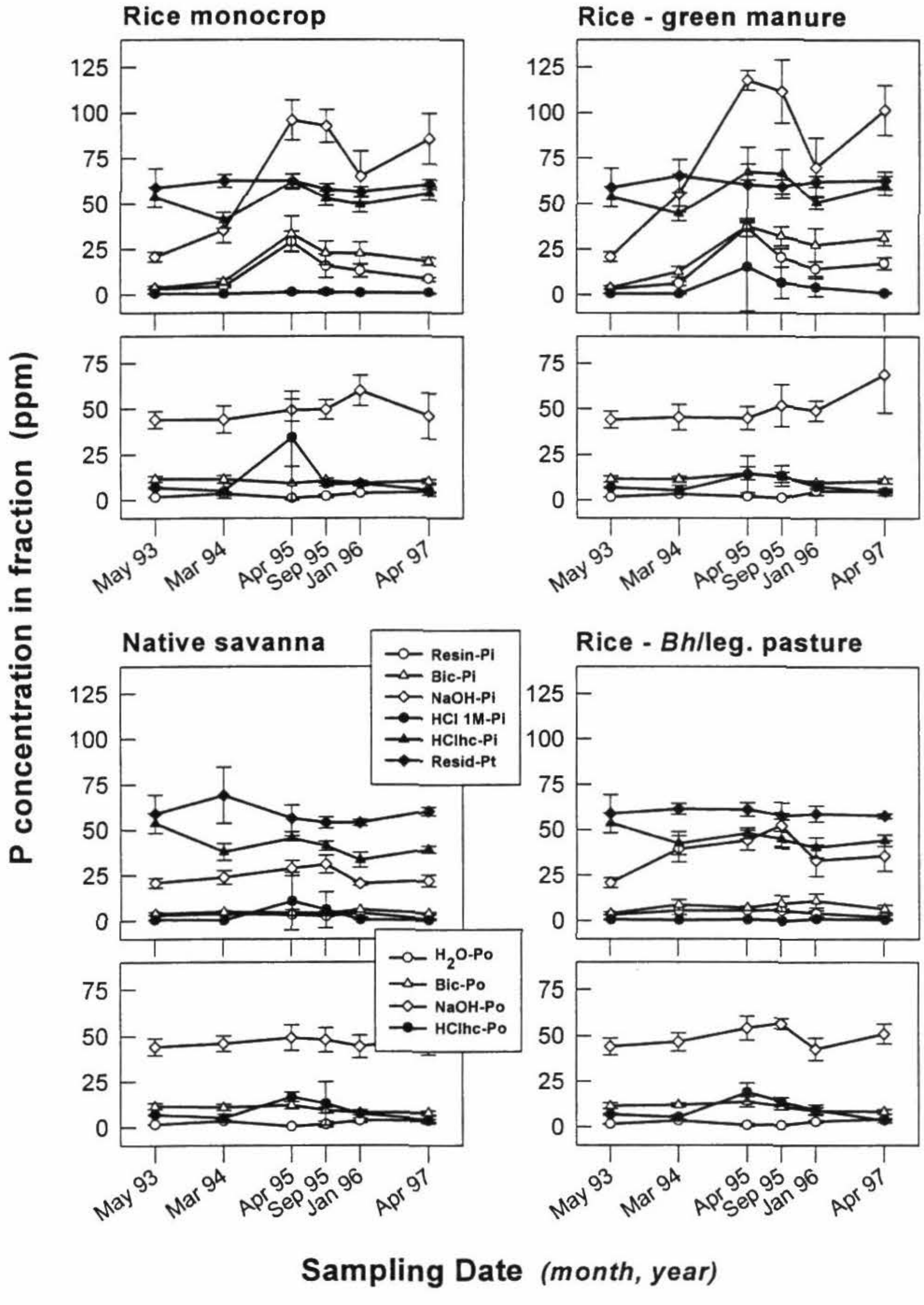


Figure 11. Seasonal dynamics of soil P fractions in an Oxisol under four contrasting productions systems during four years of cultivation (Culticore experiment).

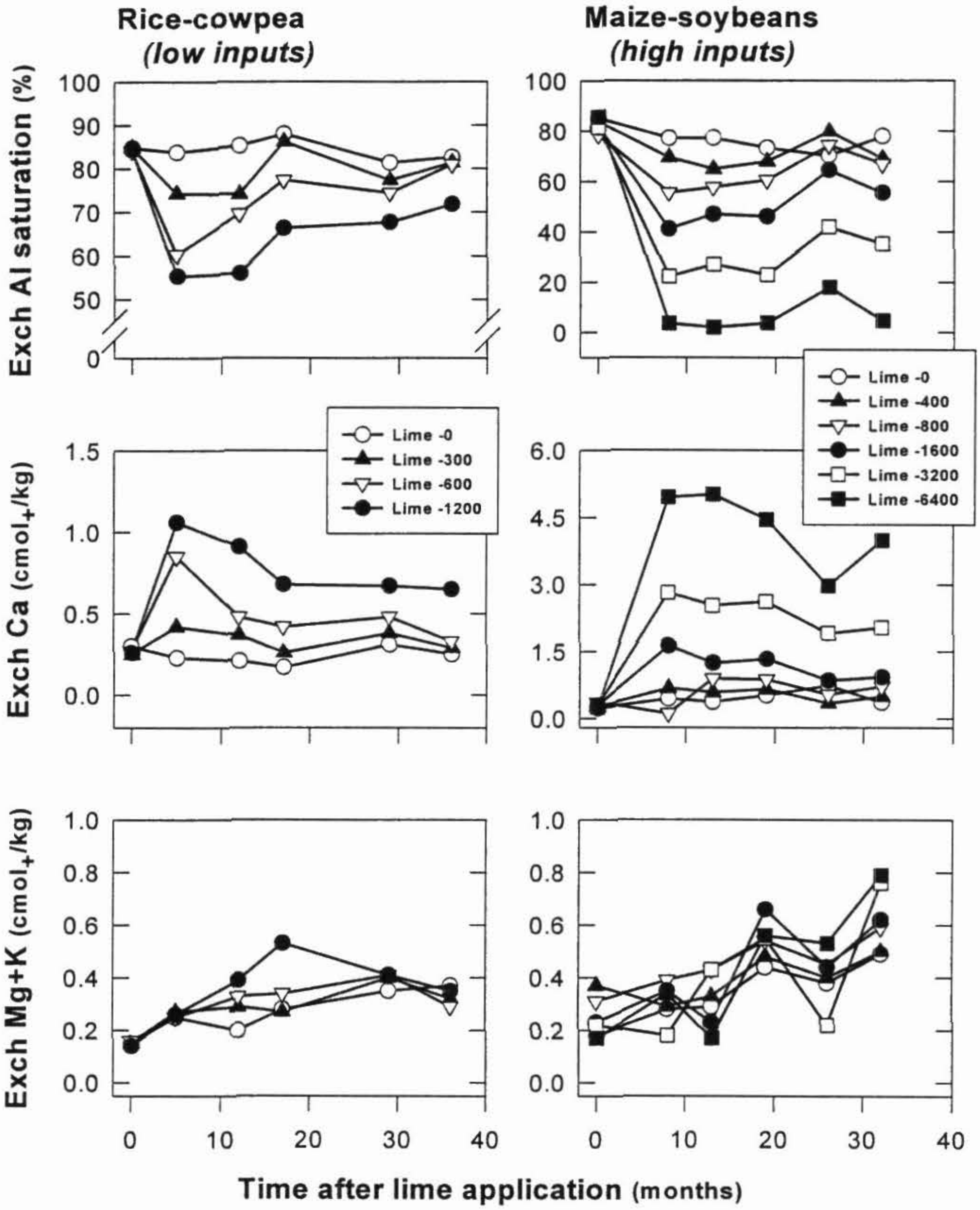


Figure 12. Long-term effects of lime (calcite) applications to two medium-textured Oxisols on soil acidity (exchangeable aluminum saturation) and nutrient cation retention in cereal-grain legume rotations at low and high inputs.

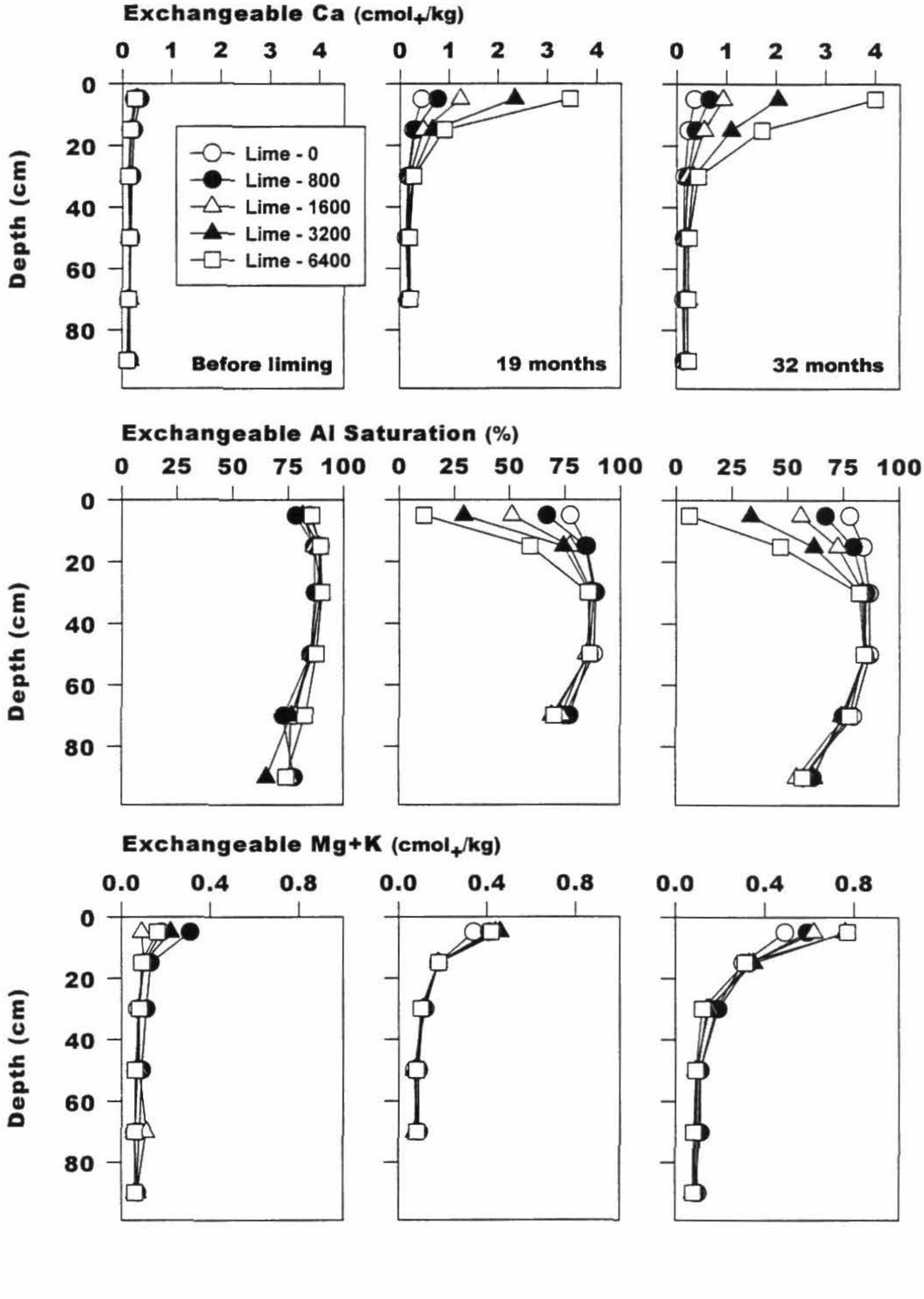


Figure 13. Dynamics of exchangeable cations during 3 years of cultivation in a medium-textured Oxisol under maize-soybean rotation at Carimagua.

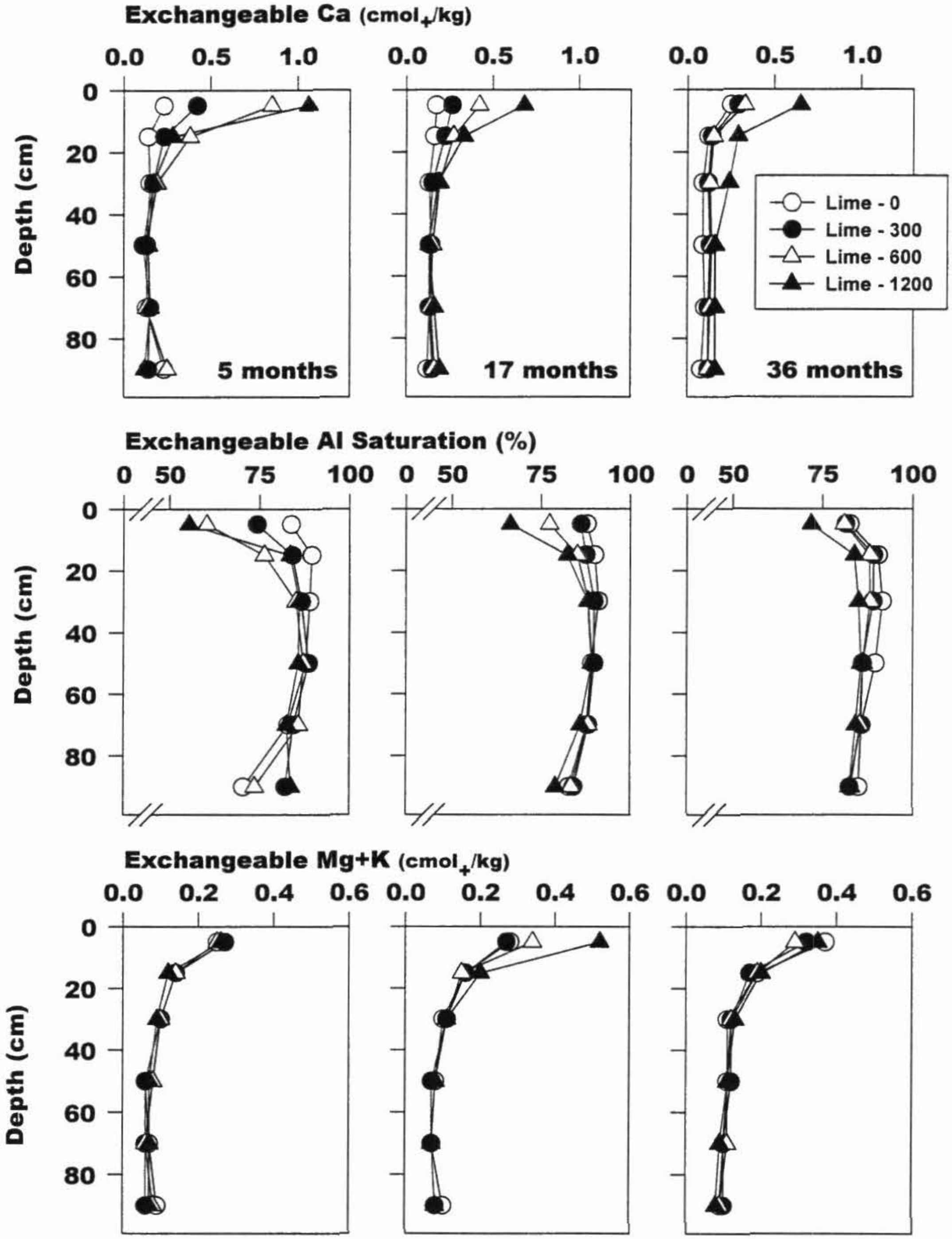


Figure 14. Dynamics of exchangeable cations during 3 years of cultivation in a medium-textured Oxisol under rice-cowpea rotation at Matazul.

Output 2: Activity iv): Estimate contribution of different systems to soil organic matter accumulation

Estimate contribution of different pasture systems to soil organic matter accumulation

Determine the differences in soil nutrient availability among native and introduced pasture systems

Highlights

- Showed that the presence of the legume in introduced pastures improved the availability of N and Ca in soil as a result of increased shoot uptake and recycling processes.

A field study was conducted to determine the differences in availability of nutrients in soil among native and introduced (16 year-old) grass alone (*Brachiaria decumbens* cv. Basilisk) and grass + legume (*Pueraria phaseoloides* cv. Kudzu) pasture systems in a clay loam Oxisol at Carimagua, Colombia. The introduced pastures were fertilized every two years (kg/ha: 10 P, 13 K, 10 Mg and 16 S) and have been under continuous grazing with seasonal adjustment of stocking rate (2 hd/ha in the wet season and 1 hd/ha in the dry season). The native savanna pastures received no fertilizer application and have been under grazing at 0.2 hd/ha stocking rate. Differences in availability of soil nutrients including NH_4^+, NO_3^-, P (Bray II) and exch. Ca in native and introduced pastures were determined at the end of the rainy season. Although the grass alone and grass + legume pastures received the same amounts of fertilizer inputs every two years, the presence of the legume improved the availability of nutrients in soil up to 40 cm of soil depth, particularly, NH_4^+ and exch. Ca (Figure 15). This is mainly attributed to the ability of the legume to fix nitrogen and recycle nitrogen and other nutrients in the association. The presence of the legume also increased carbon sequestration in soil and total nitrogen concentration in soil (Figure 16). The C:N ratio of soil was greater in the introduced pastures compared to that of the native savanna pasture. [**I. M. Rao, R. Thomas, I. Corrales, C. Plazas, R. Garcia and J. Ricaurte**]

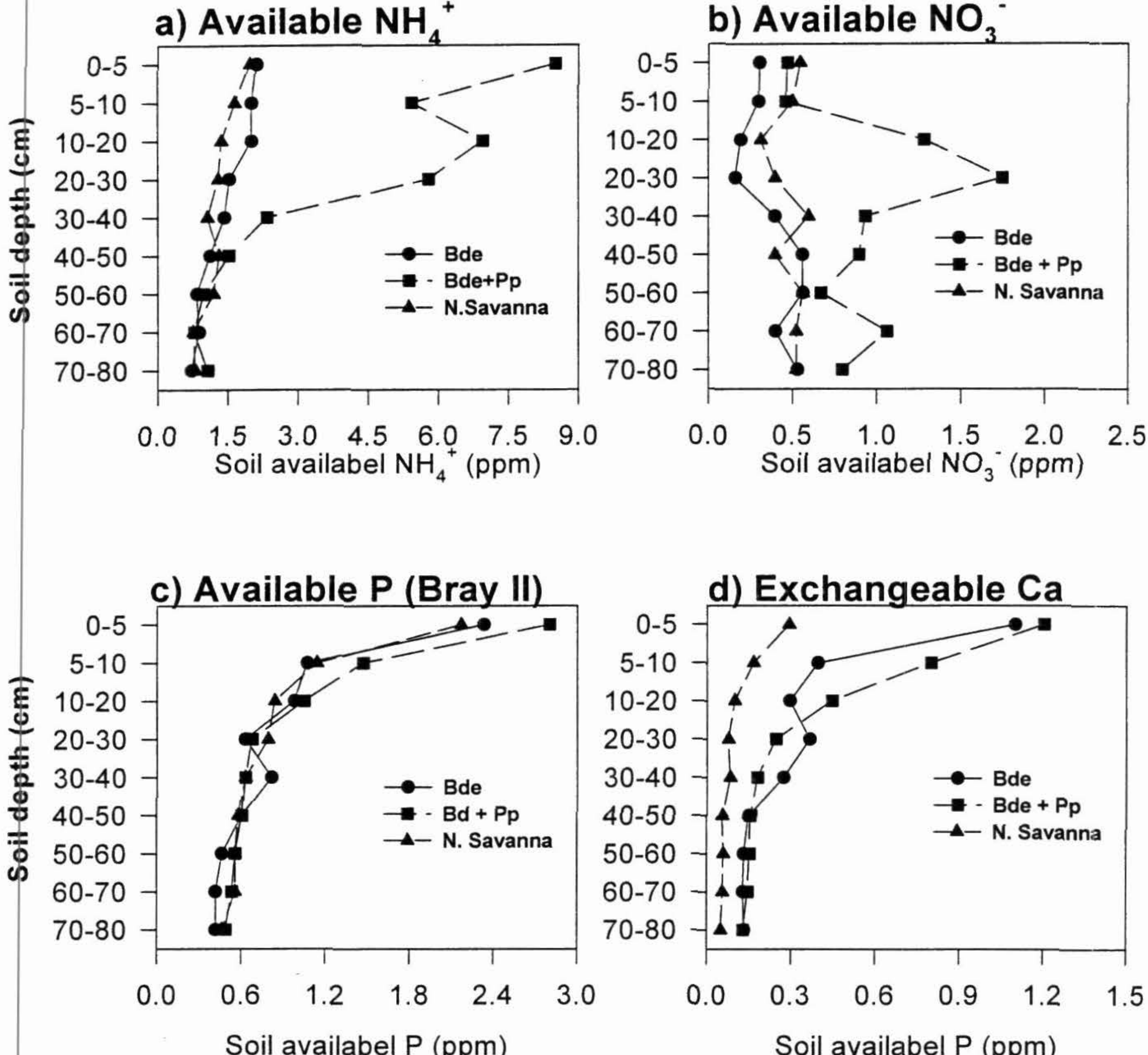


Figure 15. Differences in availability of nutrients (NH_4^+, NO_3^-, P and Ca) in soil profile (0-80 cm soil depth) among native and introduced pastures in a clay loam Oxisol site at Carimagua, Colombia.

Determine the influence of stocking rate on legume root proportion and soil organic matter accumulation

Highlights

- Showed that the medium stocking rate improved the legume (*Arachis pintoi*) root proportion and carbon sequestration in top soil by the introduced pasture of *Brachiaria humidicola*.

A field study was conducted to determine the influence of stocking rate on legume root proportion and soil organic carbon accumulation in *Brachiaria humidicola* alone (10 year-old) and *B. humidicola* + *Arachis pintoi* (6 year-old) association in a clay loam Oxisol at Carimagua, Colombia. Both pastures were grazed at three stocking rates (2, 3 and 4 hd/ha) using a flexible alternate system. The availability of *A. pintoi* on-offer in the rainy season increased over time (500 to 600 kg/ha after 4 years of grazing). Increase in stocking rate decreased the amount of forage on-offer of both pastures and the legume content in the association (see Table 5). Medium stocking rate (3 hd/ha) improved legume root proportion in the association (Fig.16). Stocking rate had no effect on accumulation of organic carbon soil of the grass alone pasture while high stocking rate (4 hd/ha) contributed to greater accumulation of organic carbon in soil profile of the grass + legume association (Fig. 16) [**I. M. Rao, C. Plazas and J. Ricaurte**].

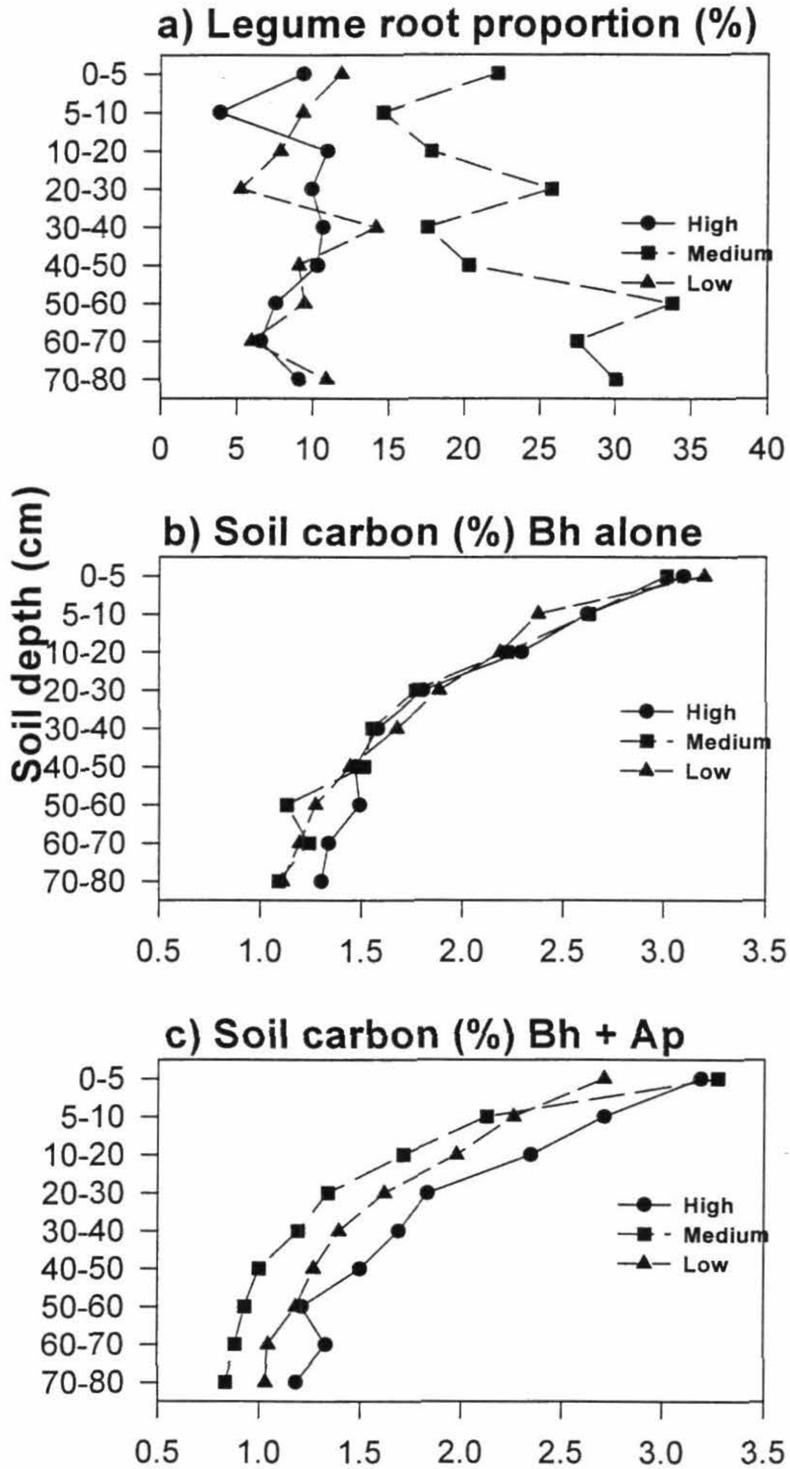


Figure 16. Influence of stocking rate on legume root proportion (A); and soil organic carbon distribution by soil depth (0-80 cm) by 10-year-old *B. humidicola* alone (B) and *B. humidicola* + *A. pintoi* (6-year-old) association (C) in a clay loam Oxisol at Carimagua, Colombia.

Output 2 - ***Activity iv - Estimate contribution of different systems to SOM accumulation.***

Highlights

- External funding obtained from the UK DIFD.
- Partners in Brazil and Venezuela select sites and initiate sampling and analyses.
- Meetings of the partners held in Mérida, Venezuela in Febrauary and in CIAT in October to agree common methodologies.
- Litter production in Brazil appears to be much higher than previously reported.
- Rate of pasture regrowth may be a sensitive indicator of degradation.

The United Kingdom DIFD (formerly ODA), agreed to fund a project (R6732: Increasing carbon sequestration through environmental management of acid soils in the tropics) within this activity. The project incorporates partners in Venezuela (Centro de Investigaciones Ecologicas en los Andes Tropicales, CIELAT, in the Universidad de los Andes, Mérida) and in Brazil (Centro Nacional de Pesquisa de Agrobiologia, CNPAB of EMBRAPA, Seripédica). The project started on 30 November, 1996.

The objective of the Project is to investigate the processes of C sequestration by introduced African grasses in acid soils of the neo-tropics and the relationships between C and N dynamics in the formation of soil organic matter. It builds on and seeks to explain the processes by which C sequestration deep in the soil, reported by Fisher et al. (1994, 1995), occurs under introduced pastures in the lowland savannas of South America.

Intensive sampling was carried out at the chosen sites in Brazil (Itabela, Goinia and Campo Grande), Colombia (Matazul Farm and Carimagua) and Venezuela (Guanare and Barinas). 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. Preliminary results show the methodology works well. Root decay studies were also installed in clay pots in the soil.

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 4 mm, which represent about 60% of the total soil mass. The implication is that the C accumulation is associated with the aggregate fraction greater than 4 mm. These aggregates will be the focus for further separation and analysis in the next quarter.

Analysis of samples from both Guanare and Barinas 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.

In Brazil, regrowth *Brachiaria brizantha* pastures of different ages measured over 45-day intervals showed that regrowth rate depended on pasture age. Two-year-old pastures regrew at 2.2 $g/m^2/day$ while one that was 7 years old only regrew at 1.2 $g/m^2/day$. Rate of regrowth 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.

Litter decay measurements at Itabela suggest 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 explains the source of the sequestered C deep in the soil.

The methodology to evaluate root distribution with depth in pastures of different ages was evaluated. Preliminary measurements of root dry matter revealed that the root mass diminishes drastically in the deeper soil layers. Image techniques are being calibrated for use in studies of root dynamics.
[M.J. Fisher]

Output 2 - ***Activity v) determine the effects of soil biota on soil fertility and structure***

Studies on the dynamics of earthworm and other macrofauna populations have continued in the llanos of Colombia together with research on their effects on soil fertility and structure. A characterization study of soil macrofauna was initiated in the forest margins of Pucallpa, Peru and in the cerrados of Uberlandia, Brazil. A study of the macrofauna in the hillsides of the Cauca valley has been reported previously elsewhere (Hillsides program annual report 1994-95).

The main objectives are;
- to evaluate the diversity and ecological functions of the predominant species
- to develop strategies to manipulate fauna communities to improve the productivity and sustainability of production systems
- to evaluate macrofauna as indicators of soil quality

Highlights

- Grass/legume pastures markedly increase soil fauna biomass in the savannas of Colombia and Brazil and in the forest margins of Peru.

Population dynamics of earthworms in Carimagua.

Dynamics of earthworm populations were followed over an 18-month period in native savanna and the long term *Brachiaria decumbens/Pueraria phaseoloides* pasture. Previous results (Tropical Lowlands Ann. Report 1995) showed that the native savanna has eight species while the improved pasture has seven species, both include the same range of diverse epigeic, anecic and endogeic species (i.e surface feeders and dwellers; surface feeders but soil dwellers and soil feeders and dwellers respectively). An updated list of species found in various sites in Carimagua is included with the names of four species new to science (Table 13).

Table 13. List of species found in different ecosystems at Carimagua

Species	Family	Location[+]	Ecological category[++]	Adult max. size[b]	
				Mm	g
Andiodrilus yoparensis sp. –nov.	Glossosc.	NS, IP, GF	Endogeic	140,	2.50
Andiorrhinus ofeliae sp. –nov.	Glossosc.	NS, IP	Endo-anecic	200,	6
Andiorrhinus sp. 2	Glossosc.	NS	Endo-anecic	#	
Mortiodrilus carimaguensis sp. –nov.	Glossosc.	NS, IP	Anecic	250,	25
Martiodrilus sp. 2	Glossosc.	CG	Anecic	#	
Pontoscolex corethrurus	Glossosc.	AP	Endogeic	#	
Pontoscolex marcusi??	Glossosc.	AP?	Endogeic		
Glossodrilus sikuani sp. –nov.	Glossosc.	NS, IP, GF	Endogeic	60,	0.20
Pheretima sp.	Megasc.	CL	Epigeic	#	
Dichogaster sp. 1	Octoch.	NS, IP	Epigeic	#	
Ocnerodrilidae 1	Ocnerod.	NS, IP	Endogeic	25,	0.015
Epigeic 1	?	NS, IP, GF	Epigeic	#	
Epigeic 2	Glossosc.?	CL, GF	Epigeic	#	
Epigeic 3	?	GF	Epigeic	#	

[+] NS native savanna, IP improved pasture, GF gallery forest, AP African palm culture, CL Carimagua lake, CG Caño Gloria, near Carimagua.

[++] Anecic, live in the soil but feed on the soil surface; Epigeic, live and feed on the soil surface; Endogeic, live and feed in the soil. [b] Size in millimetres and weight in grammes, # Not processed

Monthly monitoring of the soil to at least 50 cm depth revealed a changing pattern associated with soil moisture (Figure 17). Individual numbers of species per m^2 increased with the beginning of the rains in April and decreased from July onwards into the dry season. Earthworm biomass was much greater under the improved pasture compared with the savanna over the whole season (Figs. 18 and 19). This is mainly the result of the large increase in the population of the anecic worm *Martiodrilus carimaguensis* as reported previously from limited samplings (Decaens et al., 1994). The average density and biomass of earthworms was 49.8 individuals m^2 and 3.3 g m^2 under the savanna and 80.1 individuals m^2 and 57.9 g m^2 under the improved pasture, respectively i.e an average 17-fold increase in earthworm biomass under improved pastures compared with the native savanna. Numbers of surface casts of the anecic species, *M. carimaguensis*, followed a similar pattern to that of population densities with much greater numbers counted under the improved pasture (around 23 casts m^2 $month^{-1}$ on the improved pasture compared with 7 casts m^2 $month^{-1}$ on the savanna).

A positive correlation was observed between the number of casts per unit area and numbers of individuals in the top 10 cm soil depth (Figure 20). This finding may be particularly useful as a simple tool to estimate earthworm numbers.

An on-farm study at Matazul completed in 1995 was used to compare the on-station results from Carimagua with younger pastures established with a rice crop in 1989 and re-sown to improved pastures again with a rice crop in 1993. The treatments included;

1. Native savanna with traditional burning management.
2. Grass only pasture (*Brachiaria dictyoneura)* established with rice in 1989
3. Grass only pasture (*B. dictyoneura*) originally sown with rice in 1989 but renovated with rice in 1993.
4. As for 3. above but with the legumes *Arachis pintoi,* and *Centrosema acutifolium*
5. Rice monocrop since 1989.

Table 14 shows that greatest earthworm biomass was observed in the grass/legume pasture with the least biomass in the rice monocrop. This confirms the original findings from Carimagua that improved pastures stimulate earthworm and other fauna populations. In Matazul this occurred even though the predominant earthworm in Carimagua, *M. carimaguensis*, was absent in the on-farm trials. Perhaps of greater importance to note is the earthworm:termite ration which clearly decreases with poorer pastures (pasture without rice rotation) and monocropping i.e. the more degrading systems.

Population survival strategies

There are very few reports on the ecology of soil macrofauna in the tropics but such information is needed to develop strategies whereby populations can be manipulated to favour beneficial soil organisms. The seasonal variation in earthworm activities were monitored during the same study as that reported above (Jimenez*et al.*, 1997a,b).

Two endogeic species, *Andiodrilus yoparensis (nov. sp).* and *Andiorrhinus ofeliae (nov. sp.)* have little or no strategy to survive the dry season. They descended a few tens of cms into the soil (30-50 cm) and remain there in a sate of quiescence. Many individuals appeared to die and survivors began reproduction in the early wet season.

Table 14. Macrofauna biomass (g/m^2) under 5 different land use systems

	Pure pasture with cut rice rotation	Pure pasture with rice rotation	Grass/legume. pasture with rice Rotation	Savanna grazed/ Burned	Rice monocrop
Endogeic earthworms	3.9	4.62	6.03	3.19	1.46
Epigeic earthworms	0.0	0.0	0.0	0.32	0.0
Isoptera (termites)	7.14	3.25	2.17	2.35	1.88
Earthworm: termite ratio	0.54	1.42	2.78	1.47	0.78
Fomicidae (ants)	0.15	1.23	0.2	0.36	0.02
Coleoptera (beetles)	1.46	3.2	0.75	2.37	0.2
Arachnida (spiders/mites	0.04	0.12	0.03	0.01	0.01
Myrispoda (millipedes)	0.0	0.0	10.0	0.0	0.0
Other invertebrates	0.16	0.19	3.29	0.77	0.28
TOTAL	12.86	12.62	12.46	9.64	3.85

Glossodrilus sikuani (nov. sp). combined two strategies - 1) quiescence of individuals coiled up inside a cavity lined with mucus and 2) production of cocoons at the end of the wet season in November. Quiescent individuals became active and cocoons hatched at the beginning of the rains.

The predominant species *Martiodrilus carimaguensis*, exhibited a diapause and differing patterns for adults and juveniles. Juveniles were active for only 4 months April to July, whereas adults remained active until December (8 months). Individuals descended to 60-100 cm depth at the onset of the dry season and built an aestivating chamber in which they coil themselves up, empty their gut contents, and remain inactive until the next rains. These worms also sealed their galleries by constructing several septa in each tunnel from cast material to avoid moisture loss. The adults begin their reproductive behaviour and cocoon formation after the juveniles have become inactive in August.

Data was also collected on the vertical distribution of this earthworm in the grass/legume pasture during the season. The average depth was 30.1 cm with a minimum in may (13.5 cm) and a maximum during the dry season (47.6 cm). More than 50% of the population was located in the top 30 cm in the wet season and descended to around 80 cm depth before the onset of the dry season.

This study is the first to have considered the population dynamics of a tropical anecic species and their responses to changes in the natural environment. Roots of grasses and legumes were observed to grow into the casts of *M. carimaguensis* in burrows but the role of the casts in promoting root growth has not been determined.

The small oligohumic endogeic species of the family Ocnerodrilidae descended deep into the soil during the onset of the dry season and remain there inactive until the rains. They are found living on rich casts deposited by *M. carimaguensis*. A feature of this observation is that the endogeic species decompacts the casts at these lower depths.

These results illustrate the complexity of the macrofauna communities even in acid soils which are generally considered to be relatively poor in fauna. An important factor to emphasize in these studies is the observation that earthworm populations in savanna pastures established after native savanna contain the same species as those found under native pastures. One of these species, the anecic worm *M. carimaguensis.*, has a greatly increased population under improved pastures. This contrasts with studies of earthworms in pastures established after forest in Amazonia which are overdominated by one exotic species, *Pontoscolex corethrurus* with a consequent loss of most of the native species

Macrofauna populations under native and improved pastures in the forest margins of Pucallpa, Peru

Soil fauna populations were characterized in native pastures, improved grass only pastures (*Brachiaria decumbens*) and grass/legume pastures (*B. decumbens* and forage legumes) on four farms in the Pucallpa region which have been the subject of 10 year old trials on forages. The mean botanical composition of the four farms at the start of the measurements were;

Grass only pastures: 56% *B. decumbens*, 17% legumes, 12% weeds and 15% native pasture species.

Grass/legume pastures: 40% *B. decumbens*, 32% legumes, 13% weeds and 13% native pasture species.

On the finca Cabrera (Farm I) a native re-growth (purma) following cassava cropping was included in the study (Control 1). A similar fallow regrowth was used as a second control on the farm Romero (Control 2). Fauna were collected from the surface litter and humus, 0-10, 10-20 and 20-30 cm soil depth using the methodology recommended by the Tropical Soil Fertility and Biology program (Anderson and Ingram, 1989). The results are summarized in Tables 15, 16 and 17. Data from each of the four farms showed consistent trends of greatest fauna populations in the grass/legume treatments (grazed paddocks) followed by the grass only and native pastures treatments. Earthworms were also found in greater abundance (g/m^2, Table 15) and density (individuals m^2 ,Table 16) in the grass/legume pastures compared with the other treatments. Earthworm biomass was consistently greater than any other fauna group followed by coleopteras (Table 15).
Macrofauna densities were greatest in the top 0-10 cm of all treatments and farms (Table 17).

As reported for other tropical forest margin sites the earthworm population was dominated by one species, *Pontoscolex carethrurus*, an exotic species that commonly invades land after clearing the forest (Lavelle, 1996).

Table 15. Macrofauna biomass in four farms in the Pucallpa region, Peru

	Cabrera			Romero				Tejada			Longa			Control	Control
	I	II	III	I	II	III	mg m^{-2}	I	II	III	I	II	III	1	2
Earthworms	45270	55442	234688	4614	9246	84234		40080	62482	254410	13550	32592	69138	8056	42022
Myriapods	292	2604	1872	2	161	960		6	54	5210	12	1554	1882	34	730
Arachnids	2	90	196	2	1	90		6	0	704	0	38	130	196	1056
Ants	98	144	1252	74	44	376		198	22	350	318	390	1222	706	1090
Coleopteras	88	4260	5276	2328	737	1904		924	143	458	166	24	1452	2776	1998
Termites	0	0	4	26	401	462		0	2	0	1170	2036	10108	776	62
Other Invertebrates	4	2726	998	110	461	2176		22	535	3802	382	14	4102	76	8198

I = Native pastures; II = B. decumbens; III = B. decumbens/legumes

Table 16. Macrofauna density (ind. m^{-2}) in pastures of four farms in Pucallpa, Peru

	Cabrera			Romero			Tejada			Longa			Control	Control
	I	II	III	I	II	III	I	II	III	I	II	III	1	2
Earthworms	158	330	869	62	110	541	216	148	653	96	234	390	131	384
Myriapods	14	53	67	2	18	31	3	4	82	3	45	56	5	14
Arachnids	2	10	3	2	1	8	2	0	21	0	3	7	5	8
Ants	88	86	702	51	82	203	30	9	50	147	43	307	174	152
Coleopteras	14	38	69	11	39	69	18	13	19	16	2	32	56	26
Termites	0	69	2	10	191	144	0	1	0	214	627	1376	162	38
Other Invertebrates	4	27	19	15	14	35	6	14	67	4	2	38	2	24

I = Native pasture; II = B. decumbens; III = B. decumbens/legumes

Table 17. Vertical distribution of macrofauna density (ind $.m^{-2}$) in four farms in the Pucallpa region

Farm name	Pasture	Litter	0 – 10 cm	10 – 20 cm	20 – 30 cm
Cabrera	Native pasture	19	237	27	0
	B. decumbens	96	480	30	6
	B. decumbens/ Legumes	330	1294	122	16
Romero	Native pasture	42	101	10	0
	B. decumbens	104	338	11	10
	B. decumbens/ Legumes	157	712	136	26
Tejada	Native pasture	27	232	14	0
	B. decumbens	15	160	14	0
	B. decumbens/ Legumes	61	784	38	8
Longa	Native pasture	48	400	32	0
	B. decumbens	38	798	86	32
	B. decumbens/ Legumes	219	1779	178	29
Control	1	106	330	96	14
Control	2	95	400	102	48

Macrofauna populations under native and improved pastures in the cerrados of Uberlandia, Brazil

A survey of soil macrofauna was completed in March 1997 on two farms in the Uberlandia region of Minas Gerais concentrating on surface living fauna. The soil at Santa Inêz was a clay loam Oxisol while at the farm Cachoeira the soil was a sandy loam. The litter layer and two soil depths 0-5 and 5-10 cm were sampled. Earthworms were not sampled in this collaborative study with EMBRAPA-CPAC and ORSTOM. The numbers of individuals of soil fauna found in the litter or surface humus, 0 - 5 cm and 5 - 10 cm soil depth are shown in Figure 21. On either soil type greatest numbers of fauna were noted in the grass/legume pastures especially in the litter/surface humus layer. Total numbers were similar for the native cerrado and grass only pastures.

Future studies

Studies are on-going in the Culticore experiment which are examining the movement of earthworm populations to and from adjacent areas under different cropping and pasture management regimes. The aim of this work is to determine if soil fauna populations can be manipulated by spatial arrangements of crops and pastures where the pasture phase is used to build up fauna populations which may migrate into cropped areas where fauna populations have been depleted. A modelling exercise on populations of *M. carimaguensis* has also been initiated with a pre-doctoral student as part of the continuing collaboration with the University of Paris/ORSTOM, France.

Conclusions and Summary

Improved pastures especially those containing legumes stimulate the development of a diverse and active soil fauna population when compared with either the native savannas or monocropping systems in savannas and forest margins. Data from the hillsides (Feijoo, Hillsides Annual report 1994-95) indicated that the secondary forest and some cropping treatments had greater biodiversity of fauna including earthworms when compared with native and introduced pastures. However in this study the pastures were generally degraded compared with the other land uses and especially when compared with cropping systems which had received large amounts of organic matter in the form of chicken manure. These combined results demonstrate that fauna flourish where there are increased inputs of organic matter from plant primary productivity. Systems that are degrading for whatever reason appear to lose the fauna populations relatively rapidly.

Where the large anecic worm (*M. carimaguensis*) is present the number of surface casts can be used to estimate earthworm numbers. The earthworm:termite ratio as well as earthworm numbers may serve as an indicator of soil quality for savannas and forest margins.

Previous studies (Tropical Lowlands Annual reports 1994/1995; Project PE-2 report 1996) have shown that;

- earthworms stimulate both N and P mineralization and cycling via casting and associated digestion processes within the worm gut
- water infiltration rates are greatest where earthworm numbers are greatest suggesting an important role for earthworm galleries in water and nutrient movements through the soil profile
- casts of *M. carimaguensis* have higher amounts of large water-stable aggregates (3.15-5 and 5-8 mm), greater amounts of soil carbon (Guggenberger *et al.*, 1995; 1996a) and greater amounts of labile organic-P than the bulk soil (Guggenberget et al., 1996b)

- casts of *M. carimaguensis* are particularly enriched in slightly decomposed plant residues in the sand-size separates i.e SOM not involved in organo-mineral complexes. This carbohydrate-rich plant debris is probably responsible for the greater structural stability of the casts (Guggenberger et al., 1995; 1996a)

One can conclude from this work that to establish earthworms in sufficient numbers and biomass to significantly alter soil properties (> 30 g fresh wt m2, according to Lavelle, 1996), a productive plant component is needed to supply the fauna with carbon and energy. Once established the earthworm population can increase nutrient cycling, soil structural stability and water infiltration rates. The latter two functions of earthworms are important where soil is compacting and/or losing its structural ability. Increased water infiltration may however result in negative effects if leaching of nutrients below the rooting depth is of significance e.g with the incorporation of rapidly decomposing green manures and other plant residues.

[J.J. Jimenez, T. Decaens, J. Schneidmadl, M. Ayarza, L. Rodrigues Univ. Brasilia, L. Vilela EMBRAPA-CPAC, M. Brossard, P. Lavelle, A. Moreno, W. Zech, G. Guggenberger, K. Reategui, J. Aviles, G. Celi (University Nacional de Ucayli), G. Sanchez, J. Sanz, R. Thomas]

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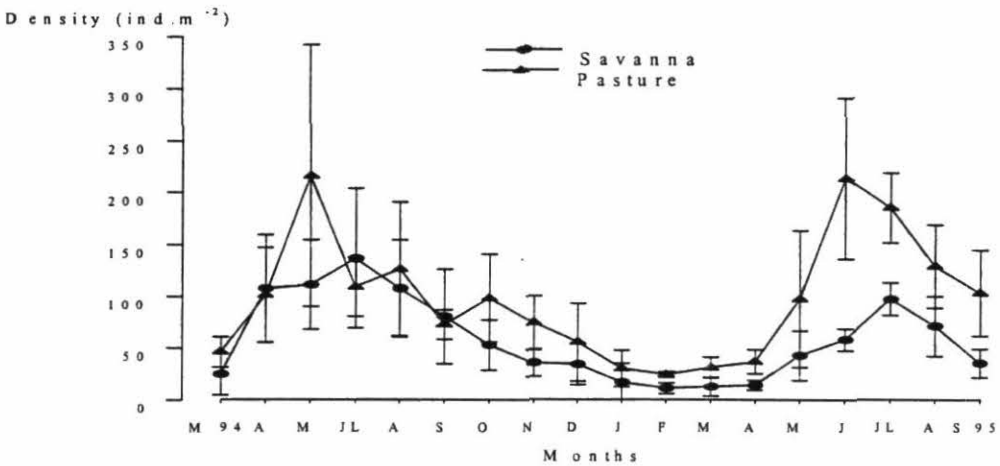


Figure 17. Monthly changes in earthworm density at Carimagua (individuals m^{-2}).

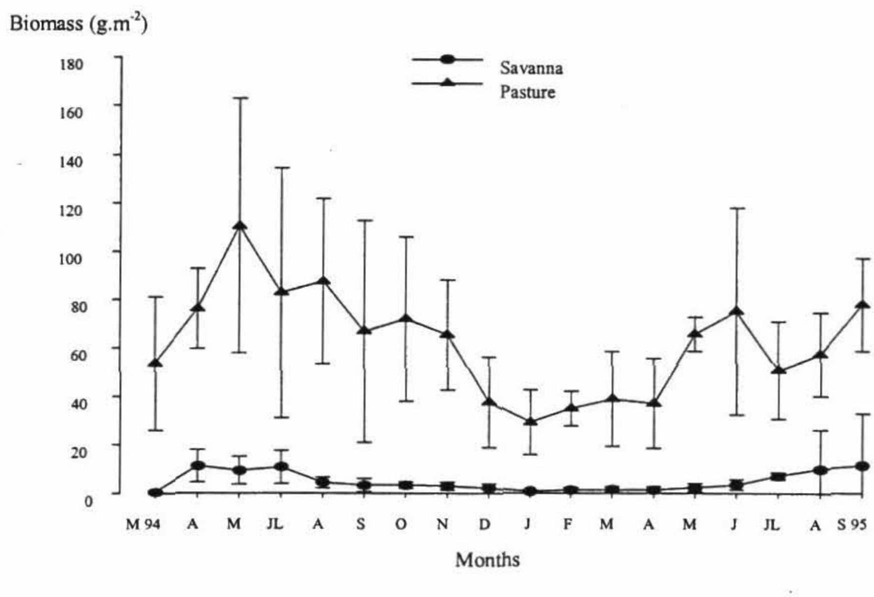


Figure 18. Monthly changes in earthworm biomass (g m^{-2}).

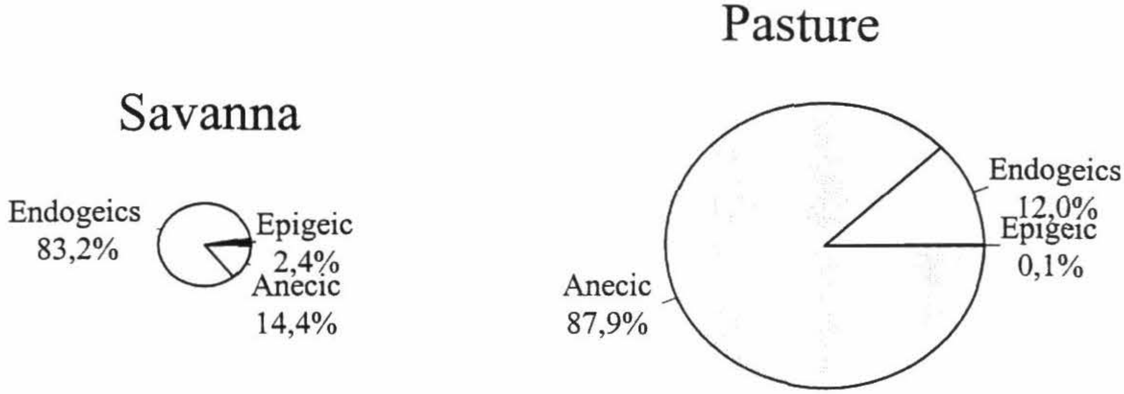


Figure 19 Annual relative contribution of earthworm categories to the total earthworm biomass. The size of the circles are proportional to the total biomass.

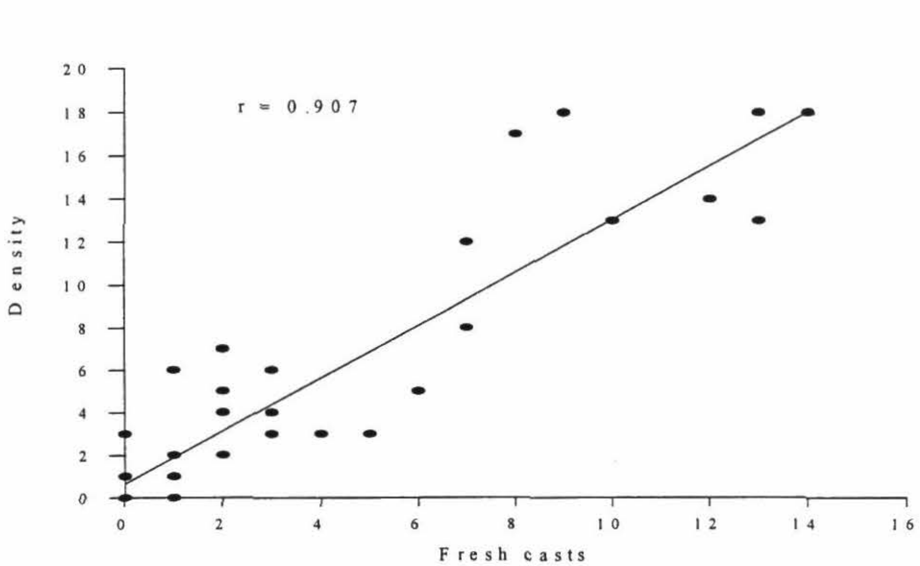


Figure 20. Relationship between the number of individuals m^2 and the number of fresh casts in a grass/legume pasture. Data obtained during the rainy season from April to December, 1994)

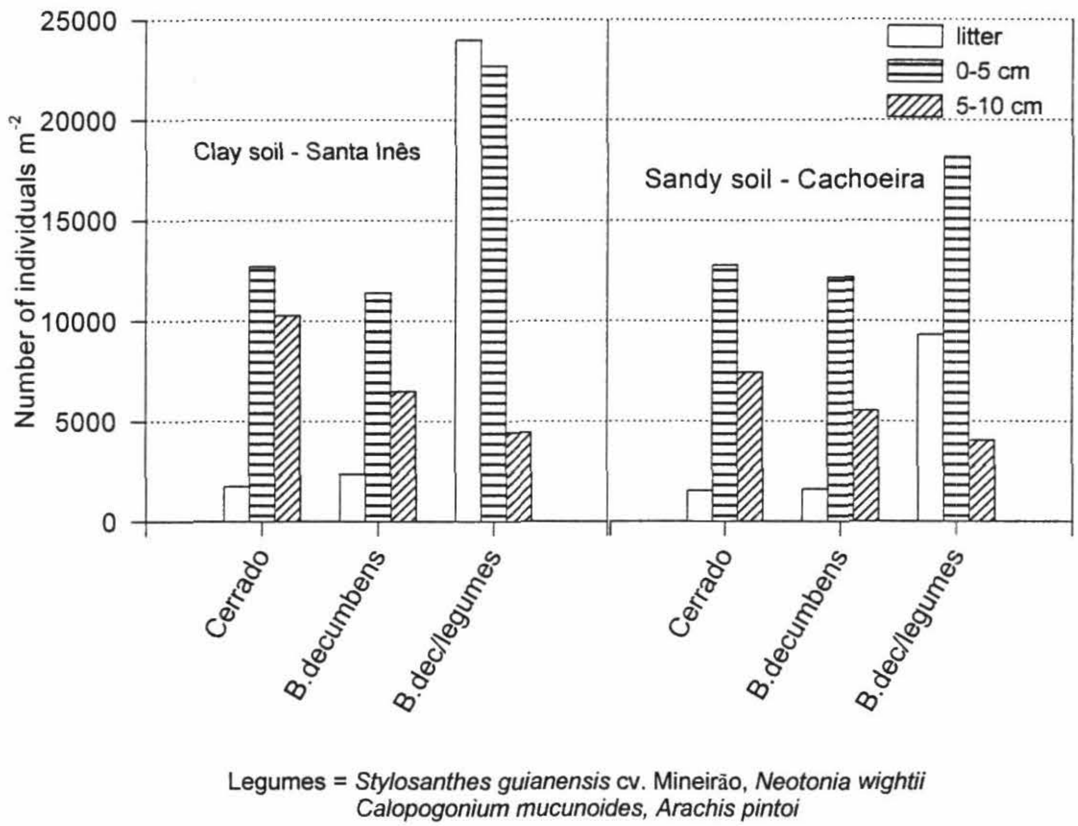


Figure 21. Macrofauna density in two on-farm studies

OUT PUT 2 - ***Activiyty vi) Strategies developed to protect and improve soil quality.***

Effect of time of use of soil with rice in the physical conditions

The continuous use of soils in agriculture, produces a decline in yields. With the purpose of studying the evolution of soil physical and chemical characteristics under continuous rice in Casanare (Llanos Orientales), a survey of farms sowing continuous rice during different periods of time elapsing from 0 to twenty years was done. Real times of cultivation were 0, 1, 2, 3, 4, 10 and 20 years.

In each farm and in a representative area, a sampling unit of 1 ha was identified. In this area three sites were chosen and a hole to a depth of 50 cm dug; soil was sampled at different depths 0-10, 10-20 and 20-30 cm.

Results show that under the conditions of permanent use of harrows, a common practice of soil preparation, the volumetric properties of the soil have changed drastically. Fig 22 summarizes the changes in total porosity and pore size distribution of the soil. The top part of the figure shows the values of these properties before the soil is under cultivation for the first time. The values after 20 years of cultivation are showing in the lower part of the figure.

From the figure it is evident that the continuous use of soil under the conditions of the current management, has produced a drastic decline in total porosity. It changes from 60% to 41% in the first 0-10 cm depth, from 53% to 34% at 10-20 cm depth and from 43% to 32% between 20 and 30 cm. There has been a reduction of 20% in total porosity in the top 20 cm and of 11% below this depth.

The decline in total porosity is the result of a reduction in pore size distribution. The percentage of macropores changes from 21% to 5% in the top layer, from 10% to 3.4% in the second and from 12 to 3% in the third layer.

These changes in macroporosity have a tremendous significance in the productive capacity of the soil. It is accepted that a macroporosity bellow 10% is a limiting factor for crop production. Three important phenomena related to plant nutrition are affected by macropores: a) root growth, b) nutrient interception by roots and c) soil drainage and aeration. As the macroporosity is reduced, the soil processes than are regulated by it are negatively affected.

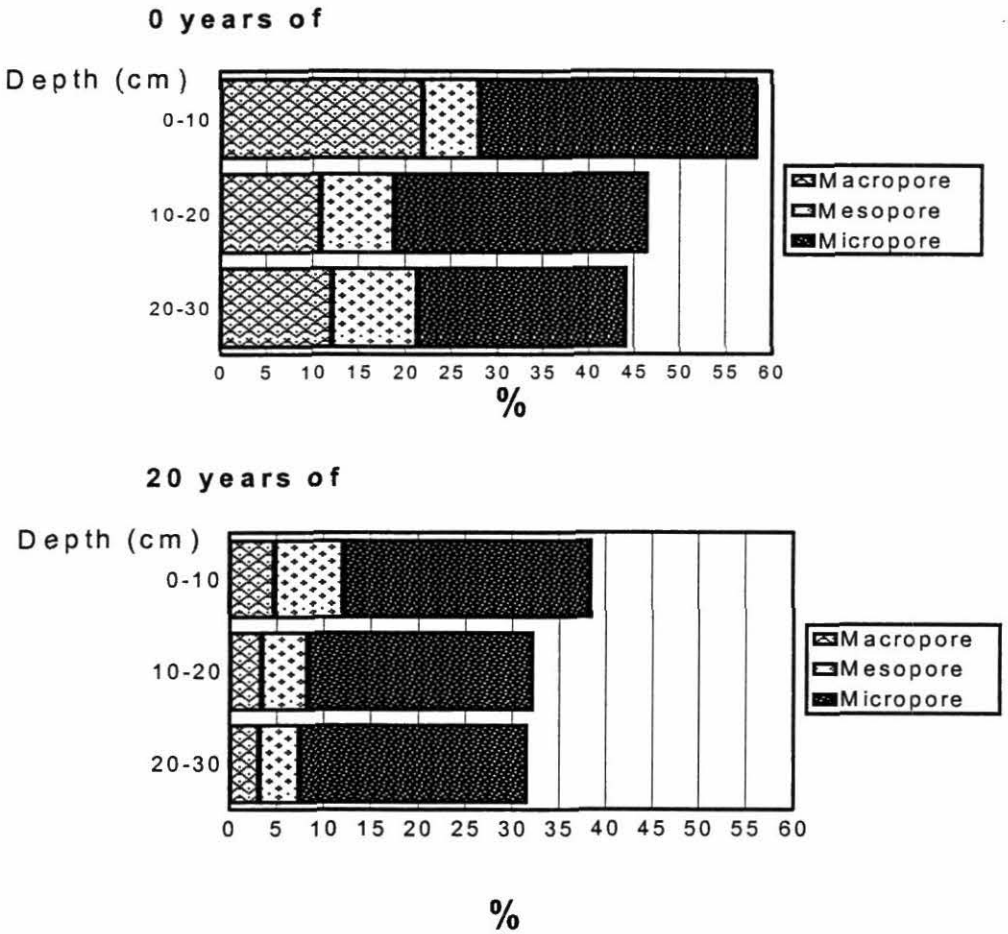
The properties that have been more affected by the time of use of the soil are shown in table 18. Void ratio, sorptivity, hydraulic conductivity and air permeability have decreased as a function of time of use, while soil strength and penetrability have increased. Susceptibility to compaction, which is the relation of actual bulk density to that obtained when a soil core sample is subjected to a presure of 200 Kpa, increased with time of use. Higher percentages indicate a more compacted soil. The soil parameters in Table 18 could be used as indicators of soil quality.

[G. Preciado, E. Amézquita, J. Galviz]

Table 18. Some soil physical properties as function of time of use in tropical soils in Casanare.

Time (Years)	Void ratio	Sorptivity (mm/seg)	Hydraulic conductivity (cm/h)	Air Permeability (cm/day)	Compactation susceptibility (%)	Soil strength (Kpa)	Penetrability (Kg/cm^2)
1	1.53	1.23	7.88	46.7	67.2	13.8	0.5
2	1.70	1.41	2.53	14.8	70.6	10.1	0.2
3	1.57	0.56	4.62	10.4	73.8	20.4	0.2
4	0.99	0.49	0.74	1.9	78.0	18.0	0.2
10	0.89	0.00	0.05	2.7	83.2	39.9	3.0
20	0.71	0.03	0.32	0.7	85.4	50.2	3.7

Fig. 22. Porosity and pore size distribution of a soil before years of continuous cultivation with rice.



Activity vi) Influence of biological and physical treatments on the building up of a cultural profile in the Llanos

As one of the main problems of the LLanos soils is its susceptibility to degradation due to the vulnerability of its structure to disruption by machinery and rains, an experiment with the objective of developing a cultural profile was established in Matazul in 1995. Basically the experiment consider two ideas: To develop a cultural profile through i) biological means using pastures and legumes and ii), through the use of chisel and the use of lime and fertilizers.

The first results on soil physical conditions as a consequence of the treatments are shown in table 19. Bulk density have decreased while total porosity and void ratio have increased as a result of the treatments. However, bulk density is very high and total porosity and void ratio are very low to support a good agricultural or animal husbandry systems. The challenge is to increase the values of total porosity to 50% or around in the first 15 to 30 cm and those of void ratio to around 1.0 at the same depths.

Table 19. Bulk density, total porosity and void ratio as a response to treatments.

Treatment	Bulk density	Porosity	Void ratio
Savanna	1.77	32.80	0.50
Legume	1.66	36.40	0.58
Pasture	1.65	36.10	0.58
Pasture + Legume	1.64	36.72	0.61
Chisel 1	1.63	36.93	0.60
Chisel 2	1.56	39.98	0.68
Chisel 3	1.58	38.10	0.64

The changes in bulk density due to the influence of treatments by depth, are shown in table 20. All treatments have reduced the values especially in the first two or three depths. In the 0-10 cm layer the high value found under native savanna (1.71) was reduced to 1.33 $g.cm^{-3}$ by the use of three passes of chisel. At a depth of 10-20 and 20-30 cm all the treatments reduced the value and some of them influenced the 30-40cm layer.

Within treatments the use of legumes has reduced the values in the whole cultural profile (0-40 cm), the use of pastures and the combined effect of pastures + legumes until 30 cm. The better influence of the legumes alone, could be attributed to an enhancement in organic matter with depth, due to a better rooting.

Table 20. Bulk density ($g.cm^3$) values as a response to treatments to improve it.

Depth			Biological	Treatment	Physical	+	Chemical
(cm)	Savanna	Legume	Pasture	P + L	Chisel 1	Chisel 2	Chisel 3
0-10	1.71	1.61	1.43	1.51	1.44	1.39	1.33
10-20	1.71	1.63	1.58	1.50	1.63	1.49	1.54
20-30	1.83	1.69	1.76	1.80	1.73	1.71	1.69
30-40	1.85	1.70	1.84	1.88	1.79	1.65	1.78

Total porosity has also been affected. Table 21, shows the mean values of this property with depth. The first aspect to note is the low values under native savanna. They are extremely low and are very far from those that could be considered good for an agricultural and productive soil. Agricultural productive soils present values of around 50%. Therefore, it is critical that these values be increased and once they have been increased to maintain

them at those higher values so that soil can be stabilized. The treatments have increased the values, but there is still scope for improving total porosity.
[E. Amézquita, D. Molina, L. F. Chavez, E. Barrios, A. Alvarez

Table 21. Changes in total porosity (%) as a response to different treatments to improve it

Depth	Native	Total Porosite					(%)
(cm)	Savanna	Legume	Pasture	Pas + Leg	Chisel 1	Chisel 2	Chisel 3
0-10	34.0	37.8	44.8	41.7	44.4	46.3	48.6
10-20	34.0	37.0	39.0	42.1	37.1	42.5	40.5
20-30	29.6	35.0	32.3	30.8	33.5	34.2	35.0
30-40	28.8	34.6	29.5	28.0	31.4	36.8	31.8

OUTPUT 3. DIAGNOSTIC AND PREDICTIVE TOOLS DEVELOPED TO COMBAT SOIL DEGRADATION

Introduction and Summary

Agricultural production systems which integrate crops, forages and/or animals at varying levels of complexity can have both adverse and ameliorative effects on the soil on which the sustainability of production depends. Identifying and characterizing improved components for systems and devising strategies which have greater potential for enhancing and protecting the soil resource and the environment requires a means of evaluating the effect of components and strategies on the soil quality, and for predicting the long term effects of these systems and strategies. This output focuses on the development of diagnostic and predictive tools for monitoring system health and for evaluating the impact of alternative systems and practices on the long term health of our natural resources.

To be effective, diagnostic tools must be sensitive to changing soil quality and well correlated with system productivity. A two-pronged approach was adopted early in the development of CIAT's natural resource management program and continues to be the basis of work under this Output. On the one hand, it involves an attempt to capture in space the effects of degradative processes which have occurred through varying periods of time under a particular type of land use under similar edaphic and climatic conditions. Identifying a sufficiently broad range on this synthetic time scale is very often difficult to achieve while maintaining an adequate level of homogeneity in true spatial variables since these can impose confounding influences on interpretation of the data. Nevertheless, this approach does offer the possibility of identifying dynamic soil properties with potential use as soil quality indicators (SQIs) even if definition of threshold values is much less certain. SQI thresholds may be more rigorously and precisely defined using a more reductionist approach (our second 'prong') of controlled experiments on well-characterized sites. Such experiments are often and necessarily long-term since degradative processes themselves are usually slow and subtle. But they have the added advantage of providing a sound platform for studying and quantifying soil processes which contribute to sustainable production and soil enhancement, and enable the development and calibration of simulation models which can reliably evaluate the effects of changes in systems and their management on the natural resource base. Both opportunistic observations across the full range of existing systems and systematic monitoring of controlled prototypes, therefore, are essential components of the approach for defining both indicators and predictive tools.

Work reported under this Output for 1997 has focussed primarily on Activity 3.1 ("Identify dynamic soil properties and test their suitability as soil quality indicators"). Nevertheless, we continue to build our databases for development and calibration of simulation models and decision support systems, and we can now report progress in modelling phosphorus in the crop-soil system through a collaborative interaction with Prof. J. Ritchie's group at Michigan State University which has recently developed a P-module for the DSSAT family of crop simulation models. This collaboration is making use of the DSSAT-based datasets built up during 1993-1997 for P response, residual value and dynamics in soil under maize-soybean rotations at Carimagua. Additionally, recent modifications to the DSSAT N-module by IFDC now make it possible to simulate nitrate retention against positive surface charge on oxidic minerals at low pH in Oxisols and will enable us to make further progress in simulating mineral N dynamics in soil under systems which receive N inputs from both fertilizers, green manures and legume residues. We have shared with Dr. Walter Bowen (IFDC/CIP) datasets on mineral N leaching under various systems in the Culticore experiment and are beginning to make progress in simulating N leaching losses under prototype systems.

Progress in identifying SQIs has occurred both through the opportunistic observations mentioned above in on-farm studies in the Uberlandia region of Brazil and in the Meta Department of Colombia, and through on-station research at CPAC-EMBRAPA, Planaltina, Brazil, and CIAT-CNI, Carimagua, Meta, Colombia. On-farm studies in Brazil compared potential SQIs in sandy and clayey Oxisols with relatively long histories (> 12 years) under different systems of land use, including cultivated crops, pastures, reforestation and native savanna. Several microbiological parameters were found to be more sensitive to soil quality changes than total soil C. Fractionation of P in these systems found that applied P accumulates primarily in labile and moderately labile pools and enters into organic pools only in heavier soils which support a higher level of microbial and biological activity. These on-farm observations agree with on-station observations at Carimagua where short-term (1-4 years) fluxes of P are primarily into labile inorganic pools under the full spectrum of systems examined (continuous cropping to improved pastures). Previously reported studies on P fate under long-term (16-year-old) improved Brachiaria pastures at Carimagua found applied P partitioned amongst inorganic and organic P pools in proportions similar to those of native soil P. Failure of P to enter organic pools is thought to be indicative of a degrading system suggesting a low level of P cycling in the system (Stewart and Tiessen, 1987). For nitrogen, examination of soil N pools in an Oxisol under various production systems in the long-term crop-pasture rotations experiment at CPAC indicated that a nitrogen management index (NMI) developed by Blair et al. (1995) may be useful in evaluating N cycling in systems on similar soil types. Both indicators require evaluation across a much wider range of soil types and systems on-farm.

Preliminary results from an extensive sampling of a range of land use types in different landscape positions in the Colombian well-drained savannas showed macroaggregate contents to be highly correlated with soil organic matter content and sand content. Comparisons of aggregate size distribution in light and heavy soils under native savanna, traditional pasture and crop/pasture systems found intensified land use resulted in declines in macroaggregate contents which were also associated with reduced organic matter content. In the on-farm studies in Uberlandia, Brazil, it was found that the large macroaggregates were more sensitive to land use changes than other aggregate sizes, and that sandy soils were more susceptible than clayey soils. It remains to relate these changes with reduced productivity and/or increased environmental degradation in order to establish critical thresholds for these SQIs.

Other works in progress include the development of a portable rainfall simulator for on-farm *in situ* evaluation of the effects of raindrop impact on structural stability of soils under different land use systems. Preliminary observations of the result of soil exposure on saturated hydraulic conductivity indicate reductions in peak infiltration rates when natural vegetation is intervened by agricultural use.

Highlights of investigations under Output 3 are listed below while more detailed reports of individual activities follow.

Highlights

- Determined that the following microbiological parameters were more sensitive to changes in soil quality than total soil C for cerrados Oxisols:
  - microbial biomass C, N and P
  - microbial enzyme activity (DMSO reduction)
  - phosphatase activity
  - microbial C quotient
- Evaluated the potential of a nitrogen mineralization index (NMI) as an comparative indicator of N cycling in different systems on similar soil types
- Identified the ratio of free to easily accessible particulate organic matter (POM) as a potential indicator of soil organic matter status
- Identified dynamic soil P pools which reflect P applications in Colombian and Brazilian savanna soils under different types of land use
- Defined soil P pools for parameterization of P subroutines in crop simulation models
- Identified the need for more sensitive P fertility indicators sensitive to low P inputs and P cycling
- Characterized microfloral and faunal populations under different land use systems in different landscapes on the Colombian savannas
- Related soil macroaggregate contents to soil organic matter and sand content in a large sample of farms under different land uses and landscape positions in the Colombian savannas
- Determined the effect of agricultural intervention (cultivation) on saturated hydraulic conductivity of a selection of savanna and hillsides Oxisols.
- Designed and calibrated a portable rainfall simulator for field studies.

[E. Amézquita, D. M. Arias, M. Ayarza, G. Borrero, L. F. Chavez, A. Freibauer, D. Friesen, S. Fuhrmann, J. Galviz, R. Gross, P. Hoyos, V. Laabs, J. Lilienfein, C.G. Meléndez, H. Neufeldt, T. Renz, M. Rodríguez, M. Rivera, T. Thiele, R. Thomas, L. Vilela, R. Westerhof, W. Zech.]

Output 3 – *Activity i) Identify dynamic soil properties and develop soil quality indicators*

In 1994, a research project funded by BMZ/GTZ was initiated on the Brazilian cerrados involving collaboration between CIAT, EMBRAPA-CPAC, the University of Uberlandia and Bayreuth University, Germany. One of the purposes of the project was to identify indicators of soil degradation and enhancement. The project concludes in 1997. Results reported in this section form part of the strategic work on soil quality indicators and complement the work presented earlier in this report on agropastoral systems (see project highlights). Research was conducted both on-farm in the region of Uberlandia, State of Goiania, and on-station at CPAC-EMBRAPA, Planaltina, and are reported separately.

Also reported under this activity are on-farm studies on the Colombian savannas in Meta Department, and on-station research at Carimagua. On-farm studies include an extensive survey and monitoring of farms to identify potential soil quality indicators, funded by PRONATTA, while the work at Carimagua reported here is being carried out in conjunction with process studies reported previously under Output 2.

Indicators of soil quality under different land use systems on Oxisols: On-farm research in Uberlandia

A brief description of the farms, land uses and important points of soil management are given in Table 22. Further details are available in the various theses produced by students of Bayreuth University (see *List of Publications*). Farms were chosen in relatively close proximity on two Oxisols of contrasting soil texture: a clay loam (very fine isohyperthermic anionic acrustox) and a sandy loam (coarse-loamy isohyperthermic typic haplustox). Contrasting production systems with known history were chosen to identify promising soil quality indicators.

Table 22 Description of study sites used to determine effects of land use on soil properties

Land use	Farm name	m.a.s.l.	Years in land use	Soil	% clay content	Management
Cerrado	Fda Pinusplan	950	--	Clay loam	68	--
	Fda Sta. Terezinha	900	--	Sandy loam	18	--
Crops maize/soybean	Fda Bom Jardin	950	9	Clay loam	66	Annual disking;
	Fda Cossisa	894	9	Sandy loam	17	75-80 kg P/ha/yr
Pastures (*Brachiaria*	Fda Sta. Terezinha	950	12	Clay loam	67	Total fertilization,
decumbens Stapf)	Fda Cruzeiro	894	12	Sandy loam	17	130 kg P/ha
Reforestation (*Pinus caribaea* Morelet)	Fda Pinusplan	955	20	Clay loam	69	Init. Fertilization unknown
Reforestation (*E. citriodora* Hook)	Fda Sta. Terezinha	885	13	Sandy loam	17	Estab. with 10 g TSP per tree

Details from Neufeldt (1997)

Effect of land use on soil macroaggregates, carbon, nitrogen and sulphur contents and distribution

The objective of this study was to assess the effects of land use (continuous cropping, pasture, reforestation and native savanna) on soil aggregate size distribution and physical protection of C, N and S within macroaggregates, and to identify those soil properties that are sensitive to changes in land use when native savanna was converted to alternative systems. Management systems studied are described in Table 22. Details of the methods and results can be found in Lilienfein et al. (1997a); only salient points are presented here.

Soil aggregation

Aggregates were separated into the following fractions:

8-2 mm	large macroaggregates
2-0-0.25 mm	small macroaggregates
0.25-0.106 mm	large microaggregates
<0.106 mm	small microaggregates

In the sandy loam soil, more than 80% of the soil was found in macroaggregates (i.e. > 0.25 mm) with the largest fraction in all treatments being small macroaggregates (59-78% of the bulk soil). The large macroaggregate fraction in the continuous cropping, Eucalyptus plantation and pasture systems was slightly smaller than that of the native cerrado and the differences were most pronounced with continuous cropping. The loss of large macroaggregates resulted in an increase in smaller macroaggregates rather than an increase in microaggregates indicating that large macroaggregates consisted largely of cemented sand particles.

More than 90% of the clay loam soil was found in the large macroaggregates in all land use systems. Pasture appeared to promote soil aggregation since more large macroaggregates were present under pastures than in the cerrado soil. The deterioration of the soil structure (loss of macroaggregates) was less pronounced in the clay soil than in the sandy soil. The large macroaggregate fraction declined by 30% with continuous cropping compared with the cerrado in the clay soil and by 78% in the sandy soil. Only the large macroaggregates in these Oxisols were sensitive to changes in land use whereas smaller aggregates appeared to be stable when the soil was plowed. This may be related to the fact that large macroaggregates (>2mm) are stabilized by roots and hyphae and, therefore, are susceptible to land use changes. Small macroaggregates are stabilized by Fe and Al oxides rather than by organic matter. This indicates that for Oxisols the changes in large macroaggregates are the most sensitive fraction to land use change.

C, N and S concentrations in bulk soil samples and aggregate size fractions

The total C content of cropped sandy soils was less than that of the cerrado (see Table 25). Nitrogen concentrations were similar in cerrado and Eucalyptus plantation but were slightly reduced in soils under pastures and continuous cropping. The most notable effect was on sulphur which was reduced by 30% in all land use systems compared with soils under native cerrado. Most large macroaggregate fractions were enriched in C, N and S whereas small aggregates had C, N and S concentrations similar to that of the bulk soil.

C, N and S concentrations in the clay soil were about twice as great as those in the sandy soil. C and S concentrations did not differ much amongst the land uses. Concentrations of C, N and S in clay soil aggregates were similar to those found in the bulk soil.

These results indicate that sandy soils are more sensitive to land use changes than clay soils. Differences in the total C, N and S concentrations, the degree of enrichment in macroaggregates compared with the bulk soil and in the extent of land use change imply different mechanisms of soil organic matter protection in the clay and sandy soils. As reported in other studies, organic matter is protected against microbial attack by adsorption onto clay minerals in clay soils. In the sandy soils, C enrichment in large macroaggregates implies that organic matter is physically protected within the aggregate's fine pores. To confirm this, a mineralization experiment was conducted on disrupted macroaggregates using soils from pastures. Mineralization was measured using an aerobic mineralization test of Keeney and Bremner (1967).

For the sandy soil, mineralization rates for the bulk soil were similar to those of intact large macroaggregates. Approximately 35 mg N/kg soil were mineralized in bulk and large intact macroaggregates after 3 days. In contrast, the N mineralization rate for crushed aggregates was 120 mg N/kg soil after 3 days. This difference is assumed to be due to the mineralization of physically protected organic matter within the large macroaggregates implying that about 66% of the mineralized N from crushed aggregates originated from formerly protected organic matter.

As for the sandy soil, N mineralization rates of bulk and intact large macroaggregates of the clay soil were similar at around 40 mg N/kg soil after 7 days. Over the same period N mineralization of crushed aggregates was similar to that in intact macroaggregates, although greater mineralization was found in the crushed aggregates after 3 days incubation. The initial faster rates of mineralization in crushed aggregates implies an enrichment of easily mineralizable organic matter in the large macroaggregates.

Conclusions

Land use effects were more apparent on sandy than on clayey soils. Soil under tree plantations and cropping showed increased concentrations of smaller aggregates compared with soil under cerrado. Disruption of large macroaggregates partly explains the lower C, N and S concentrations observed especially in the sandy soils. The sandy soils contain significant concentrations of physically protected organic matter within macroaggregates. Intra-aggregate organic matter is more readily mineralizable than organic matter on aggregate surfaces and between aggregates.

Plowing disrupts sandy soils to a greater extent than clay soils. Crop-pasture rotations appear to be an option for restoring structure and function to sandy soils. For clay soils other options including crop-pastures could serve the same purpose since plowing did not result in significant deterioration.

Large macroaggregates are more sensitive to changes in land use than either the bulk soil or microaggregates.

[J, Lilienfein, W. Wilcke, H. Neufeldt, M. Ayarza, W. Zech]

Influence of land use on P pools

The phosphorus status in bulk soil and two aggregate size fractions of clayey and sandy cerrados Oxisols was studied under the four land use systems described above (Table 1). Composite soil samples (0-12 cm) taken at the beginning of the rainy season were separated into large (2 - 8 mm) and small (0.25 - 2 mm) macroaggregates. Phosphorus in the bulk soil and macroaggregates was partitioned according to a modified Hedley procedure into the following fractions: Olsen ($NaHCO_3$)-Pi and -Po, NaOH-Pi and -Po, hot concentrated HCl-Pi and -Po and residue P (determined by ignition and extraction with 1 *N* H_2SO_4). P binding was examined using ^{31}P NMR spectroscopy on dialyzed, freeze-dried 0.1 *M* NaOH extracts.

Total P concentrations were three times higher in the clayey than in the loamy soil (Table 2). The largest P fraction was the NaOH-soluble P (33-55% of the total P concentration). Generally, P concentrations followed the order NaOH-P > HClhc-P > Residual-P > Olsen-P. A smaller percentage of the total P was plant available in the clayey soil than in the loamy soil, probably due to a higher content of Fe oxides and consequent greater fixation capacity in the former. Although pastures and plantations received P fertilizer inputs, only cropped soils showed a significant enrichment in total P content. Some P was exported in cattle products in the pasture systems whereas inputs into plantations were relatively minor in relation to total P contents and, consequently, were probably not detectable.

Table 23. P fractions in the bulk soil of two Oxisols under different land uses on the Brazilian savannas

Land Use*#	Olsen		NaOH		HClhc	Residue	Total
	Pi	Po	Pi	Po	Pi	Pt	P
			(mg P / kg soil)				
Loamy Oxisol							
Cerrado	2.5 a	3.3 a	14 a	24 a	36 b	15 a	95 a
Pasture	3.2 a	2.1 a	15 a	29 a	27 a	14 a	90 a
Plantation	5.6 a	5.1 a	27 b	33 a	34 ab	12 a	113 a
Crops	15.0 b A	3.1 a AB	53 c A	40 a AB	43 b A	16 b A	170 b A
- Large MA	17 A	5.5 A	77 B	54 A	85 B	28 B	267 B
- Small MA	14 A	2.0 B	58 A	28 B	41 A	21 A	134 A
Clayey Oxisol							
Cerrado	4.3 a	6.2 a	33 a	66 a	100 a	93 a	303 a
Pasture	4.6 a	4.4 a	33 a	82 ab	117 a	108 a	349 a
Plantation	5.8 a	6.2 ab	49 a	90 b	97 a	88 a	337 a
Crops	14.0 b	8.6 b	95 b	100 b	94 a	106 a	444 b

* on a given soil type, land use systems followed by the same lowercase letters are not significantly different.
# bulk soil or aggregate size fractions within cropped soil followed by the same uppercase letter are not significantly different.

Fertilization particularly increased easily available ($NaHCO_3$) P concentrations in cropped soils compared to the other systems. Secondary P (NaOH) was also increased under tree plantations. Only soil Pi fractions were enriched in the loamy soil whereas both Pi and Po fractions were enriched in the clayey soil. Immobilization of Pi into Po pools depends mainly on biological activity. Consequently, higher microbial biomass in the clayey soil (data not shown) together with edaphic conditions more favorable for higher growth and biological activity may explain greater immobilization and cycling of P fertilizer in systems on that soil. Residual P concentrations were similar in all land uses indicating very little movement of applied P into more recalcitrant P pools.

Only in the large macroaggregates (>2 mm) in the loamy soil and only under crops were P concentrations higher than in bulk soil (Table 23). Higher concentrations in aggregates indicates the presence of more protected P.

Dialyzed 0.1 *M* NaOH extracts of bulk soil and large macroaggregates (Table 24) were dominated by monoester phosphates and diester phosphates according to ^{31}P-NMR analysis. Inorganic P forms in the dialyzed extracts were only about 10-15% of the P measured by ^{31}P-NMR, due to the high loss of Pi during purification. The clayey soil had a greater proportion of monoester-P than the loamy soil resulting in higher monoester-P/diester-P ratios in the former. The higher monoester-P/diester-P ratio implies that Po is less plant available; higher microbial activity in the clayey soils may result in faster transformation of fertilizer P into stable monoester forms. This agrees with the results obtained by the modified Hedley fractionation. Higher monoester P proportions with the large macroaggregates in unplowed systems indicates an older intraaggregate soil organic matter than at the aggregate surfaces. In the plowed systems the monoester/diester ratio was not different between bulk soil and aggregate fractions indicating faster aggregate turnover.

Table 24. Partitioning of P compounds in the NMR extract of loamy and clayey Oxisols under four land use systems

Land Use	Aggregate size fraction	Ortho-phosphate	Pyro-phosphate	Monoester phosphate	Diester phosphate	Monoester-P / Diester-P
		NMR signal intensity (% of total intensity)				
Loamy Oxisol						
Cerrado	Bulk	5	6	40	39	1.0
	LMA	10	4	48	20	2.4
Pasture	Bulk	8	6	41	31	1.3
	LMA	18	5	46	13	3.5
Plantation	Bulk	5	6	38	40	0.9
	LMA	11	3	45	21	2.2
Crops	Bulk	15	15	39	17	2.3
	LMA	9	15	38	24	1.6
Clayey Oxisol						
Cerrado	Bulk	8	3	61	11	5.4
	LMA	-	-	-	-	-
Pasture	Bulk	8	4	65	4	14.6
	LMA	6	5	60	7	8.2
Plantation	Bulk	10	4	57	12	4.6
	LMA	9	4	59	14	4.3
Crops	Bulk	7	8	52	10	5.0
	LMA	8	9	53	12	4.3

Conclusions

Results of this study indicate that fertilizer P accumulates mainly in labile and moderately labile forms in soils, with total P concentrations depending both on parent material and texture, and on total P applied under the different land use systems. In loamy soils, inorganic P fractions are enriched and fertilization compensates for loss of organic P. In the clayey soils, P fertilization results in accumulation in inorganic as well as organic fractions due to a higher microbial activity. According to Stewart and Tiessen (1987), accumulation of fertilizer P in inorganic fractions only is indicative of a degrading system; this was the case with the loamy soils. On the other hand, increases in both inorganic and organic fractions (as found in the clayey soil) indicates a more stable system with higher microbial activity.

J, Lilienfein, W. Wilcke, H. Neufeldt, M. Ayarza, W. Zech]

Effect of land use on soil microbial biomass and activity

Microbial biomass and activity were studied in seven different land use systems on a clayey Oxisol and in three systems on a sandy loam Oxisol (see Table 25) on farms in the Uberlandia region of Brazil. Selected farms have been described previously in Table 22. Microbial biomass C was measured using a fumigation-extraction methodology. Microbial activity was measured by a modified dimethyl sulfoxide (DMSO) enzyme reduction assay (Tilman, 1997). Acid monophosphatase activity was measured after Alef et al. (1995).

Table 25. Microbial biomass and activity in soils under different land uses

Treatment[#]	Microbial-C	DMSO reduction	Phosphatase activity	Total soil carbon	C_{mic}/C
	(µg C/g soil)	(µg/g soil/h)	(µg nitrophenol/ g-soil/h)	(mg C/g soil)	(%)
Native cerrado	730	0.68 ab	549 ab	22.7 abc	3.2 c
Pine forest	538	0.49 a	406 a	20.8 ab	2.2 ab
No-till crop	511	0.48 a	464 a	22.2 abc	2.1 a
Tilled crop	428	0.45 a	385 a	20.1 a	2.1 a
Degraded pasture	716	0.97 bc	893 c	25.4 c	2.7 bc
Grass pasture	734	0.94 bc	892 c	24.3 bc	3.1 c
Grass/legume pasture	809	1.09 c	947 c	25.3 c	2.9 c
Sandv soil					
Native cerrado	465	0.56	343 b	8.9 ab	5.3
Crop	252	0.27	245 a	8.0 a	3.2
Degraded pasture	406	0.35	338 b	9.9 b	4.4

[#] Within columns values followed by the same letter are not significantly different (Tukey $p<0.05$).

Microbial biomass C was greater in the clay loam soil than the sandy loam soil (Table 25). Greater microbial biomass, DMSO and phosphatase activities, and C_{mic}/C quotients were found in clay soils under native savanna and pastures than under cropped or Pine forest soils. However, there were no differences among degraded and recuperated pastures. A similar pattern, but with smaller differences among the land uses, was observed for total soil C content. DMSO activities, but neither microbial C biomasses nor microbial C quotients, were greater in sown pastures compared with native cerrados. Similarly, microbial biomass C, DMSO and phosphatase activities, and microbial C quotients were greatest in the native savanna and degraded pastures compared with crops on the sandy soil (Table 25).

The results indicate a more rapid decline in microbial biomass and activity than in tota. soil C when cerrado soils are cropped or converted to Pine plantations. The continued carbon input from pasture plant roots is probably reflected in the higher levels of microbial activity. These results differ slightly from those reported for the Colombian savannas where there were little or no differences in microbial biomass C between land use treatments including grass pastures, grass/legume pastures and crop-pasture systems. In the latter study, microbial N and P appeared to be more sensitive to the different systems than microbial C (Tropical Lowlands Annual Report, 1995). C quotients, however, followed a similar trend in both savanna ecosystems.
Based on these studies, microbial biomass C, DMSO and phosphatase activities, and the C quotient of C_{mic}/total soil C appear to be better indicators of soil quality than total soil C.

However, the actual amounts and quotients need to be related to the soil type (in this case clayey versus sandy soils) and a wider range of land use types and stages of degradation in order to establish diagnostic thresholds.
[T. Renz, M. Ayarza, W. Zech]

Soil quality indicators of sustainable agropastoral systems on Brazilian cerrados: On-station strategic research at CPAC-EMBRAPA, Planaltina

The effect of different land use systems on soil quality indicators was studied in a long-term experiment established at the EMBRAPA-CPAC research station at Planaltina near Brasilia (15° 35'S, 47° 42' W at 1200 m.a.s.l.) in 1991. on a very fine isohyperthermic Anionic Acrustox (Dark Red Latosol) containing 52-65% clay. This experiment evaluates the integration of crops and pastures in long-term rotations at low and normal levels of fertility, and compares the effects of land use on soil properties to native cerrado treatments which are included in the trial as controls. A more detailed description of this experiment may be found in the CIAT Savannas Program Biennial Report 1992-93 and the Tropical Lowlands Annual Report 1995.

Effects of land use on particulate organic matter in bulk soil and soil

Particulate organic matter (POM) is thought to be a more sensitive indicator of changes in land use than total organic matter or carbon. POM is defined here as the soil fraction <2 mm with a density of <1.6 g cm^{-3} consisting mainly of partly decomposed plant and root material. Changes in POM reflect changes in organic matter inputs into the soil and hence changes in total soil organic matter over the longer term. Three POM fractions were defined for this study (Golchin, 1994):

1) free POM,
2) easily accessible POM loosely bound in peds 2-8 mm, and
3) occluded POM comprising old POM firmly bound in aggregates with low turnover rates.

Since the study was concerned only with short term changes, only free and easily accessible POM was studied. The following treatments from the long-term integrated crop-pasture rotations experiment were chosen for study:

1) Continuous cropping with conventional tillage, soybean/maize rotations (CT)
2) Pure grass pasture of *Andropogon gayanus* Kunth (PG)
3) Grass/legume pasture of *A. gayanus* and *Stylosanthes guianensis* cv. Minerão
4) Native cerrado savanna (NC)

Soil samples (0-12 cm depth) were taken in November 1994 just after the start of the rains and after plowing CT plots and again three months later in February 1995. Only the November data are presented here. Total POM was separated from air-dry bulk soil sieved to <2 mm. The samples were shaken in 1.6 g cm^{-3} polytungstate solution and floating particles collected. The material obtained comprised all POM between particles of < 2 mm diameter including POM out of peds crushed during sieving. Thereafter, POM was separated out of water-stable peds after sieving them to <2 mm (easily accessible POM). Free POM was calculated as the difference between total POM and easily available POM and is expressed in mg-C/g-soil.

Both grass and grass/legume pastures had higher total POM contents than crops or native cerrado (Table 26). The POM-C/total soil C ratio was also highest in pastures. The POM-N/total soil N

Table 26. Particulate organic matter and relative concentrations of POM-C and POM-N in an Oxisol under different land uses

Treatment[#]	POM (mg/g)	POM-C/total C (g/100g)	POM-N/total N (g/100g)	POM C/N ratio
			Total POM	
Continuous cropping	4.8 a	9.6 a	5.1 b	30 a
Pure grass pasture	7.4 b	12.8 b	6.1 b	35 b
Grass/legume pasture	6.5 b	11.4 b	6.4 b	29 a
Cerrado	4.1 a	8.1 a	3.5 a	37 b
			Free-POM	
Continuous cropping	2.9 b	4.2 b	2.2 b	28 a
Pure grass pasture	4.2 c	3.9 b	1.9 b	33 b
Grass/legume pasture	3.6 b	4.3 b	2.4 b	27 a
Cerrado	1.8 a	2.4 a	1.0 a	35 b
			Easily accessible POM	
Continuous cropping	1.8 a	2.6 a	1.2 a	36 a
Pure grass pasture	3.3 a	4.0 a	1.7 a	42 b
Grass/legume pasture	2.9 a	3.1 a	1.5 a	35 a
Cerrado	2.3 a	3.1 a	1.2 a	42 b

[#] values within a column and POM class followed by the same letter are not significantly different according to Duncan's multiple range test.

ratio was similar under crops and pastures and lowest in the cerrado. In all treatments, the C/N ratio of the total POM was about 1.5 times greater than values in the bulk soil (C/N = 16) indicating the relatively undecomposed character of POM. Free POM was significantly higher under cropping, pure grass and grass/legume pastures compared with the cerrado. This was probably the result of high root density of the grass and incorporation of fresh crop residues after plowing. Easily accessible POM did not differ amongst treatments.

The ratio of free POM to easily accessible POM could indicate the degree of protection of young POM in soil. In this study, the ratio decreased in the order: CT (1.6) > PG, GL (1.3) > NC (0.8).

The C/N ratio of easily accessible POM in all treatments was about 8 units greater than that of free POM, indicating that easily accessible POM was less humified than free POM and was probably more physically protected from biological attack. Also of note were the lower C/N ratios of free and easily accessible POM in grass/legume pastures compared with pure grass. This presumably reflects the input of organic material with higher N concentration and therefore lower C/N ratio in grass/legume pastures. This agrees with findings from the Colombian savannas reported earlier (e.g., Tropical Lowlands Annual Report, 1995).

Conclusions

Total POM contents were greatest under pastures followed by cropping and then the native cerrado. In pastures and under cropping, fresh plant material accumulated in the soil as free

POM. In the cerrado, relatively more new material was occluded within peds as easily accessible POM and, thus, was physically protected from decomposition.

These results suggest that the ratio of free to easily accessible POM is a more sensitive indicator of changes in soil organic matter than measures of bulk soil C or N. This ratio may also serve as an indicator of the degree of physical protection of newly added organic matter to the soil. Total POM could serve as an indicator of soil organic matter status.
[A. Freibauer, M. Ayarza, L. Vilela, W. Zech]

Effect of land use on the availability of soil nitrogen

The effect of land use on the availability of soil nitrogen was studied by separating total soil N into a labile and a stable fraction by oxidizing the labile-N with potassium permanganate. A nitrogen management index (NMI) was estimated following the concept of Blair et al. (1995) for carbon. Nitrogen released upon oxidation with permanganate is assumed to represent a more labile source of N since previous reports have indicated a correlation with potential aerobic mineralization rates.

The study used the following treatments from the long-term integrated crop-pasture rotations experiment at EMBRAPA-CPAC: native cerrado, continuous legume-based pastures, continuous soybean and maize crop rotation systems at low and high fertility, and legume-based pasture-crop rotations at two fertility levels (see Savanna Program Annual Report, 1992-93). Total-N in soil was measured with an elemental analyzer. Labile-N was estimated indirectly after extraction with 333 mM potassium permanganate according to Blair et al. (1995). Nitrogen remaining after extraction with permanganate was considered stable-N and N released upon oxidation with permanganate was calculated as the difference between total-N and stable-N. Potentially mineralizable-N was estimated by anaerobic incubation at 40°C for one week.

Three to 4 years under continuous cropping or pastures produced significant in total soil N in the 0-10 cm soil depth (Table 27). Grass/legume pasture and pasture-crop systems given low fertilizer (LF) inputs had higher total-N than the cerrado soil while pasture-crops with normal fertilization (NF) and soybean/maize rotations at both low and normal fertilization had total-N levels similar to that in cerrado soil. In no system was total-N content significantly less than that of the cerrado.

Stable-N values decreased in the order: legume pasture > soybean/maize-LF > Cerrados > Pasture-crop-LF > pasture-crop-NF > soybean/maize-NF, although differences were not significant. Labile-N was also greatest in the legume-based pastures but not significantly so. An increase in labile-N, however, was indicated by greater potential mineralization rates in the legume-based pasture, the pasture-crop-LF and the pasture-crop-NF compared with the cerrado control and the soybean-maize crop rotation systems. Sampling on 2 other occasions during the season gave significant effects on all fractions except Stable-N (results not shown).

Table 27. The effect of land use on total N, labile-N, stable-N, potentially mineralizable-N and soil mineral-N

Land use	N-fraction (kg/ha)[#]				
	N-total	N-stable	N-labile	N –potential	N-mineral
Cerrado	1567 bc	941	626	21 b	9 c
Legume-pasture	1673 a	974	699	24 a	5 d
Soybean/maize, low fertility	1518 bc	949	569	20 b	20 a
Soybean/maize, normal fertility	1450 c	856	594	19 b	20 a
Pasture-crop, low fertility	1604 a	934	670	26 a	18 ab
Pasture-crop, normal fertility	1537 b	873	664	25 a	12 bc

[#] Values in same column followed by the same letter are not significantly different (Duncan's $p<0.05$).

Labile-N was positively correlated with potential mineralization rates ($r = 0.73$, $p < 0.01$) whereas stabile-N was more weakly correlated with potential mineralization ($r = 0.54$, $p < 0.1$), indicating that permanganate-extractable-N may be useful as an index for potentially mineralizable-N.

A Nitrogen Management Index (NMI) was estimated from the data as an indicator of potentially mineralizable-N using the following equations and the cerrado soil as the reference (Blair et al., 1995):

Nitrogen pool index (NPI) (1) $=$ N-total in sample $\times$ N-total cerrado^{-1}

Lability of N (L) (2) $=$ N-labile $\times$ N-stable^{-1}

Lability index (LI) (3) $=$ L sample $\times$ L cerrado^{-1}

Nitrogen management index (NMI) (4) $=$ NPI $\times$ LI $\times$ 100

Using a reference value of 100 for cerrado, values below 100 indicate a degrading system whereas values above 100 indicate an improving system relative to the cerrado. (Alternative systems may also be chosen as a reference.) The estimated NMI of the land use systems studied were as follows:

legume-based pastures	= 115
pasture-crops- NF	= 112
pasture-crops-LF	= 110
Cerrado	= 100
soybean/maize-NF	= 96
soybean/maize-LF	= 88

Conclusions

Although the differences amongst the soil N parameters in this study were generally not significant, the observed trend in NMI is similar to that found in other studies on similar systems which indicate the degradative effects of continuous cropping and restorative effects of pastures, especially those containing forage legumes (see Ayarza et al., this report). These preliminary results, therefore, indicate that the development of an NMI may be a useful indicator of soil quality when comparing systems on similar soil types.

[R.Westerhof, M. Ayarza, L. Vilela, W. Zech]

Dynamic soil properties and potential soil quality indicators for the Colombian Llanos

Impact of land use in soil characteristics: On-farm studies in Meta Dept.

An interinstitutional project funded by PRONATA and involving the participation of CIAT, CORPOICA and the University of the Llanos (UNILLANOS) was initiated in 1996 to study changes in soil physical, chemical and biological properties caused by human intervention of the Colombian savannas. Approximately 50 farms in different landscapes (Altillanura plana, Altillanura Ondulada and Altillanura Disectada) and land use systems, representing 30% of the Orinoquia (approximately 9.8 million hectares), are being studied. Here we present results of the impact of land use on microflora and fauna populations and soil aggregation.

Table 28. Abundance of bacteria, fungi and actinomycetes under different land use systems.

	Bacteria	Fungi	Actinomycetes
		Colonies / g of soil[#]	
Vegetation			
1. High savanna	24 b	1110 a	161000 ab
2. High savanna	203 b	1180 a	314000 a
3. Medium savanna	35 b	800 ab	281000 ab
4. Low savanna	527 a	720 ab	327000 a
Land use system			
1. Traditional pasture	69 b	1450 b	219000 ab
2. Crop/pastures	54 b	850 b	312000 a
3. Annual monocrops	0 b	1500 a	154000 ab
4. Crop rotations	0 b	140 b	98000 b
5. Perennial crops	0 b	240 b	106000 b

[#] values within column followed by the same letter are not significantly different ($p < 0.05$).

Populations of microflora and fauna were very small in all agricultural systems studied (Table 28). On average, approximately 160 colonies of bacteria, 980 colonies of fungus and 232,000 colonies of actinomycetes were found per gram of soil. The dominance of the latter indicates that organic matter is mainly comprised of high molecular weight compounds which are very recalcitrant and decompose at very slow rates. In addition, it was found that fungus and actinomycetes were more abundant in the top 0 – 5 cm depth while bacteria (*Pseudomonas*) were dominant in the 5 – 20 cm depth. *Pseudomonas* bacteria are facultative and able to reduce nitrates.

Microflora and fauna populations were also affected by the type of land use. Table 29 shows the number of colonies under different vegetation and soil use systems. There was a higher number of bacteria colonies under "Sabana baja" than in other geomorphological positions, probably due to better moisture conditions. Under the other soil use systems, bacteria populations were insignificant. Fungi populations were variable but, in general, low. Actinomycetes were high in relation to the other species but not much difference was found between land uses.

The effect of three types of land use on soil aggregate size distribution was also examined in on-farm studies. Table 29 shows the aggregate size fractions for light and heavy soils under native savanna, traditional pasture and a crop/pasture rotation. In the light soil, a reduction in the percentage of aggregates > 1 mm was associated with intensified use of the soil in pasture and crop/pasture systems. Macroaggregates > 1 mm fell from 61% under native savanna to 24% under pasture and 40% under crop/pasture rotation. These changes were associated with a decline in the organic matter content from 2.7% in native savanna to 1.0% in traditional pasture. In the heavy soil, the decline in the percentage of macroaggregates (>1 mm) was less important, falling from 85% under native savanna to 75% under traditional pasture. These changes were also associated with organic matter content which declined with reduced percentage of macroaggregates.

Table 29. Effect of land use, soil texture and organic matter content on aggregation

Aggregate size#	Native savanna	Traditional pasture	Crop / pastures
		---------- % ----------	
Light soil (70 % sand)			
> 6 mm	29 a	4 b	19 ab
4 - 6 mm	4 a	3 c	5 bc
1 - 4 mm	23 a	17 b	17 b
Total	61 a	24 c	40 b
Organic matter (%)	2.7 a	1.0 c	1.6 bc
Heavy soil (35 % sand)			
> 6mm	38 a	34 a	39 b
4 - 6 mm	15 a	13 a	14 a
1 - 4 mm	31 a	29 a	29 a
Total	85 a	75 b	82 ab
Organic matter (%)	4.4 a	3.7 c	4.7 b

values within a row followed by the same letter are not significantly different ($p<0.05$).

In a sample of 50 farms, strong correlations were found between soil organic matter content and the fraction of aggregates >1 mm, and between the fraction of aggregates >1 mm and percentage of sand (Figure 23). Threshold values for soil organic matter and sand were 3.4% and 50%, respectively. Thus, for soil organic matter contents <3.4%, soil aggregation (>1 mm) declines, indicating poorer soil structure and possible soil degradation. With soil sand content > 50%, the presence of macroaggregates larger than 1.0 mm is expected to be less and soil structure is expected to be more susceptible to degradation when disturbed. These parameters could be useful as soil quality indicators.

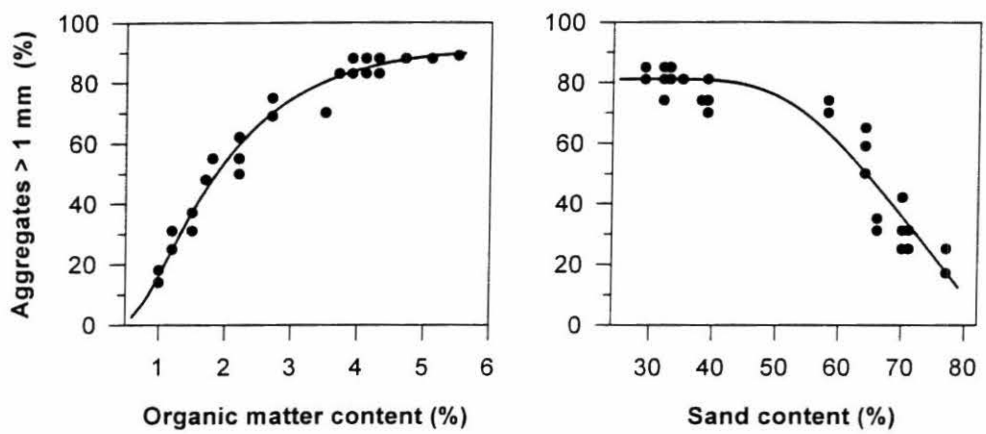


Figure 23. Relationship of soil content of macroaggregates (> 1 mm) and (a) soil organic matter content, and (b) soil sand content on farms under different land uses and in different landscapes in the Colombian savannas.

Effect of drop impact on structural stability of some soils.

Structural stability of soils is usually determined by the Yoder method in which soil aggregates under submerged conditions are subjected to the destructive action of water while under vertical oscillation in a fitted set of sieves. In this case, there are two active forces that destroy aggregates: wetting and friction with water; however, under natural conditions soil structural stability is attacked by the impact of falling raindrops at different intensities and with different kinetic energies.

The influence of the energy of impact of waterdrops falling from a height of 200 cm on changes in saturated hydraulic conductivity (used as an index of structural stability) was determined as a function of time in "natural" undisturbed soils and soils subjected to different forms of agricultural intervention. Measurements were carried out in both the savannas (at Matazul and Carimagua [Culticore experiment]) and the hillsides (San Isidro [Pescador, prototype systems experiment]) agroecosystems.

At all sites, under non-intervened ("natural") soil conditions, the peak values of hydraulic conductivity were higher than those in intervened soils (Figure 24). Hydraulic conductivity after 15 minutes was 25.4 mm h^{-1} under savanna while was it 14.9 in soil which had received 6 passes of a harrow. This represents a reduction of 58% in the capacity of the soil to conduct water. In the "Culticore" experiment, hydraulic conductivity after 15 minutes fell from 24.2 mm h^{-1} under native savanna to 16.4 mm h^{-1} under rice, a reduction of 68%. In San Isidro, hydraulic conductivity under bush fallow was 25.2 mm h^{-1} whereas it was to 16.4 mm h^{-1} under maize, a reduction of 65%. This implies that soil use at all sites has had a negative impact on the structural stability of the soils. **[D. M. Arias, E. Amézquita,]**

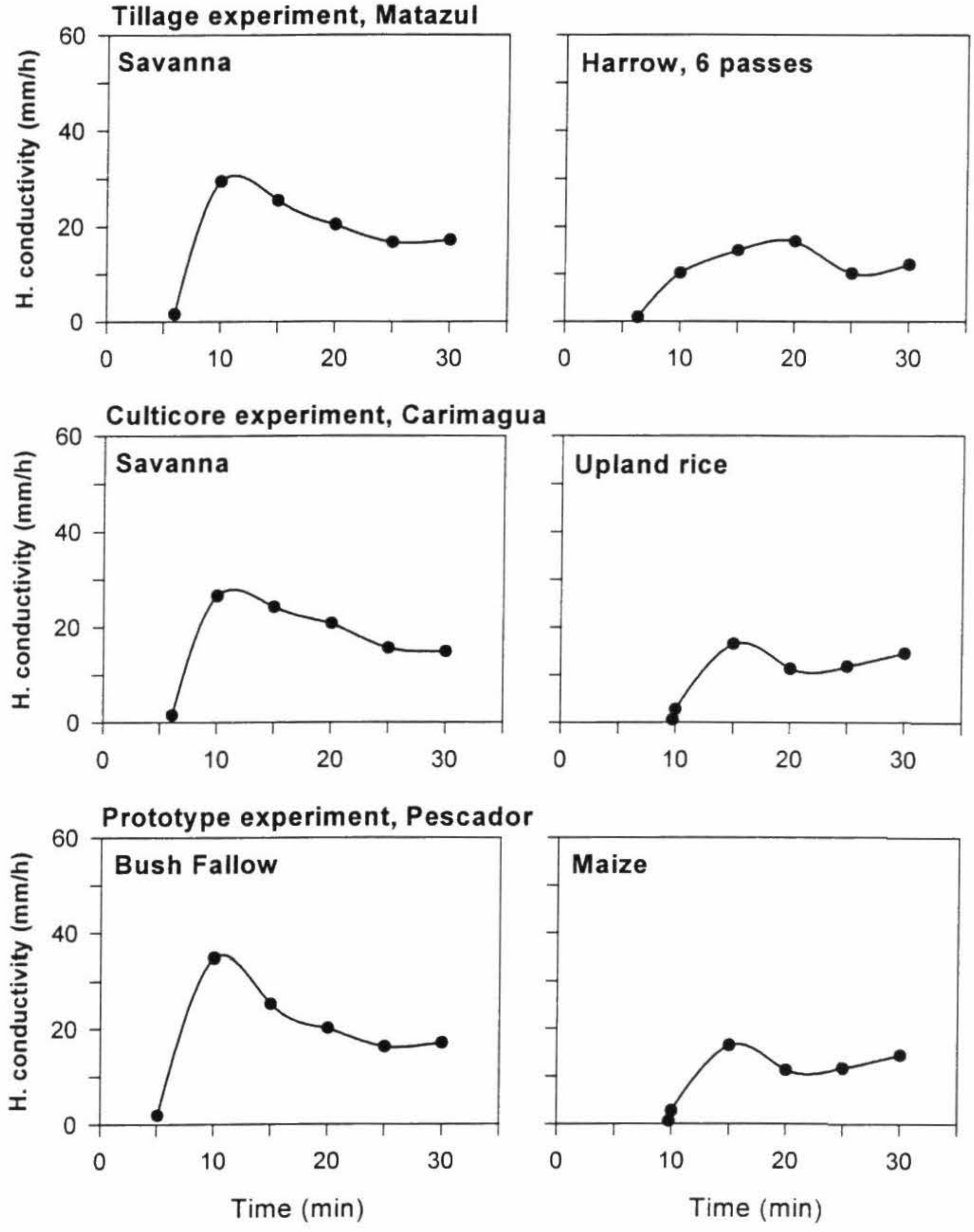


Figure 24. Effect of drop impact on saturated hydraulic conductivity of soils (0-2.5 cm depth) with different levels of use (virgin soils on left; intervened soils on right).

Dynamics of soil P pools under a maize-soybean rotation receiving annual and residual applications of P fertilizer

The dynamics of soil P fractions were studied in two P residual effectiveness experiments (at Carimagua and Matazul) for the purpose of quantifying the rate of movement of applied P into less available P pools and provide the basis for estimating the residual value of P fertilizer applications. Soil samples (0-15 cm) were taken prior to fertilization and planting

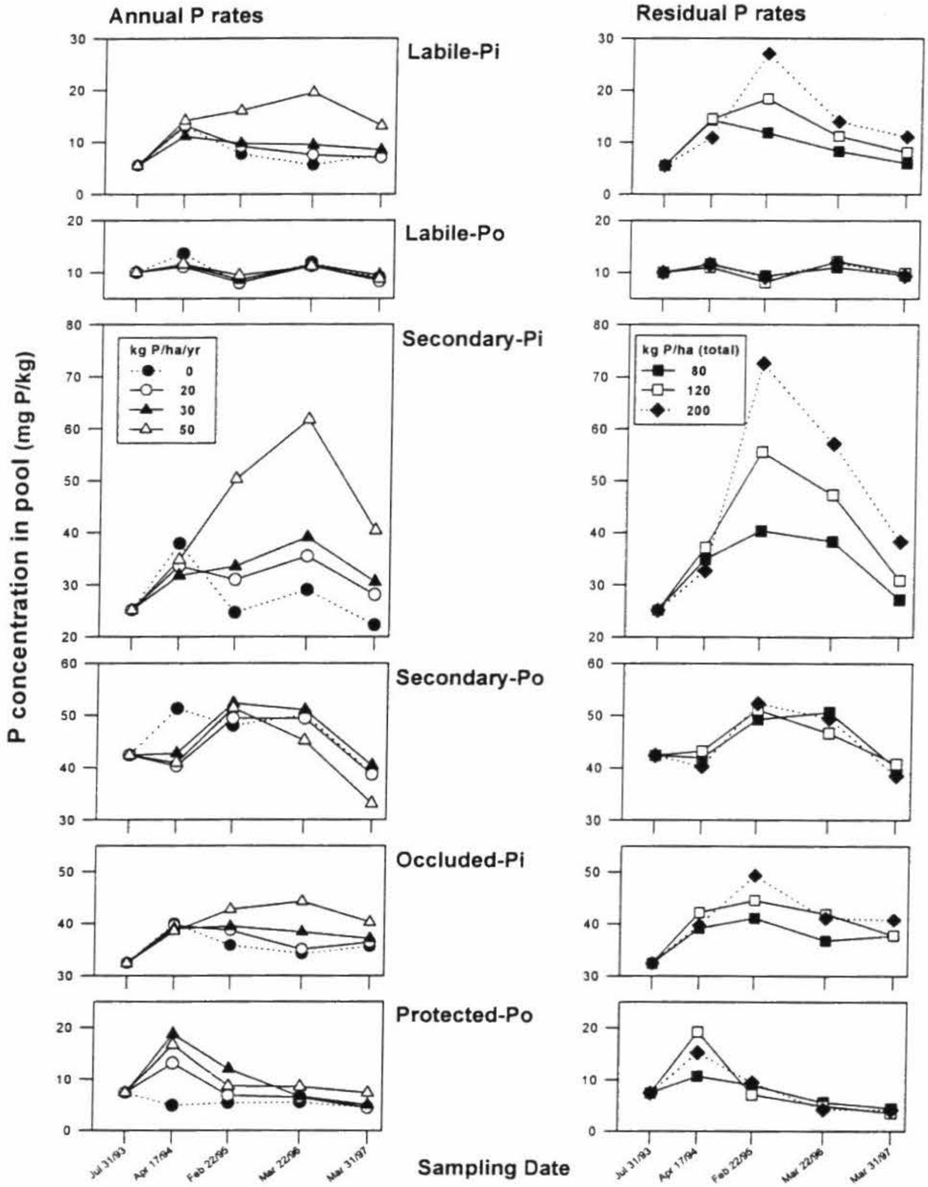


Figure 15. Dynamics of phosphorus in soil P pools in an Oxisol under a maize-soybean rotation receiving annual and residual (once only at establishment) applications of phosphate fertilizer.

each season and, for selected treatments, fractionated according to the modified Hedley procedure as described above. Fractions were combined into defined P pools according to the scheme adapted for the CENTURY soil organic matter model. Dynamic P pools were identified which were sensitive to both P applications and time since application. Such pools may serve as the basis for identifying soil quality indicators for soil P status and cycling. Results for the Carimagua experiment (planted in a maize-soybean rotation) are presented in Figure 25.

Phosphorus was applied to both annual and residual P treatments after sampling in July 1993 at rates ranging from 0 to 200 kg-P ha^{-1} as triple superphosphate. Although P applications initially produced higher P concentrations in all inorganic P pools, the observed increases did not reflect the increasing levels of P applied. Greater separation of P pools sizes occurred after two years in both annual P and residual P treatments even though the latter did not receive additional TSP applications. Only annual P applications of >30 kg-P ha^{-1} resulted in (generally) increasing concentrations of labile and secondary Pi. After increasing in the second year, pool concentrations in residual P treatments declined with time, as expected. Overall, that pool most affected by fertilizer and time was the secondary-Pi pool extracted by 0.1 *M* NaOH solution. Weaker extractants such as the anion exchange resin and 0.5 *M* $NaHCO_3$ were less sensitive to the effects of fertilization and time on changing P availability. Correlation of P pool sizes with crop response and P acquisition is required to identify which fractions and pools are most suitable indicators of soil P fertility status. Since these soils appear to be less sensitive to conventional P soil test indicators of P status, alternative tests including the FeO-impregnated filter strip method are being evaluated to indicate the dynamics of P availability in high P-sorbing soils.

Although maize and soybean residues were recycled in this experiment, labile organic P pools were unaffected by P fertilizer. Increases in secondary Po pools were not P rate sensitive. In agreement with our observations of P dynamics in the Culticore systems experiment, either of these pools, therefore, would serve as indicators of improved P cycling.
[G. Borrero, M. Rodríguez, C.G. Meléndez, D. Friesen]

Output 3 – ***Activity ii) Develop diagnostic kit to assist farmers and extensionists in resource management decision making***

Design and use of a portable rainfall simulator for field studies.

A portable rainfall simulator for use *in situ* in field studies would be very useful in obtaining a wide range of values of soil structural stability to relate to other physical parameters of soil degradation under different types of land use. Such a rainfall simulator has been designed and calibrated under laboratory conditions using needles of different diameters and lengths which were tested for drop mass and diameter under a constant head of water. Those producing drops close to 3 mm diameter were selected for the rainfall simulator manufacture. Its manufacture is now almost complete and field evaluations will commence in the coming weeks.
[L. Cobo, E. Amézquita]

Output 3 - ***Activity iii) Compile data bases to feed into simulation models and decision support systems***

Since the initiation of process-based systems research in the Culticore and satellite experiments at Carimagua and Matazul in 1993, efforts have been made to the extent possible to acquire the minimum data set necessary to run the DSSAT family of crop simulation models, and to provide a basis for the modifications required to apply them to the systems and soils of our agroecosystems. Data sets from the Culticore experiment and satellites have been digitized and, in many cases, are structured in DSSAT files. Table 30 below summarizes some of the data that are available. Selected datasets among these are currently being used in a collaborative project with Prof. J. Ritchie at Michigan State University, USA, to test and calibrate a phosphorus module developed for the DSSAT family. Other datasets are being used in a collaboration with Dr. W. Bowen, IFDC/CIP, to evaluate modifications in the DSSAT N-module for mineral N dynamics in variable charge soils which have anion retention properties. It is expected that results from these collaborative efforts will be available in 1998.

Output 3 – ***Activity iv) Calibrate simulation models to predict system performance and overcome site specificity***

No activity reported.

Output 3 - ***Activity v) Develop a decision support system to assist in resource management decision making***

No activity reported.

Output 3 - ***Activity vi) Test diagnostic tools with NARS and farmers***

Testing diagnostic tools with NARDS and farmers.

Since its development 2 years ago, the soil micro-relief meter has generated considerable interest among other researchers and farmers in the Cauca hillsides in which has been tested to evaluate soil erosion as well as accumulation behind erosion control devices such as live contour barriers. A wooden design has been made for future use in tillage experiments in the "Llanos" where it will be used to follow the process of repacking of soils subjected to different tillage treatments.

For Hillsides studies, a new smaller wooden design is planned for possible use not only for slope and erosion determinations but also for laying out level contours in the field. Given farmer interest, it is hoped that they will use this apparatus themselves to make their own assessment of erosion on their fields.
[E. Amézquita]

Table 30. Summary of Databases for Culticore and Phosphorus Residual Value Experiments, Carimagua, 1993-97[#]

Experiment (Site)	Year/Sem	Crop	Crop measurements	Soil depths (depth x interval)	Date sampled	Soil analyses	Meteorological Data	Other
CULTICORE (Carimagua)	1993A	Rice (sabana 6) Rice + Pastures	G S IH R YC PD G S IH R YC PD NPKCaMg	0-40 x 10	Apr-93	pH Al H Ca Mg K BP TN TOC TP TS TK TCa	SR RF TMX TMN RH ST	Mycorrhiza
	1993B	Cowpea Cowpea GM	G S S	0-90 X 20	Sep-93	pH Al H Ca Mg K BP TN TOC		
	1994A	Rice	G S IH YC PD LAI PD NPK	0-90 X 20	Apr-94	pH Al H Ca Mg K BP TOC N-NH4 N-N03 %W (t1)		N-15 budgets
	1994B	Cowpea Cowpea GM	G S IH R YC LAI PD S IH R YC LAI PD	0-90 X 20	Aug-94	pH Al H Ca Mg K BP TN TP TK TCa		
	1994A	Maize	G S IH YC PD LAI PD NPK	0-90 X 20	Apr-94	pH Al H Ca Mg K BP TOC N-NH4 N-N03 %W (t6)		N-15 budgets
	1994B	Soybean Soybean GM	G S IH R YC LAI PD S IH R YC LAI PD	0-90 X 20	Aug-94	pH Al H Ca Mg K BP TN TP TK TCa		
	1995A	Rice	G S IH YC PD LAI PD NPK	0-90 X 20	Mar-95	pH Al H Ca Mg K BP TN TOC PF N-NH4 N-N03 %W TX		N-15 budgets
	1995B	Cowpea Cowpea GM	G S IH YC LAI PD S IH YC LAI PD	0-90 X 20	Aug-95	pH Al H Ca Mg K BP TN TOC		
	1995A	Maize	G S IH YC PD LAI PD NPK	0-90 X 20	Mar-95	pH Al H Ca Mg K BP TN TOC N-NH4 N-N03 %W TX		N-15 budgets
	1995B	Soybean Soybean GM	G S IH YC LAI PD S IH YC LAI PD	0-90 X 20	Aug-95	pH Al H Ca Mg K BP TN TOC		
	1996A	Rice	G S IH YC PD LAI PD NPK	0-90 X 20	Apr-96	pH Al H Ca Mg K BP TN TOC TN TP TK TCa PF N-NH4 N-N03 %W		
	1996B	Cowpea Cowpea GM	G S IH YC LAI PD S IH YC LAI PD					
	1996A	Maize	G S IH YC PD LAI PD NPK	0-90 X 20	Apr-96	pH Al H Ca Mg K BP TN TOC TN TP TK TCa N-NH4 N-N03 %W		
	1996B	Soybean Soybean GM	G S IH YC LAI PD S IH YC LAI PD					

Experiment (Site)	Year/Sem	Crop	Crop measurements	Soil depths (depth x interval)	Date sampled	Soil analyses	Meteorological Data	Other
	1997A	Rice	G S IH YC PD LAI PD	0-90 X 20	Apr-97	pH Al H Ca Mg K BP TN TOC N-NH4 N-N03 %W		
	1997B	Cowpea Cowpea GM	G S IH YC LAI PD S IH YC LAI PD					
	1997A	Maize	G S IH YC PD LAI PD	0-90 X 20	Apr-97	pH Al H Ca Mg K BP TN TOC N-NH4 N-N03 %W		
	1997B	Soybean Soybean GM	G S IH YC LAI PD S IH YC LAI PD					
Residual Phosphorus (Carimagua)	1993B	Maize	G S MLZ P	0-90 X 20	Jul-93	pH Al H Ca Mg K BP TN TOC PF OP S TX TK TP TCa	SR RF TMX TMN RH ST	
	1994A 1994B	Maize Soybean	G S MLZ YC R LAI P G S YC P	0-10	Apr-94 Aug-94	BP OP PF BP		
	1995A 1995B	Maize Soybean	G S MLZ YC LAI PD IH P G S YC P	0-90 X 20	Apr-95 Sep-95	pH Al H Ca Mg K BP TN TOC PF BP OP		
	1996A 1996B	Maize Soybean	G S MLZ YC LAI PD IH P G S YC P	0-15	Mar-96	pH Al H Ca Mg K BP PF		
	1997A 1997B	Maize Soybean	G S MLZ YC LAI PD IH P		Mar-97	BP		

*Codes in columns correspond to observations/data listed below:

A = 1st semester
B = 2nd semester

G = grain
S = straw/stover/trash
IH = intermediate harvests
R = roots
YC = yield components
LAI = leaf area index
PD = phenological dates
NPK.. = nutrient analysis
P= phosphorus

pH = pH in H2O
Al = exch Al (N KCl)
H = exch H (N KCl)
Ca = exch Ca (N NH4OAc)
Mg = exch Mg (N NH4OAc)
K = exch K (Bray-2)
BP = Bray-2 P
TN = total N
TOC = total organic C
TX = texture
PF = P fractionation
N-NH4 =Ammonium
N-NO3 =Nitrate
TK=Total K
TP=Total P
TCa=Total Ca

SR = solar radiation
RF = rainfall
RH = relative humidity
WD = wind speed & direction
AT = air temperature
ST = soil temperature (10 cm)
PE = pan A evaporation
TMX = temperature max
TMN = temperature min

OUTPUT 4: INSTITUTIONAL CAPACITY ENHANCED FOR STRATEGIC RESEARCH ON SOIL, WATER AND NUTRIENT MANAGEMENT

Introduction and summary

The project has developed and/or maintained active links with nine advanced or specialized research organizations in Europe and the USA via complementary projects and the CGIAR systemwide program on Soil, Water and Nutrient Management. A total of thirty three students from developing and developed countries participate in these collaborative activities. A major international training course on soil physics is being organized for 1998 as part of the project's activities. The project will continue to seek and develop partnerships to strengthen its strategic research efforts with specialized research organizations. At the same time the project will develop closer links with participatory research activities within the centre starting with the Andean and Central American hillsides and forest margins.

Activity i) Organize and coordinate field days and workshops

See activity iii).

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

Two brochures were produced for general circulation. One outlined the Managing Acid Soils consortium (MAS) project and the other the Soil, Water and Nutrient Management Program of the CGIAR. Two updates of SWNM activities were published in 1997 and all these materials are available on the CIAT home page (www.ciat.cgiar.org).

Activity iii) Promote and participate in specialized training courses, prepare training materials

The project is participating in the organization of the III ELAFIS (Escuela Latino Americana de fisica de suelos). This training course has an international and national committee. The international committee involves ICTP (International Centre for Theoretical Physics) Trieste, Italy. In addition the project participates in a local organizing committee with Universidad Nacional, CORPOICA and the Colombian Soil Science Society. The course will involve 30 students, 15 from Colombia and 15 from other parts of the region and is planned for early 1998.

Activity iv) Publish research results in refereed journals and other publications

See publication list at the end of this report. Over the last two years the number of collaborative publications i.e. with partners, has increased from 16 to 40% of the total publications of the project.

The project's activities were also highlighted by inclusion in two radio programs which were broadcast worldwide in January and July 1997, by the British Broadcasting Corporation (BBC) as part of the weekly program named "Farming World".

Activity v) Supervise postdoctoral research, graduate and undergraduate theses

See lists of students supervised under Training.

Activity vi): Foster research linkages with institutions in the region and advanced research organizations

The systemwide program on Soil, Water and Nutrient Management became active in 1997 with all four consortia initiating the agreed plan of work. A progress report on the SWNM program was prepared and presented at the Mid-Term CGIAR meeting held in Cairo, Egypt in May. Pledged funding for 1997 program is around $850,000 to be distributed amongst the four consortia.

A meeting of MAS representatives was held in June 1997 in Bayreuth at a workshop on the finalization of the GTZ special project on indicators of land use in the Brazilian cerrados. The MAS group identified six areas for new research initiatives. These were consolidated into four areas and concept notes are currently being prepared by the group that will be initially collated by EMBRAPA-CPAC. Parts of these projects may be submitted to the Brazilian competitive grants program organized with the World Bank (PRODETAB).

A memorandum of understanding between the International Atomic Energy Agency and CIAT (PE-2) was prepared at a meeting of IAEA representatives and members of the SWNM program held in November 1996. This agreement was signed by CIAT in August 1997 and will result in cooperative projects between IAEA and CIAT combining the expertise of IAEA in the use of isotopes for increasing and sustaining soil fertility with the efforts of CIAT, mainly in project PE-2, on confronting soil degradation.

Training:

Name	Nationality	Research topic	Duration	Degree
Arnulfo Gomez	Colombian	Adaptation responses of tropical forages grown in a degraded andisol of Colombia	1991 - 1997	Ph. D.
Peter Wenzl	Austrian	Biochemical and molecular mechanisms of tolerance to aluminum and low nutrient stress in Brachiaria species	1994 - 1997	Ph. D.
Luz Elena Caicedo	Colombian	Root and shoot development in two accessions of Arachis pintoi and two species of Stylosanthes	Feb 1995 – Aug 1997	Ing. Agr.
Yaneth Conta Diaz Hernan Javier Baracaldo	Colombian Colombian	Determining root growth and distribution among native and improved pastures in the Amazonian Piedmont of Caqueta, Colombia.	1996 - 1997	Ing. Agr. Ing. Agr.

Nilsen Lasso	Colombian	Evaluation of Brachiaria species for adaptation to simulated acid soil stress in solution culture	Sept 1996- August 1997	B.S.
Adriana Hernández	Colombian	Cell wall characteristics of Brachiaria species	Jan 1996 Dec 1997	B.S.
Delphine Filipe	French	Root growth and distribution in native and introduced systems in a low P supplying andisol	May–August 1997	Diploma
Patrick Troy	USA	Genotypic variation in drought tolerance in beans	July-August 1997	Graduate
Gonzalo Borrero	Colombian	Fate of fertilizer P applied to Oxisols and modeling its residual valve for crop.	1997-1998	M.Sc.
Susanna Beuter	Swiss	Assessing the impact of adapted germplasm on the P fertility of low phosphorus supplying soils	1997-2000	Ph.D.
Marco Rondon	Colombian	Assessment of greenhouse gas fluxes in savannas	1996-1999	Ph.D.
Wilma Trujillo	Colombian	Carbon sequestration by tropical grasses	1997-2000	Ph.D.
Lucero Mariani	French	Management of soil biota	1997-1999	Ph.D.
Dora Maria Arias	Colombian	Drop impact on soil structure	1996-1998	Ing. Agr.
Leonardo Cobo	Colombian	Rainfall simulator	1996-1998	Ing. Agr.
Ibonne Balcazar	Colombian	Water movement	1997-1998	Ing. Agr.
Guimar Perea Botero	Colombian	Water movement	1997-1998	I.A.
Horacio Rivera	Colombian	Erodability of hillside soils	1996-1999	Ph.D.
Edgar Madero	Colombian	Soil structure in Mg soils	1996-1999	Ph.D.
Ana Maria Patiño	Colombian	Bio-structure of soils	1997-1998	M.Sc.
Guillermo Preciado	Colombian	Influence of land use on soil physical properties	1996-1997	M.Sc.
Hugo Ruiz	Colombian	Improvement of degraded soils	1997-1998	M.Sc.
R. Westerhof	Netherlands	Soil aggregation, N management index	1996-1998	Ph.D.
J. Lilianfein	German	Influence of land use on	1994-1996	M.Sc.

		chemical and physical properties of the cerrados		
H. Neufeldt	German	Influence of land use on chemical and physical properties of the cerrados	1996-1997	Ph.D.
T. Renz	German	Influence of land use on microbial parameters in Cerrado Oxisols	1996-1997	M.Sc.
A. Frebauer	German	Short term effects of land use on soil inorganic matter	1995-1996	M.Sc.
S. Fuhrman	German	Effect of improved pastures on amino sugars/sugar mono-mass.	1996-1997	M.Sc.
V. Laabs	German	Fate of pesticides in Cerrado soils	1996-1997	M.Sc.
R. Gross	German	Fate of pesticides in Cerrado soils	1996-1997	M.Sc.
T. Thiele	German	Podzolisation in Oxisols	1996-1998	M.Sc.
Y. Zinn	Brazilian	Soil organic matter characterization	1997-1999	M.Sc.

Complementary Projects:

Donor/Project	Duration	Total Pledge (US$)
Austrian Academy of Sciences Mechanisms of acid soil tolerance	1994 – 1997	119,426

Linkages with Advanced Research Organizations

Collaborator	Institution	Research Topic	Duration
Dr. Samira Daroub, Prof. Joe Ritchie	Michigan State U., USA	"Simulation of Phosphorus Dynamics in the Soil-Plant System"	1997-1999
Dr. Astrid Oberson Prof. Emmanuel Frossard	ETHZ, Switzerland	"Assessing the impact of adapted germplasm on the phosphorus fertility of low phosphorus supplying tropical soils"	1997-2000
Dr. Christian Morel	INRA, France	Adaptation of a ^{32}P isotopic exchange methodology to assess the dynamics of inorganic P supply in Oxisols.	1997-
Prof. W. Zech	Bayreuth Univ./ Germany	Soil Indicators of sustainable production systems	1995-1997
Prof. J. Duxbury	Cornell Univ. USA	Greenhouse gas fluxes in savannas	1996-199
Dr. J. Wilson	MLURI UK	Carbon sequestration by tropical grasslands	1998-1999
Prof. P. Lavelle	ORSTOM/Univ. Paris, France	Management of soil fauna	1994-1999
Prof. R. Lal	Ohio State Univ. USA	Erodability of hillside soils	1996-1999

5. PUBLICATIONS

Refereed Journal

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6. LIST OF DONORS

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PRONATTA, Colombia

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7. STAFF LIST

Senior Staff
Richard J. Thomas
Dennis K. Friesen
I.M. Rao
Edgar Amézquita
Edmundo Barrios
Myles J. Fisher

Associates
Neuza Asakawa
Marco Antonio Rondón

Assistants
Gloria Isabel Ocampo
Irlanda Isabel Corrales
Mariela Rivera
Gloria Marcela Rodríguez
Gonzalo Borrero
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