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SAVANNAS PROGRAM

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EXECUTIVE SUMMARY

INTRODUCTION

The Savannas Program became operational in August, 1992. Its initial activities benefited from a number of initiatives taken by various CIAT Programs before then. In 1989, the Rice and the Tropical Pastures Programs, together with the Colombian Agricultural Research Institute, ICA, and the Colombian rice grower's association, FEDEARROZ, began a substantial research project in the Colombian Llanos to integrate experimental lines of upland rice and existing commercial cultivars of pasture grasses and legumes. The Savannas Program has since continued this well-known "rice-pasture project".

In 1991 CIAT created a Savannas Working Group, which led, jointly with EMBRAPA's Center for Agricultural Research in the Cerrados (CPAC), to an ambitious study to characterize the Cerrados of Brazil. This study is based on existing secondary information, including data on farming systems, land use, and censuses. In 1991 and 1992, we also initiated a series of feasibility studies of the rice-pastures system, including a number of Delphi surveys and rapid rural appraisals in both the Cerrados and the Llanos, as part of a continuing effort to evaluate the feasibility of the technological options generated by on-going research.

At the same time CIAT contracted a Brazilian NGO, the Instituto Sociedade, Populaçâo e Natureza, to conduct a socio-economic study of the Brazilian forest margins and savannas, entitled "Settlement and Agriculture in Brazil's Forest Margins and Savannah Agro-ecosystems". All these activities, supplemented with analyses by CIAT's economists, were key components that allowed the Savanna Working Group to formulate the Program's research strategies and to select the study areas where its activities are and will be concentrated.

Implemented of Program's Strategies

The overall goal of the Program is to develop and adapt technologies to increase the productivity of the infertile acid savanna soils of the tropical Americas while maintaining or enhancing the quality of the natural resource base.

The Program's strategies to achieve this goal were set out in April, 1993, in a document entitled "Making Resource Management Plans Operational: The CIAT Savanna Program". Although presented in some detail, the Program's strategies will remain dynamic and will evolve as the understanding of the savanna ecosystem increases. At present the strategies revolve around three inter-related research areas:

(1) analysis of trends in land use patterns, leading to agro-ecological characterization of the savannas;
(2) analysis within current patterns of land use to determine the relationships of predominant farming systems with agricultural production, resource conservation (degradation or enhancement) and socio-economic circumstances; these analyses are cross-sectional since some of the trends that occur over time are also simulated in space;
(3) development of prototypes of sustainable agro-pastoral systems, based on an understanding of the bio-physical and socio-economic processes that affect resource management.

Institutional relations

From an institutional point of view, we recognize that the Program's strategies and research initiatives are only a part of the activities required to achieve sustainable agricultural development of the savannas of Latin America. The Program is therefore developing active collaboration with numerous national, regional and international research and development institutions that have comparable interests. In this context, the International Fertilizer Development Center, IFDC, outposted a senior soil chemist to CIAT in late 1992 who is an integral part of the research team. Similarly, the savanna plant ecologist of the French

IEMVT-CIRAD, who was previously assigned to the former Tropical Pastures Program, transferred to the Savannas Program.

With respect to national programs, close links have been forged with ICA, Colombia, at both the Carimagua and La Libertad experiment stations, with the establishment of a number of collaborative trials. In other different fields of activities, active collaboration has been established with the Department of Biology of the National University, Bogotá, with the Technological University of the Llanos, Villavicencio, with the Secretariat of Agriculture of the Meta Department, with FEDEARROZ, and with the Colombian National Geographic Institute (IGAC), Bogotá.

In Brazil, a Savannas Program scientist is outposted to EMBRAPA-CPAC and has established a number of on-station and on-farm experiments in collaboration with the station's scientists. In addition, we have established regular contacts with other EMBRAPA Centers: CNPAF, the rice and beans center; CNPGC and CNPGLC, the beef and the milk centers; CNPMS, the maize and sorghum center; and CNPS, the soybean center. In the savannas of Venezuela, we have established close links with the Experimental University of the Llanos, UNELLEZ, and with FONAIAP. A number of joint research projects have been prepared with several of these institutions for submission to various national an international donors. We learned recently that one of these projects based at Uberlândia, Brazil, has been accepted for funding by the German agency, BMZ.

In an effort to consolidate and standardize research methodologies, a network of workers in agro-pastoral research is being established that incorporates several of the institutions named above plus the Centre for Research in Tropical Agricultural, CIAT, in Santa Cruz, Bolivia. So far, two workshops financed by the Inter-American Development Bank have been held in Villavicencio, Colombia in 1992 and in Goiânia, Uberlândia and CPAC, Brazil in 1993.

In late 1993 the Program organized an international workshop on research on tropical acid soils, attended by representatives of five US and two German Universities, CATIE, CPAC-EMBRAPA, ICA, and the Universidad Simón Bolívar, Venezuela. At the workshop, the participants decided to create a research consortium to develop a joint research agenda for acid soils based on common sites in the forest margins, the hillsides and the savannas.

At the Grassland Congress in NZ/Australia in February, members of the Program presented four posters, including a summary of the philosophy of the long-term pasture experiment and some preliminary results, and joined in the presentation of two plenary papers, one emphasizing the need to match training of tropical forage researchers to community needs, and the other (with Dr. M. Saleem, ILCA) reviewing legume-based ley farming system in the tropics.

RESEARCH ACTIVITIES

Agro-ecological characterization

CIAT's Land Use Program (LUP) led a study of the agro-ecological characterization of the Cerrados of Brazil and part of the Llanos of Colombia. In the Cerrados, the studies were based on secondary information, which was introduced into a GIS database and was completed by the LUP in July 1992. In a follow-up workshop with various EMBRAPA Centers in September, 1992, priorities were assigned to 12 candidate areas based on their representativity, intensity of land use, perceived demand for technology and relative strength of local institutions. Four of those areas (Uberlândia, in Minas Gerais state; Río Verde, in Goiás; Campo Grande, in Mato Grosso do Sul, and Rondonópolis, in Mato Grosso) were given high priority.

The Savannas Program, in collaboration with Brazilian scientists, undertook the responsibility of performing rapid rural appraisals (RRA). The aim was to verify the findings of the initial characterization, to determine with more precision the characteristics of the main farming systems and to identify problems and opportunities in the area of resource management. The RRA's were complemented with additional secondary information and its subsequent analysis by the RRA team. The process will conclude in late 1993 with the selection of one or two sites, and the definition of research priorities for joint projects.

A similar initiative was undertaken in 1993 for a sample of the Llanos of Colombia, in the area of influence of Puerto López. Here traditional cattle ranching is in a dynamic process of change to mechanized agriculture under the influence of economic factors ant the rice-pastures technology. As in Brazil, the use, analysis and interpretation of secondary information is led by the LUP, in cooperation with IGAC. The next step is the incorporation of additional data based on socio-economic, farming systems and soils surveys, which have been collected over time by the previous Tropical Pastures Program and more recently by the Rice and the Savannas Programs.

Preliminary contacts were established with several Venezuelan institutions interested in a similar study for the Llanos of that country.

Cross-sectional studies, characterization of farming systems and participatory research

Existing farming and ranching systems in the savannas offer many opportunities to assess the implications of alternative, and highly contrasting management practices on the evolution of natural resources and on agricultural productivity. We hypothesize that some of the temporal trends in the condition of these resources is replicated over space, such that cross-sectional studies could, within the limits imposed by varying policy scenarios, provide estimates of temporal trends.

Cross-sectional studies have been started at a modest scale in the Colombian Llanos and Uberlândia, one of the high priority areas of the Cerrados. More comprehensive studies will require additional resources.

The rapid rural appraisals in the Cerrados led to the identification of a small number of farms in the Uberlândia area with sharply contrasting management, particularly in the use of inputs. There are also large differences in agricultural productivity, soil quality and economic performance, amongst others.

One of these farms, on very fragile, sandy soils, has records of inputs and outputs going back 10 years. During this time the farm was transformed from a traditional, extensive cattle ranch to a management-intensive agro-pastoral system with regular, planned rotation of crops with pastures.

Preliminary analyses shows that soybeans yields increased when planted after pastures and that the older the pasture, the higher the yield. Moreover, about half the farm is now sown to crops each year, but, because pastures planted after 3-4 years of crops are more productive, it now carries more cattle than the whole farm did before. Soil parameters are being monitored in fixed sites. The data show that the size of the soil aggregates declines under crops, but that the soil physical properties and organic matter content recover during the pasture phase of the rotation.

Brazilian researchers estimate that about half of the 78 million ha of pastures on the Cerrados suffer some degree of degradation. We hypothesize that this large area of degraded pasture, almost invariably all without a legume, provides a unique opportunity to introduce crops and renovate the pastures at the same time. These areas where these pastures occur are already heavily exploited, so that increasing pasture productivity will help prevent exploitation of the remaining areas of native vegetation.

Several exploratory and participatory trials have been established in Uberlândia on farms with contrasting soils and systems with differing fertilizer inputs. Results so far indicate that the vigorous regrowth of pasture grasses in a low input system severely reduced rice yields. But legumes, particularly *Stylosanthes guianensis* cv. Mineirao, established well in all soils. In contrast, in the high input system both corn yields (7 t/ha) and grass establishment were excellent, but here the legumes suffered badly from competition. These results have important implications in terms of compatibility of crop and pasture germplasm, which are being taken up with colleagues in the germplasm programs.

A similar strategy is being followed in the Colombian Llanos, where we are undertaking monitoring and on-farm participatory research activities on a smaller scale, again in contrasting farming systems. These studies are also supported by socio-economic characterization based on regular surveys and monitoring of whole farm inputs and outputs, which will be intensified when the senior economist joins the Program shortly.

In contrast to the Cerrados, pastures in the Colombian Llanos at present are more important than crops, particularly in those areas where soil and topographic constraints limit their potential for cropping. We are therefore concentrating in the Llanos on the potential contribution of forages to increase farm productivity and to prevent degradation. On a small number of farms and ranches that vary widely in resource endowment and management intensity, we are monitoring material input/output ratios. We have also selected fields in contrasting systems of land use, and are monitoring soil chemical, physical and biological parameters, biomass productivity and, where applicable, animal productivity.

It is implicit that as land use on the Colombian Llanos intensities, the native savanna will come under increasing pressure. We are therefore complementing the studies based on introduced crops and forage species with studies of the dynamics of native vegetation in response to system intensification. These studies are conducted at several complementary scales of aggregation.

An inventory and classification of the vegetation using satellite images of differing spectral frequencies has been undertaken in collaboration with IGAC, Bogotá, and the Ecole Nationale Agronomique of Paris-Grignon. The classifications are verified (ground truth) in field studies at Carimagua, and the extent to which trends in plant dynamics and soil cover can be detected by satellite images is being assessed.

In a census of native vegetation, conducted in collaboration with the National University of Colombia, Palmira, 150 species (108 genera of 45 families) were identified. These were classified into the main vegetation groups in the well-drained, flat savannas using statistical clustering techniques, and were related to physiographic features of the land. Two keys were prepared for the identification of the main savanna grasses, one based on vegetative characters and another on floral characters.

If native pastures are mismanaged by over grazing or injudicious burning, their species composition changes and they are said to degrade. To understand how degradation as a process is related to trends in population dynamics, a long-term experiment on time and frequency of burning and grazing intensity on native savanna is being carried out at Carimagua. Dutch students are assisting with some preliminary studies of the vegetation in the undulating "serranía" savannas with the aim of relating the species composition to management practices and soil type.

A student from the University of Paris conducted a preliminary survey of soil macro-fauna under native pastures compared with gallery forest, improved pasture and several crops. Compared with the gallery forest, the savanna had lower diversity and numbers of macro-fauna. An old *Brachiaria decumbens*/Kudzu pasture maintained the diversity and dramatically increased the populations of earthworms. In contrast, crops of rice, and especially cassava, almost eliminated macro-fauna.

Long term strategic studies

Long-term experiments have been established in the Colombian Llanos and the Brazilian Cerrados at Carimagua and CPAC-EMBRAPA research stations and on farms. The aim is to quantify the soil and soil/plant processes associated with changes in primary biomass productivity in typical systems of land use, contrasted with 'best bet' options, and to a lesser extent, animal performance. These experiments interact closely with simulation modelling and are supported by shorter-term, satellite experiments to answer more specific questions.

A long-term crop-pasture experiment began in 1991 in CPAC-EMBRAPA as a collaborative project with CIAT's former Tropical Pastures Program, and involves a large number of Brazilian scientists, who are studying various aspects of alternative cropping systems. Preliminary results have shown that mycorrhizal infestation levels and spore populations were on average 50% higher in pasture systems than in crop systems. On the other hand, water infiltration rates and the mechanical resistance of the top soil were reduced by grazing animals in the pasture systems and by machine traffic in the crop systems. Soybean leaves a large amount of residues with low C/N ratios, both above and below ground, but root biomass of soybean was similar to the pasture.

In the Colombian Llanos, the oldest crop-pasture rotation experiment was started in 1989 by the Rice and the former Tropical Pastures Programs. It is located on Matazul farm, and contrasted two pastures undersown in a rice crop, *Andropogon gayanus* with *Stylosanthes capitata* (Ag/Sc) and *Brachiaria dictyoneura* with *Centrosema acutifolium* (Bd/Ca), with rice alone in replicated 1 ha plots. The rice was Line 3, which yielded 2 t/ha with no differences between treatments.

Subsequently in 1990, a pasture of *B. dictyoneura* without legume was established in the plots formerly sown to rice alone. Animal performance in the resulting pastures was monitored.

Weight gains during the first two years were higher than those previously recorded for similar pastures established with traditional methods. Animal performance declined in 1992, when the legumes were lost in both associated pastures. In 1993, one half of each of the plots was sown again with rice (using Line 3 in half the sown area and cv. Oryzica Sabana 6 in the remainder), leaving the other half as a grazed pasture control. The rice sown on the old associated pastures was undersown with a mixture of forage legumes, and at the same time a parallel small plot experiment was established with the same treatments on native savanna.

Yields of paddy rice for Line 3 were 2.5, 2.9 and 3.7 t/ha (14% moisture) after Bd, Bd/Ca and Ag/Sc respectively, and for Sabana 6 were 2.8, 3.4 and 3.9. In the small plot experiment on native savanna, the highest yields were 3.1 and 2.7 t/ha for Line 3 and Sabana 6, respectively, clearly showing the benefits of three years of grazed grass-legume pastures.

Soil nutrient contents at the end of the 1992 grazing season were still above those of virgin soil, reflecting the residual value of the fertilizer applied to the rice in 1989. Soil physical measurements, made by a collaborating ICA scientist at the end of 1992, showed a trend for higher porosity and lower bulk density in the rice-pasture systems than in native savanna, but the differences did not reach significance. Penetrometer measurements at the beginning of the 1993 rainy season suggest that there was soil compaction at depths below 20 cm in the sown pastures, while native savanna was more compacted in the superficial horizons. Land preparation prior to planting rice completely overcame soil compaction in the introduced pastures.

In contrast, in an experiment with rice sown each year as a mono-crop since 1989 there was a steady decrease in rice yields until 1992, associated with increased weed populations and apparent soil nutrient imbalances. The latter were corrected in 1992, but weeds continued to be a major problem. In 1993 two treatments were superimposed: land preparation with a mouldboard plough contrasted with the currently recommended preparation followed by chemical weed control. Preliminary results suggest that rice yields in both treatments were better than in previous years. Soil physical and chemical parameters have been monitored since the beginning of the experiment.

A survey of soil chemical parameters in the Llanos during 1990-1992 suggested that mineral nutrient status in virgin soils varies with soil texture, which is an important issue in the development of predictive models. A series of short-term, on-farm experiments with a limited number of crops, starting with upland rice, to determine the responses to Ca (lime), Mg, K, P and Si in soils of contrasting texture.

The experiments with Si are being carried out in cooperation with the Rice Program, which is assessing the effect of Si on the susceptibility of rice to blast. Results indicate a yield increase of 500-1000 kg/ha and lower incidence of blast with Si application. However, the economic feasibility of Si application remains to be evaluated.

During 1993 a long-term experiment was initiated in Carimagua in collaboration with ICA and IFDC to study processes underlying degradation or enhancement of the soil resources in a wide spectrum of alternative crop rotations. These systems represent extremes in land management from mono-crops to agro-pastoral systems. Given the very limited set of crop germplasm adapted to acid, low-fertility soils, the major constraint to intensification addressed in this experiment is the extent to which lime is used as a fertilizer to supply Ca an Mg, or as a soil acidity ameliorant to enable production of more Al-sensitive crops. Thus, the fertilizer-lime systems are based on adapted upland rice, either as mono-crop, in rotations with grain or forage cowpea or as a pioneer crop to establish grass-legume pastures of *Brachiaria humidicola,* with a mixture of *C. acutifolium, S. capitata*, and *Arachis pintoi*. The remedial-lime systems, to be started in 1994, will be based on more demanding crops and forage species (maize and soybean, *Panicum maximum* and perennial soybean). The first-year crop of rice yielded about 3.4 t/ha of paddy over an area of 7 ha, and there was very good establishment of the pastures undersown with the rice crop.

A number of satellite experiments is being set up to assess nutrient requirements of different crops, both as system components and to estimate efficiency of nutrient use under alternative management strategies. These complementary experiments center on the major crops with potential for the savannas. Nevertheless, it is anticipated that intensification of fertilizer use in the savannas may have consequences also in terms of the performance of some key forage species; ongoing research has recently suggested that K may be used to manipulate grass-legume balance at least in sandy soils (see below). Other alternatives will also be investigated.

This set of on-station and on-farm trials will contribute to understanding the processes responsible for stability of instability of alternative prototype systems. As a consequence, the dynamics of soil chemical, physical and biological properties are being studied. The same data will enable the Program to adapt, develop and validate computer simulation models for the acid soils savannas. Several of these research activities involve close cooperation with a substantial number of US and European Institutions with expertise in different research areas.

Particular attention is being paid to the dynamics of soil organic matter and factors affecting it, since it is well known that SOM is closely related to changes in soil physical conditions and to nutrient cycling. In this context, pastures are important components of potentially sustainable cropping systems, particularly if they involve effective N-fixing legumes. This is one of the aspects being studied by a multi-disciplinary team in a long-term experiment initiated by the former Tropical Pastures Program in Carimagua, which seeks to understand the functioning of perennial tropical legume-grass pastures. The experiment has since continued jointly between the Savannas and Tropical Forages Program.

On the sandy soil site, the legume *C. acutifolium* disappeared in all plots at the start of 1992, and since that time, both quality of the grass forage, the litter, and animal live-weight gains have fallen to the same level as the grass control sown without legume. This indicates, that on this soil at least, the initial spectacular increase in animal performance, and the litter quality depends absolutely on the maintenance of a satisfactory proportion of the legume component. As the performance of these pastures continues to decline, the processes will be followed to obtain information on the key processes that ndicate the degradation. The other side of the coin is to develop indicators of sustainability. Preliminary indicators appear obvious: proportion of the legume, litter quality, grass quality and animal performance.

Subsequent analyses of samples of both the grass and legume during the first two years of grazing show that the K concentrations of the legume fell dramatically, and at the time of the disappearance of *C. acutifolium*, the tissue K concentrations were less than half the accepted critical values. In contrast, the associated grasses had tissue K levels at least twice that of the legume, which is a clear indication that K nutrition of the legume is a key factor in its survival, and that the grass competes vigorously for K. This finding suggests a number of management options to manipulate of grass-legume relations, such as limiting grass growth by grazing management to reduce root competition, application of potassium fertilizer, and in the longer term by screening grasses for less aggressive competitiveness for potassium.

In the *S. capitata* pastures, the legume showed symptoms of potassium deficiency, although it continued to persist with reduced populations. The tissue K concentrations of *S. capitata* were below the critical values, but not so low as in *C. acutifolium*, suggesting that it competes better for K than does *C. acutifolium*. To follow up these important findings, a greenhouse experiment to define in more detail the competitive relationships between three legume species (*A. pintoi*, *C. acutifolium* and *S. capitata*) and two grasses (*B. decumbens* and *B. dictyoneura*) at high and low levels of applied potassium is currently under way.

Potassium has been applied to the *S. capitata* pastures, leaving untreated strips. A pre-graduate student from Wageningen is making measurements of growth and potassium concentrations in selected treatments to determine the relative uptakes of the grass and legume components of the pasture.

After three years of grazing, it has been shown that contrasting stocking rates had little effect on monthly litter production on either the clay loam or sandy loam soil. The initial higher concentrations of N, P and Ca in litter of grass-legume pastures compared with grass-only pastures disappeared after 2 years of grazing, probably as a result of declining legume populations. Rates of N fixation in satellite experiments in *A. pintoi, C. acutifolium* and *S. capitata* were low as a result of low legume populations, but N derived from fixation remained greater than 85% regardless of legume and fertilizer treatment. The important implication is that rates of N fixation may be estimated from simple estimates of legume biomass.

Many of the research activities center around the contribution of pastures to soil enhancement and to animal productivity, and are used as well to support the development of a simulation model that aims to represent mechanistically the interactions between tropical forages, soils and grazing animals. The model is being developed jointly with Dr. J. Thornley, from the Institute of Terrestrial Ecology, UK, and thus complements the crop simulation models referred to above.

Litter from crops and forages may contribute to SOM and may affect soil biological properties. Decomposition of leaf and root litter from forage grass and legumes, leaf litter from legume shrubs and crop residues were determined in litter bag studies. Rates of decomposition of residues of cassava, maize and rice were as high as those of forage legumes and greater than those of forage grasses. The lignin/N ratio was the best predictor of decomposition ($r^2 = 0.67$). Simulations of litter decomposition using the Century model were highly correlated ($r^2 = 0.92$) with actual rates, thus validating the model for tropical conditions. Mixing of legume litter with grass litter did not result in any synergistic effect. Century simulations indicated a rapid loss of C metabolic pools under tropical conditions, which may be associated with the observed lack of synergistic effects.

Decomposition parameters of litter from shrubby legumes were only weakly correlated with *in vitro* dry matter digestibility and thus the latter methodology has limited use as indicator of litter decay rates. In parallel with dry and organic matter decomposition of litter, loss of nutrients has been determined. The pattern generally observed is that of a rapid loss of K, and slower losses of N, P and Ca.

A laboratory for SOM and soil physical studies was set up during 1993. A laboratory manual for various methods has been prepared and new and refined techniques continue to be introduced. Given the contribution of the Program to the TSBF network, many of the techniques employed by that network have been adopted. Some of the soil parameters thus evaluated may eventually serve as indicators of changes in the system being monitored. As an example, a correlation was noted between stability of soil aggregates in water and hot water extractable carbohydrates. Thus the latter may serve as a quick early warning method for small changes in aggregate stability. Initial data comparing native savanna and three long-term grass and grass-legume pastures on a clay loam soil indicated little differences in aggregate distribution or in micro-aggregate stability. Nevertheless the inclusion of the legume *Pueraria phaseoloides* did result in an increase in macro-aggregate stability in the top soil, whereas increasing stocking rates tended to decrease the average aggregate size of this soil.

A specialized laboratory for soil chemistry and nutrient cycling studies was also equipped in 1993. Work was initiated by a Swiss Science Foundation fellow on the installation and development of procedures to estimate the dynamics of the pools of organic P in soils, including the microbial P, which is possibly the most dynamic P pool. These pools represent important pathways of P cycling and their manipulation to improve P-use efficiency has important implications for sustainability. Preliminary measurements indicate that the microbial P pool is significantly larger in old legume-grass pastures compared with the grass alone, which does not differ from native savanna.

Collaborative Research Projects

This section briefly summarizes collaborative research activities, some of which have already being referred to.

The major project under way is the Inter-American Development Bank-financed project on the development of agro-pastoral systems for the savannas. This project provides approximately one-third of the Savannas Program's budget.

Collaborative activities with IFDC were briefly mentioned above and center around studies on nutrient-use efficiency and recycling in alternative agro-pastoral systems, and on the use and adaptation of existing crop simulation models. A complementary pasture grass and grass-legume model is in an advanced stage of development in cooperation with the Institute of Terrestrial Ecology, UK. Preliminary contacts have been made with a number of groups at Wageningen in the area of crop and ecosystem modelling; a similar approach was tentatively explored with the University of Florida.

Research on the dynamics of native savanna vegetation is carried out in collaboration with IEMVT-CIRAD, and is further supported by IGAC, Bogotá, the Ecole Nationale Agronomique of Paris-Grignon and the Embassy of France in Colombia.

With core resources, the Program has been an active participant in the Tropical Soils and Biological Fertility network and has been interacting with a number of US Universities in trying to identify areas of overlapping research interests in acid-soil-based production systems.

A CIAT-wide grant received from BMZ, Germany, has allowed the Program to explore possible joint research projects with various German universities. Towards the end of 1993, a project financed by BMZ on the dynamics of soil organic matter and physical parameters in cooperation with the University of Bayreuth was approved. This work will be developed beginning in 1994 at Uberlândia and CPAC, Brazil. Other possibilities are being explored.

The active cooperation with ICA in both on-farm and on-station research was already mentioned. Special project funds are being sought to reinforce some of these activities.

An in-depth study of soil fauna, with emphasis on earthworms has been started at Carimagua in association with ORSTOM, France and the Universidad Complutense of Madrid, Spain. A previous short survey carried out by a French student from the University of Paris, France, had suggested the existence of major differences between alternative land use systems. The Swiss Science Foundation is assisting with the organic P project.

A number of project ideas regarding evaluation of selected aspects of water, vegetation and fauna resources of the Llanos of Colombia in conjunction with the National University, Bogotá and the Technological University of Villavicencio are under consideration. Among these, a preliminary survey of savanna fauna, as affected by land use intensity, has been undertaken by the National University in Carimagua.

Lastly, the very substantial in-kind and intellectual contribution of a large number of farmers in both Brazil and Colombia should be acknowledged.

CHAPTER I

NUTRIENT CYCLING

EXECUTIVE SUMMARY

Development of sustainable integrated crop/ pasture production systems for the acid soil savannas

The savannas of South America are increasingly being targeted for intensive agricultural production to meet the demands for food and fibre of a growing urban population. The savannas ecosystems are dominated by soils which are highly acidic, infertile and prone to degradation when brought into cultivation. There are indications that the current profitable exploitation of savannas soils with intensive annual cropping systems in Brazil and Venezuela is leading to their physical deterioration by soil compaction, erosion, and loss of soil organic matter. To sustain intensified land use in the savannas, therefore, new technologies are required that maintain soil structure and organic matter above critical levels and protect the soil against erosion.

During 1993, CIAT in collaboration with ICA and IFDC initiated a major experiment at Carimagua on the Colombian Llanos to study the processes contributing to sustainability or lack of sustainability in a spectrum of alternative production systems involving long term (five year) rotations. These systems represent the extremes in land management from monocultures to agropastoral systems with various intermediate options. Since the major constraints to intensified production on the savannas are the lack of diversity in acid (aluminum) tolerant germplasm and poor soil fertility, the choice of system components depends on whether lime is applied as a fertilizer (to supply Ca and Mg to Al-tolerant crop and pasture species) or as a soil acidity ameliorant (to enable production of more Al-sensitive species).

In the long term rotations experiment at Carimagua, the "fertilizer lime" systems are based on CIAT's Al-tolerant upland rice line, Sabanas-6. It is being grown in continuous monoculture, or in annual (within year) rotations with grain legume cowpea and forage cowpea (for green manure), or as a pioneer crop with adapted legume-based pasture (*B. humidicola/ C. acutifolium/ S. capitata/ A. pintoi*). "Remedial lime" systems (which will be implemented next year) are identical but based on maize with soybeans (grain or forage [green manure]) and a less-adapted but better quality mixed pasture (*P. maximum/ G. wightii/ A. pintoi*). The experiment is designed with plots that are sufficiently large to permit grazing and the use of conventional machinery which are likely to influence soil physical properties. They are also large enough to allow splitting for the imposition of additional treatments in the future. (We already contemplate the imposition of conventional and minimum tillage treatments.) Complementing the systems trial are a number of satellite experiments designed to more accurately assess nutrient requirements of component crops, and estimate losses and use efficiency under alternative management strategies.

Although the ultimate objective of rotations experiment is the development of sustainable prototype production systems for the acid soil savannas, the immediate objectives are to understand the processes which contribute to and interact with each other in determining the stability of any particular system. Consequently, the dynamics of soil physical properties, micro- and macro-faunal populations, soil organic matter and nutrients (including acquisitions, losses, recovery and tranfer among various pools within each system) are being studied and the dynamics of weed populations is being monitored. Data are also being collected for the development/adaptation/ validation of computer simulation models of system components which will be used in the agronomic, economic and environmental assessment of different configurations of the systems under different agro-climatic conditions and managerial alternatives. This will lead to the development of indicators of sustainability and will facilitate the extrapolation and adaptation of viable systems to other agroecological environments.

Development of sustainable integrated crop/ pasture production systems for the acid soil savannas (D.K. Friesen, M.J. Fisher, R. Thomas, A. Gijsman, G. Rippstein, H. Carmen, H. Delgado, E. Owen)

During 1993, CIAT in collaboration with ICA and IFDC initiated a major experiment at Carimagua on the Colombian Llanos to study the processes contributing to sustainability or lack of sustainability in a spectrum of alternative production systems involving long term (5 year) rotations. These systems represent the extremes in land management from monocultures to agropastoral systems with various intermediate options.

Among the major constraints to intensified production on the savannas are the lack of diversity in acid (aluminum) tolerant germplasm and poor soil fertility. Consequently, the choice of system components in the experiment was based on two scenarios: (a) whether lime is applied as a fertilizer (to supply Ca and Mg to Al-tolerant crop and pasture species), or (b) as a soil acidity ameliorant (to enable production of more Al-sensitive species). The "fertilizer lime" systems are based on CIAT's Al-tolerant upland rice line, Sabanas-6. It is being grown in continuous monoculture, or in annual (within year) rotations with grain legume cowpea and forage cowpea (for green manure), or as a pioneer crop with adapted legume-based pasture (*Brachiaria humidicola/ Centrosema acutifolium/Stylosanthes capitata/ Arachis pintoi*). The "remedial lime" systems are identical but based on maize with soybeans (grain or forage [green manure]) and a less-adapted but better quality mixed pasture (*Panicum maximum/ Glycine wightii/A. pintoi*).

The experiment is designed with plots that are sufficiently large to permit grazing and the use of conventional machinery which are likely to influence soil physical properties. They are also large enough to allow splitting for the imposition of additional treatments in the future; the introduction of tillage treatments is contemplated in 1994.

Although the ultimate objective of the rotations experiment is the development of sustainable prototype production systems for the acid soil savannas, the immediate objectives are to understand the processes which contribute to and interact with each other in determining the stability of any particular system. To this end, the dynamics of soil physical properties including soil aggregate stability (A. Gijsman), water infiltration rates, hydraulic conductivity and bulk density (E. Owen, ICA) which are most likely to be affected by cultivation practices are being closely monitored. Macro-faunal populations such as earthworms are also known to be influenced by vegetation and tillage; these are being studied by a post-graduate student in collaboration with ORSTOM, France, and the Universidad Complutense of Madrid, Spain. The dynamics of soil organic matter and nutrients (including acquisitions, losses, recovery and transfer among various pools within each system) are being quantified (A. Gijsman, R. Thomas and D. Friesen). The Century Model (Parton et al. 1988) will be tested against these data and modified and adapted to tropical soils as a predictive tool for estimating the effects of agricultural systems on soil organic matter maintenance which is strongly linked to soil structural integrity.

Weed populations tend to increase when land is brought under cultivation, based on experience with monocultures of rice in recent experiments at Carimagua and Matazul. The dynamics of weed populations is being monitored to determine how well populations are controlled in contrasting cultural systems (G. Rippstein, CIRAD-EMVT). Collaborating ICA scientists (H. Delgado and H. Carmen) have taken responsibility for agronomic issues in the experiment including pest management.

Crop phenological data are also being collected for the adaptation, validation and development of computer simulation models of system components (M. J. Fisher). In the first instance, focus is on the suite of CERES crop models developed under the IBSNAT Project. Two team members (M.J. Fisher and D.K. Friesen) participated in a training workshop at IFDC in May to become familiar with these models. It is anticipated that the models will be used to assess the agronomic, economic and environmental impact of different configurations of the systems under different agro-climatic conditions and managerial alternatives. This will lead to the development of indicators of sustainability and will facilitate the extrapolation and adaptation of viable systems to other agroecological environments.

"Fertilizer lime" rotations were implemented in May of this year. The rice crop, harvested in September, yielded approximately 3.5 t/ha. The pasture was well established at harvest with an especially good strike of legumes, in particular Arachis which grows well under shady conditions. The "remedial lime" rotations will be implemented in 1994. Maize and soybean germplasm from CIMMYT and ICA tolerant of moderate levels of exchangeable Al are currently being evaluated in separate satellite experiments. These satellite experiments are also being used to determine optimal nutrient requirements for component crops and to examine nutrient dynamics and interactions in more detail than is possible in the main experiment. Preliminary results from satellite experiments are described below.

Balanced lime-potassium-magnesium requirements for crops on the Colombian Llanos (D.K. Friesen and J.I. Sanz)

The predominant soils of the Colombian Llanos are highly acidic Oxisols and Ultisols whose mineralogy is dominated by the end-products of weathering: kaolinite and the oxides and hydrous oxides of iron and aluminum. These minerals impart to the soils properties which are not conducive to crop production and the efficient use of nutrient inputs. The cation exchange capacity is very low (typically 2-5 meq/100 g), largely pH-dependent and highly saturated with exchangeable aluminum (Al). Levels of exchangeable calcium (Ca), magnesium (Mg) and potassium (K) are consequently also low so that the application of fertilizer needs to be carefully balanced to avoid unfavorable interactions which would lead to nutrient deficiencies in the crop, inefficient use of inputs and exacerbated losses through leaching.

Because we lack sufficient knowledge of balanced rates of lime (Ca), Mg and K for crops on Llanos soils and because there is a need to understand how these nutrients interact in crop growth and cation leaching, experiments were established on three different soils at three sites on the Llanos during 1993 with the following specific objectives:

1) Determine optimum rates of lime (Ca), potassium (K) and magnesium (Mg), and the optimal balance of these cations for maize, rice and soybeans on contrasting acid savanna soils.

2) Monitor the dynamics of applied cations, and Al and pH in the soil, and the interaction of amendments on nutrient fluxes and fate.

3) Estimate residual effectiveness of lime, K and Mg applications, and requisite maintenance rates for optimal crop growth.

Experiments were sown with upland rice (Sabanas 6) on a loamy Oxisol at Matazul and on a sandy Oxisol at La Florida in May. Maize (the CIMMYT SAB-3 population) was sown on a heavy Oxisol in Carimagua in August. Five or 6 rates of lime (as calcite), four of K (as KCl) and three of Mg (as $MgSO_4$) were applied in selected combinations to give a total of 32 treatments in an incomplete factorial design (see Figures 1 and 2). Blanket applications of N (120 and 80 kg-N/kg for maize and rice respectively), P (80 kg/ha), S (35 kg-S/ha) and Zn (10 kg-Zn/ha) were applied to all treatments.

Only rice grain yield data are currently available from the two experiments at Matazul and La Florida; the maize experiment is still in the field at this writing. Rice responded strongly to lime (calcite), K and Mg at both sites (Figures 1 and 2). However, the only significant interaction was between lime and Mg at Matazul (Table 1). Nevertheless, response to any one nutrient was severely limited by the absence of any one of the others. Maximum yields of about 3 t/ha were obtained at both sites with adequate levels of all nutrients. Without lime, yields were reduced by 800-1000 kg/ha while, without K or Mg, they were reduced to less than 800-1200 kg/ha.

Magnesium was able to compensate for Ca to a degree in the Matazul soil (significant lime x Mg interaction; Figure 1b). A similar but nonsignificant trend was evident at La Florida (Figure 2b). On both soils, about 150-300 kg/ha of calcitic lime and 30 kg/ha of Mg appeared optimal. With a Ca content of about 30%, these values imply an optimal Ca:Mg ratio of between 2:1 and 3:1. Analysis of three commercial dolomitic lime sources all had Ca:Mg ratios of between 2.1 and 2.8. However, when applied at a rate of 200 kg/ha of dolomite (22-24% Ca, 8.4-10% Mg), they would provide Mg at about 17-20 kg/ha, thus explaining the need to apply supplementary Mg in earlier trials in this area. Based on rice's Mg requirements, therefore, these results indicate a minimal lime application of 300 kg/ha as dolomite on both soil types.

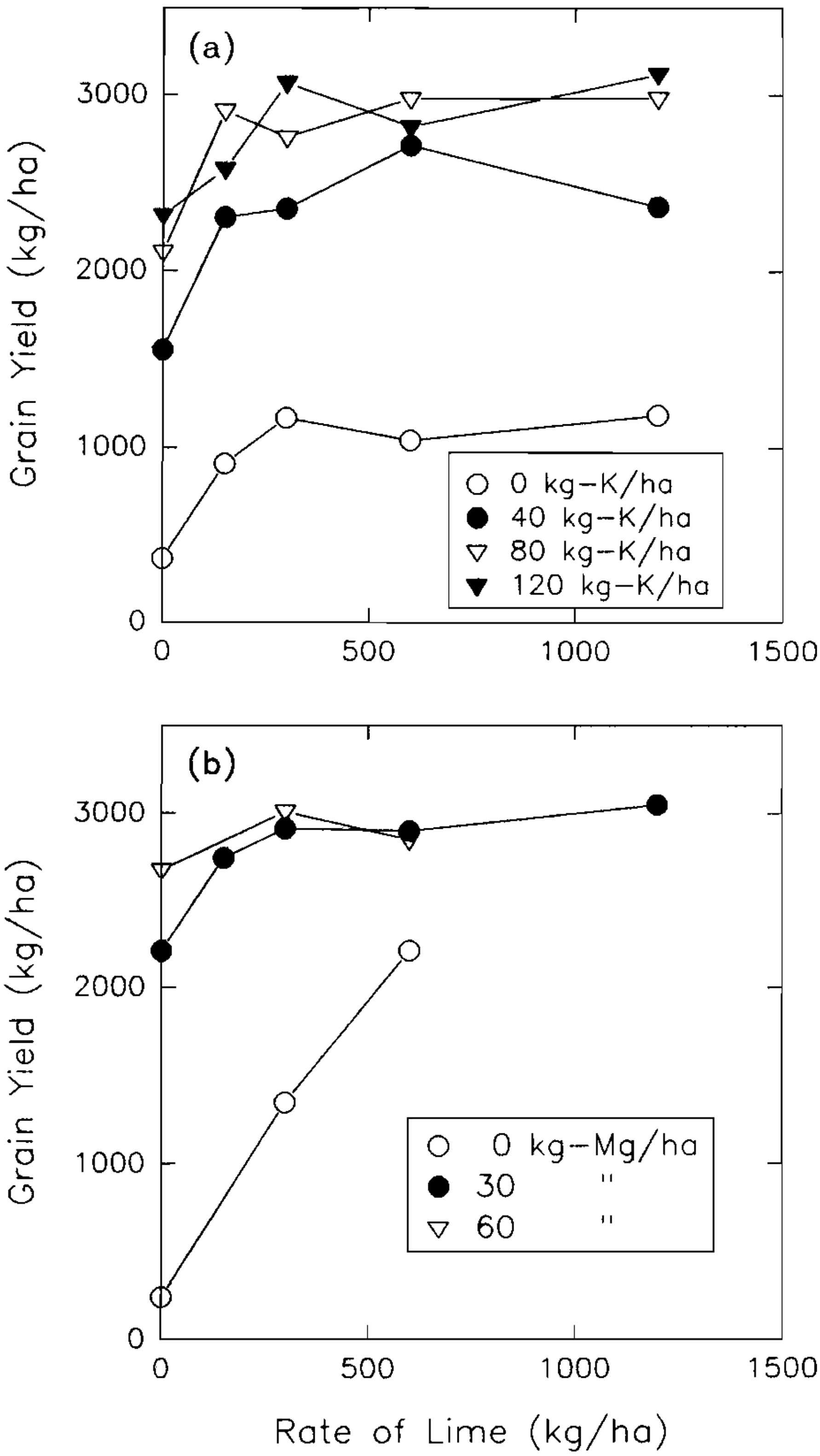

Figure 1. Interactions of lime (calcite) with (a) potassium and (b) magnesium on rice grain yield on a loamy soil at matczul.

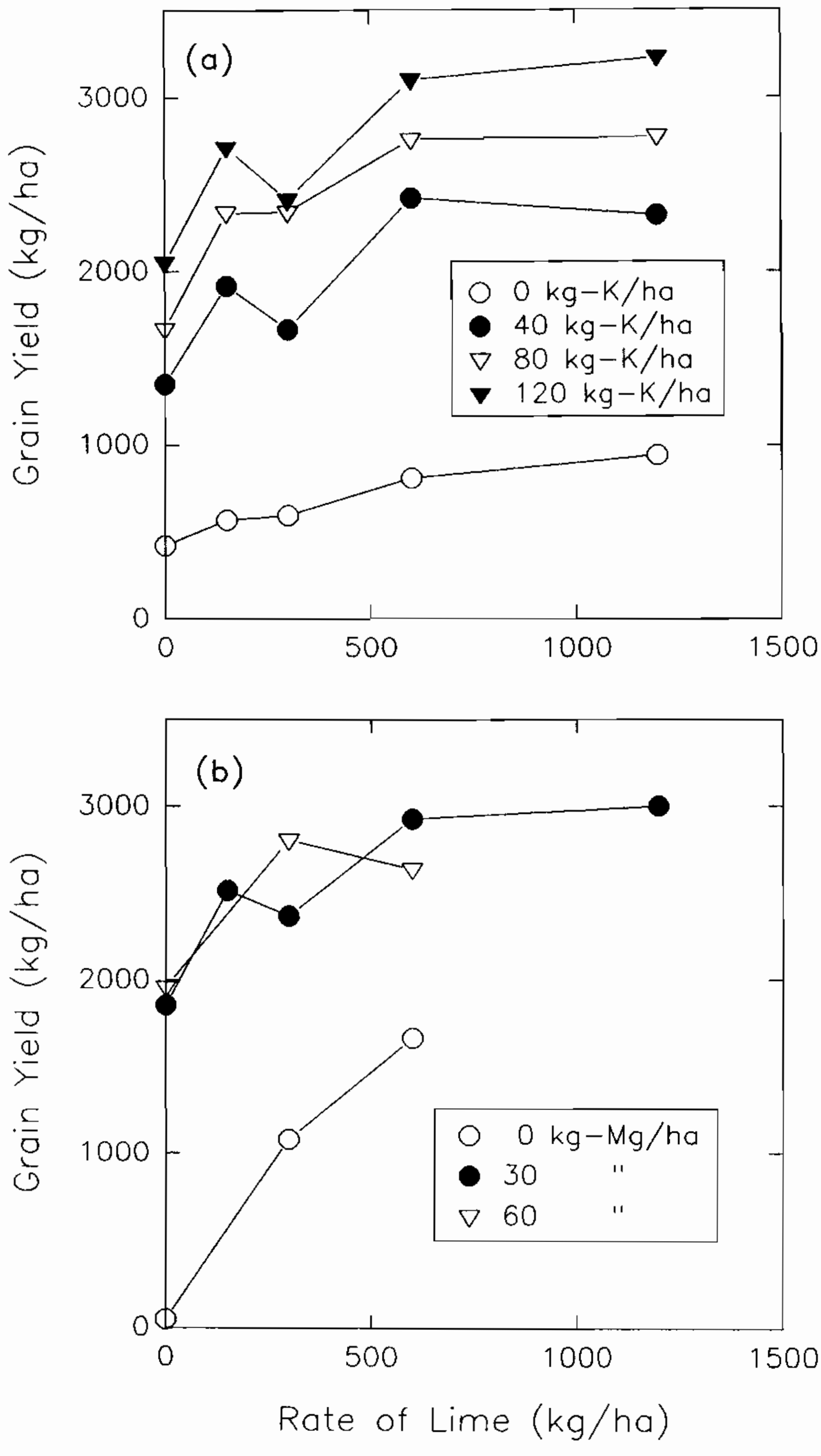

Figure 2. Interactions of lime (calcite) with (a) potassium and (b) magnesium on rice grain yields on a sandy soil at La Florida.

Table 1. Summarized analysis of variance of grain yield data from lime-K-Mg balance trials at Matazul and La Florida in 1993.

Source of Variation	df	Matazul		La Florida	
		F-Value	prob > F	F-Value	prob > F
Blocks	2	0.17	0.8485	10.58	0.0057
Lime	4	7.65	0.0077	9.89	0.0035
error (a)	8				
Potassium (K)	3	84.64	0.0001	45.12	0.0001
Magnesium (Mg)	2	103.29	0.0001	51.80	0.0001
K x Mg	2	0.85	0.4349	0.61	0.5445
Lime x K	12	0.56	0.8628	0.36	0.9711
Lime x Mg	4	10.42	0.0001	1.81	0.1407
Lime x K x Mg	4	1.00	0.4163	1.34	0.2678
error (b)	54				
CV (%)		17.0		27.7	

Potassium was optimal at about 80 kg/ha on the heavier soil at Matazul (Figure 1a) whereas response to K continued up to 120 kg/ha and possibly beyond on the sandy soil at La Florida (Figure 2a). Higher leaching rates are indicated in the latter soil. Since potassium was applied in three equal splits with N, there would seem to be little scope for further improving its efficiency in this way. Soil profile samples taken prior to treatment application and after harvest will provide information on the relative leaching rates of Ca, Mg and K in these soils. These data are not yet available. Concentrations of Ca, Mg and K yield components at harvest will also be determined for calculation of total uptake and nutrient use efficiencies.

Crop response to, and residual value of, soluble phosphate fertilizers on acid savanna soils (D.K. Friesen and J.I. Sanz)

The high oxide contents of highly weathered Oxisols and Ultisols present surfaces which strongly sorb phosphates, giving rise to what is commonly referred to as a 'high P fixation capacity'. However, 'fixed' P is often P which is merely more slowly available and several researchers have found very substantial residual effects of applied P on so-called high P-fixing soils (Wolf et al. 1987). To maximize P fertilizer use efficiency, it is necessary to be able to quantify the residual value of previous P fertilizer applications. This requires knowledge of the fate of applied P and its rate of movement between important P pools in soil. Therefore, experiments were established at Matazul (in May with rice) and Carimagua (in August with maize) with the following objectives:

1) Determine optimal levels of soluble phosphate fertilizer for annual crops on the highly weathered acidic soils (Oxisols) of the eastern savannas.
2) Characterize the fate of P applications (uptake by crop, removal in products, immobilization in organic matter, reversion to less soluble inorganic phases).
3) Determine the residual value of phosphate applications and parameterize a model of P residues in highly weathered soils.

The experiments comprise a total of 16 treatments involving rates of soluble phosphate fertilizer (TSP) applied once only at the beginning of the experiment, or annually to the cereal crop in a cereal-grain legume rotation. Taken together these treatments will fully characterize the P response function in the first year (13 different rates) and will enable estimation of the residual effectiveness of the initial application in the 2nd, 3rd and 4th years. In each year of the trial (over a period of 4 years), cumulative applications in several 'annual' treatments will be equivalent to certain 'residual value' treatments, enabling a direct comparison of alternative P fertilizer management strategies, that is, 'corrective' fertility adjustments versus gradual 'build-up' applications.

Phosphorus treatments are broadcast and incorporated at planting. Lime and blanket applications of N, K, S, Mg and Zn are applied to all treatments at rates chosen to remove all other constraints to crop growth (however, no Si was applied [see following section]). Surface soil samples (0-15 cm) are being taken from all plots prior to treatment application and planting each semester. Determinations of several P pools (labile P by soil tests and ^{32}P exchange, organic and inorganic P fractions according to Hedley et al. [1982], total P) will be made to enable parameterization of two models: that of Barrow and Carter (1978) for evaluating the residual value of phosphate applications, and the CENTURY model (Parton et al. 1988) which simulates P cycling in agroecosystems.

Rice was harvested at Matazul in September and re-sown to cowpea. Rice grain yields (Figure 3) increased 8-fold with P fertilizer. Based on a Mitscherlich response function fitted to mean data and a 'target' yield of 90% of the estimated maximum, rice required 20 kg-P/ha for optimal growth on this soil when broadcast and incorporated as soluble phosphate (TSP) at planting. The effect of banding is not being examined in this experiment although it has been observed to affect P response rates especially in high 'P-fixing' soils. The results obtained here (in contrast to what is often remarked upon in the literature) clearly suggest that this is not one of those soil types. However, results from an adjacent experiment (described below) suggest that the low requirement may be due in part to inadequate levels of Si in this soil.

Silicon requirements of upland rice on highly leached acid savanna soils (D.K. Friesen, J.I. Sanz, K. Okada, F. Correa, M. Winslow)

Although the function and mechanism of Si in rice is not fully understood, inadequate levels may limit yields and increase crop susceptibility to pathogens and disease (Winslow 1992). Since the weathering process is essentially one of desilication (from weatherable secondary minerals such as feldspars through 2:1 smectitic clays and 1:1 kaolinites to Fe and Al oxides), low levels of soluble silicon may be expected in the highly weathered Oxisols and Ultisols of the Colombian Llanos. Consequently, in a preliminary assessment of this potential (unrecognized) constraint, two field experiments on contrasting Llanos soils were established in May at Matazul and La Florida to determine:

1) whether upland rice responds to soluble Si applications on two contrasting savannas soils.

2) if there are varietal differences in response to Si.

3) if there is an interaction with phosphate applications (that is, does Si substitute for P?).

Experimental treatments consisted of factorial combinations of three levels of Si (0, 250 and 500 kg-Si/ha as wollastonite [$CaSiO_3$, 24.2% Si] broadcast and incorporated to 15 cm depth), two of P (25 and 50 kg-P/ha) and two rice varieties of apparently contrasting tolerance to Si deficiency (Sabanas 6 as well as a Brazilian variety [IAC-165]). Due to the basic properties of calcium metasilicate, chemically equivalent amounts of calcitic lime were applied to the 'nil' and intermediate Si treatments to equalize the lime value across treatments. Based on pure materials, the total lime value applied across treatments was 2400 kg $CaCO_3$/ha. All other nutrients were applied at adequate levels.

Mean rice grain yields and analyses of variance are summarized in Tables 2 and 3. Silicon application increased yields between 600-900 kg/ha (Figure 4). Sabanas-6 appeared to require a higher level of applied Si than the Brazilian IAC-165 line, particularly at Matazul, although the Brazilian variety consistently yielded 600-1000 kg/ha more than Sabanas 6 (Figures 4a and 4b).

Rather than reducing the requirement for P, response to P application was greater at higher levels of Si than at lower levels (Figures 4c and 4d). In the absence of Si, grain yields of both varieties at both sites was approximately 2500 kg/ha and neither responded beyond 25 kg-P/ha.

With 500 kg-Si/ha, yield increased to 3500 kg/ha provided the P rate was increased to 50 kg/ha.

Grain coloration and incidence of neck blast also appeared to be affected by Si application. These factors are being evaluated by the Rice Program, as is milling quality. Concentrations of Si in flag-leaf samples taken at flowering and grain and straw at harvest will provide information on critical Si tissue concentrations.

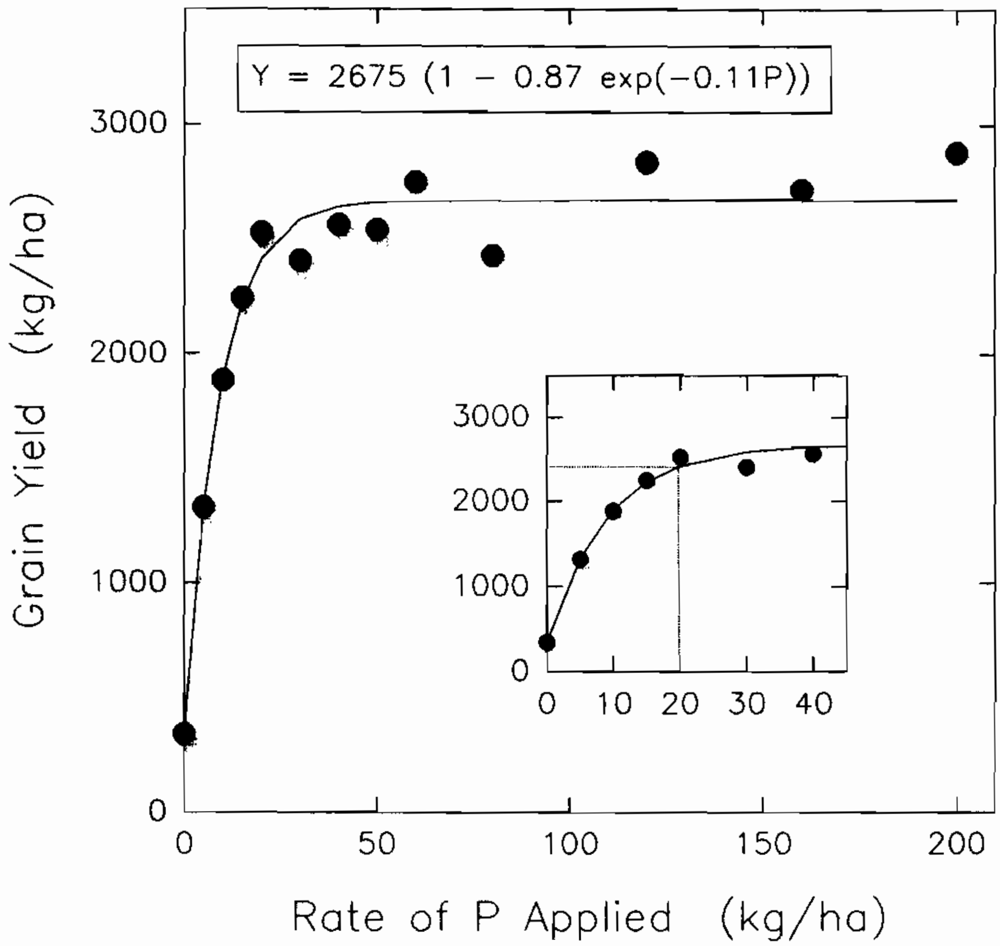

Figure 3. Response of rice (Sabanas–6) to rates of soluble P fertilizer (TSP) broadcast and incorporated at planting on a virgin Oxisol at Matazul. (Insert shows optimal P rate to obtain 90% of estimated maximum yield calculated from the Mitscherlich response function.)

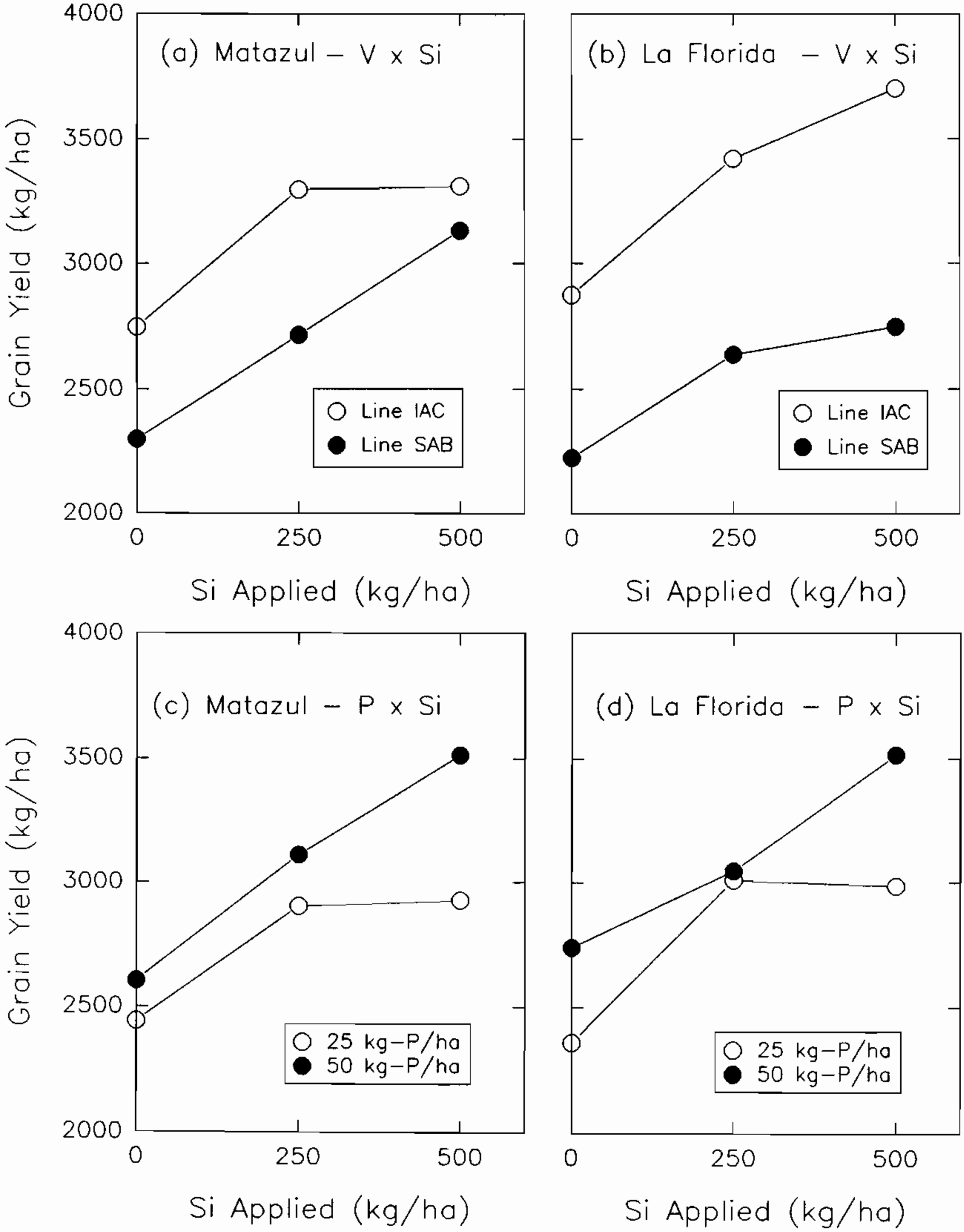

Figure 4. Response of Brazilian and CIAT rice lines to silicon and phosphorus at Matazul and La Florida.

Table 2. Rice grain yields of two upland varieties in response to applications of Si (as wollastonite) and P on two soils of the Llanos

Rate of Si (kg/ha)	Rate of P (kg/ha)	Matazul		La Florida	
		Line IAC	Sabanas 6	Line IAC	Sabanas 6
0	25	2607	2282	2676	2046
250	25	3062	2744	3467	2553
500	25	2973	2881	3561	2414
0	50	2890	2319	3077	2403
250	50	3530	2693	3373	2723
500	50	3644	3382	3849	3133

Table 3. Summarized analysis of variance of grain yield data from trials on varietal response to silicon and phosphorus at Matazul and La Florida in 1993.

Source of Variation	df	Matazul		La Florida	
		F-Value	prob >F	F-Value	prob >F
Block	3	9.34	0.0495	0.59	0.6638
Variety (V)	1	344.21	0.0003	91.17	0.0024
error (a)	3				
Phosphorus (P)	1	34.31	0.0001	33.20	0.0001
Silica (Si)	2	57.35	0.0001	59.35	0.0001
P x Si	2	6.12	0.0034	8.14	0.0006
V x P	1	8.20	0.0054	1.74	0.1913
V x Si	2	4.70	0.0118	0.94	0.3967
V x P x Si	2	0.94	0.3942	1.01	0.3675
error (b)	78				
CV (%)		9.1		8.8	

The observation of significant responses to Si, not only in terms of yield but also in grain quality, on two contrasting soils suggests that Si deficiency in rice may warrant greater investigation on the Llanos. Soil analyses from these experiments (as yet unavailable) should provide some indication of deficient levels. These will be further explored in a greenhouse experiment currently being mounted with a wider range of soil types. The high rates of application which are apparently required raise the issue of economic viability of corrective measures as well as that of available sources--questions which need to be explored. There exists the possibility of using rice hulls (or rice hull ash), products of the rice industry, as an Si source. These materials are known to accumulate Si. However, this approach merely recycles Si extracted from deficient soils and alone will not correct the problem (unless the material is concentrated onto specific areas close to the mills). Inexpensive sources and methods of improving efficiency and hence reducing rates also merit investigation if the problem is indeed widespread.

Investigations of dynamic phosphorus pools in savannas soils under differing management and use (A. Oberson and D.K. Friesen)

Organic P pools in soils represent important pathways of P cycling in soil-plant systems and their manipulation to improve P-use efficiency has important implications for sustainability. Microbial P is considered as the most active P pool in soil, turning over once every 1.2-2.5 years in semi-arid, subtropical ecosystems (Brookes et al., 1984; Goyal et al., 1993). Turnover rates may be even greater in tropical ecosystems due to higher temperatures and longer periods of activity during the year. Microbial uptake of P and its subsequent release and redistribution therefore play a central role in the soil P cycle (Stewart and Tiessen, 1987).

While microbial P has been shown to be important in soils of the temperate zone (Brookes et al., 1984), very few studies have assessed the quantity of microbial P in tropical soils. As part of a project to assess the effects of improved pastures on soil P dynamics in tropical acid soils, P bound in the microbial biomass was estimated in soil samples taken from a long-term grazing experiment established in 1978 on Oxisols (pH 4.5, 96% Al saturation, 1-2 ppm $Bray_2$ P) at Carimagua . The treatments sampled were (1) a grass only pasture (*Brachiaria decumbens*), (2) a grass-legume pasture (*Brachiaria decumbens-Pueraria phaseolides*) and (3) native savanna (details of treatments, stocking rates and fertilizer inputs may be found in Lascano and Estrada, 1989).

Soil microbial P was measured according to the method of Morel et al. (1993) after modification for soils with a strong sorption capacity. The method estimates biomass P liberated from microbial cells during chloroform fumigation and corrects for P sorption occurring during fumigation and incubation. Fumigation caused the release of 4-12 μg P/g soil, corresponding to a microbial biomass P content of 10-30 μg P/g soil if one assumes that only 40% is released on fumigation (Brookes et al., 1982). The importance of this value is readily apparent when compared to the low amounts of $Bray_2$ P found in these soils (1-2 μg P/g) and is comparable to the amounts of microbial P found in temperate soils (5-72 μg/g; Brookes et al. 1982, Morel et al. 1993).

Pasture composition was also found to influence soil microbial P content. The microbial P pool was larger in the grass-legume pasture compared with the grass alone, which in turn was slightly higher than the native savanna. $Bray_2$ P contents followed the same trend suggesting that the presence of legumes in these pastoral systems influences the efficiency of P cycling (through microbial biomass) and the maintenance of P fertility. These differences cannot be explained by the mere 3 kg higher P input to the grass-legume plots since the trial was established in 1978.

Information about the P sorption characteristics of the pasture samples was also obtained as part of the method for microbial biomass P determination. The results indicate a reduction in the soil P sorption capacity of the grass-legume pasture. This may be explained by the fact that P sorption capacity decreases as available P quantities increase (Fardeau and Frossard, 1991), a result already noted above in the $Bray_2$ P contents of the grass-legume soils. Furthermore, although the soil organic matter contents of the grass-only and grass-legume pastures were similar, legume-induced changes in the quality of organic matter and in biological activity may affect P sorption (Rao et al., 1992).

One of the principal objectives of the P-dynamics project is to test the ability of the Century Model (Parton et al., 1988) to simulate P dynamics in highly weathered tropical soils. The results obtained thusfar indicate the need to include microbial P as an independent pool in this model. The adaptation and validation of Century (and other simulation models) for tropical cropping systems will provide an important tool for assessing the net effects of different interacting processes on resource sustainability.

Establishment of a soil chemistry/nutrient cycling laboratory (D.K. Friesen)

During 1993, a new laboratory for specialized soil chemical analyses (adjacent the new Analytical Services Laboratory) was equipped and made operational by late August following a move from the old IFDC laboratory in the West Wing Laboratory. Apart from some glassware and minor instruments salvaged from that lab, purchases of virtually everything from the most basic essentials upward were required. Additionally, purchases of capital equipment for field based research including soil sampling equipment was coordinated by the Nutrient Cycling Section. Total expenditures during 1993 are estimated at more than $100,000.

This Section also provided overall supervision and technical guidance to the Analytical Services Laboratory.

Dennis Keith Friesen

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- Myles J. Fisher
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References

Barrow N.S. and Carter E.D. 1978. A modified model for evaluating residual phosphate in soil. *Aust. J. Agric. Res.* 29:1011-1021.

Brookes P.C., Powlson D.S., Jenkinson D.S. 1982. Measurement of microbial biomass phosphorus in soil. *Soil Biol. Biochem.* 14:319-329.

Brookes P.C., Powlson D.S., Jenkinson D.S. 1984. Phosphorus in the soil microbial biomass. *Soil Biol. Biochem.* 16, 169-175.

Fardeau J.C., Frossard E. 1991. Processes de transformations du phosphore dans les sols de l'afrique de l'ouest semi-aride: application au phosphore assimilable. In: Tiessen H., Frossard E. (Eds.) *Phosphorus cycles in terrestrial and aquatic ecosystems*. Proc. SCOPE and UNEP Workshop, Nairobi, 18-22 March 1991, pp. 108-128.

Goyal S., Mishra M.M., Dhankar S.S., Kapoor K.K., Batra R. 1993. Microbial biomass turnover and enzyme activities following the application of farmyard manure to field soils with and without previous long-term applications. *Biol. Fertil. Soils* 15, 60-64.

Hedley, M.J., Stewart, J.W.B., Chanhan, B.S. 1982. Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. *Soil Sci. Soc. Am. J.* 46:970-976.

Lascano C., Estrada J. 1989. Long-term productivity of legume-based and pure grass pastures in the eastern plains of Colombia. *XVI International Grassland Congress*, Nice, France, pp. 1179-1180.

Morel C., Tiessen H., Stewart J.W.B. 1993. Correction for P-sorption in the measurement of soil microbial biomass P by $CHCl_3$ fumigation. *Soil Biol. Biochem.* with the editor.

Parton W.J., Stewart J.W.B., Cole C.V. 1988. Dynamics of C, N, P and S in grassland soils: a model. *Biogeochemistry* 5, 109-131.

Rao I.M., Ayarza M.A., Thomas R.J., Fisher M.J., Sanz J.I., Spain J.M., Lascano C.E. 1992. Soil-plant factors and processes affecting productivity in ley farming. In: CIAT (Ed.) *Pastures for the tropical lowlands*, pp. 145-175.

Stewart J.W.B., Tiessen H. 1987. Dynamics of soil organic phosphorus. *Biogeochemistry* 4, 41-60.

Winslow M.D. 1992. Silicon, disease resistance, and yield of rice genotypes under upland cultural conditions. *Crop Sci.* 32, 1208-1213.

Wolf J., de Wit C.T., Janssen B.H., and Lathwell D.J. 1987. Modeling long-term response to fertilizer phosphorus. I. The model. *Agron. J.* 79, 445-451.

CHAPTER II

NITROGEN RECYCLING AND FIXATION

INTRODUCTION

Highlights of the section's activities for 1992-93 are presented in this report. It should be noted that although the section has been transferred to the savanna program, maintenance of the *Bradyrhizobium* collection and the preparation and dispatch of inoculants continue to be the section's responsibility. The selection of strains for *Arachis pintoi* has also been an activity this year and a summary report of these activities is presented in the report of the Forage Progam.

The section's range of activities have expanded to include aspects of nutrient cycling via crop residues as well as on going studies on forage grass and legume litter decomposition. The installation of a mass spectrometer at CIAT has resulted in the first estimates of the amounts of N_2 fixed by forage legumes under pasture conditions using ^{15}N isotope labelling. These experiments are "satellite" activities to the multi- and interdisciplinary work undertaken in the "core" experiment by members of the Tropical Forages Program and the Savanna Program. In addition a study on soil organic matter and soil physical properties in long term pastures was initiated with the appointment of a post-doctoral fellow to the section in August 1992.

Decomposition of residues and litter from crops and forage species in a tropical savanna ecosystem

In the envisaged ley farming systems for the savannas and other agroecosystems an improved recycling of nutrients via litter and crop residues is thought to be a key process for reducing or complementing fertilizer inputs and achieving long term productivity. The comparative rates of residue and litter decomposition from cassava, maize, rice and forages were therefore studied using a litter bag technique described earlier (TPP Ann Rpt p12-17, 1991).

Leaf litter of the forage species was collected from the respective pastures during April/May 1991. Crop residues, mainly leaves, of cassava (*Manihot esculenta* Crantz cv. CM523-7) and maize (*Zea mays* CIMMYT lines SA3-SA7) were collected from experimental plots at Carimagua and rice (*Oryza sativa* cv. Metica 1) straw was collected from experimental plots at CIAT headquarters, Palmira. All litters and residues were dried at 60°C before use.

Bags of litter were prepared as before (TPP Ann Rpt, p12-17, 1991) and distributed in the corresponding pastures for forage grasses and legumes at both sites of the core experiment (clay loam soil at Intro II and sandy loam soil at Alegria). Litter bags contained single forage species and 50:50 mixtures of grass and legume species. Crop residues were all placed in pastures of *Brachiaria dictyoneura* at the Intro II site of the core experiment and bags were protected from grazing by use of exclusion cages.

The initial composition of litter and residues of each species used in the litter bag experiments is given in Table 1. As expected litter of the legumes *Centrosema acutifolium, A. pintoi* and *Stylosanthes capitata*, contained greater quantities of N, P, K and Ca than the grass *B. dictyoneura* at both sites. For the forage species, *B. dictyoneura* and *C. acutifolium,* the concentration of N tended to be greater in material collected from the clay loam site (Intro II) compared with the sandy loam site (Alegria) but the opposite was noted for Ca. For the crop species of note was the high concentrations of most nutrients in leaf litter of cassava and especially N, P and K. Rice straw was notable for its high concentration of K compared with other litter and residues (Table 1). Maize generally had concentrations of nutrients similar to rice except for N and K, and slightly greater concentrations than those of *B. dictyoneura*. There was a wide range of both C:N (15-191) and lignin:N (7-27) ratios amongst the species studied.

Figs 1 and 2 show the loss of OM, N, P, K, Ca and Mg from litter of forage species and crop residues at Intro II. In general both the loss of OM and

Table 1. Initial composition of litter

Species	Pasture	N	P	K	Ca	Mg	C	lignin	C:N	L:N
		% (w/w) element							Ratio	
Site: Alegria										
B. dictyoneura	*B. dic.*	0.27	0.02	0.03	0.41	0.23	51.5	7.2	190.8	26.7
B. dictyoneura	*B. dic/C.a.*	0.34	0.01	0.05	0.44	0.32	52.5	7.1	154.4	20.9
B. dictyoneura	*B. dic/S.cap.*	0.32	0.02	0.04	0.91	0.21	53.6	7.5	167.5	23.4
C. acutifolium	*B. dic/C.a.*	2.68	0.04	0.05	1.39	0.10	53.4	31.0	19.9	11.6
B. dic./C.a.	*B. dic/C.a.*	1.51	0.03	0.05	0.91	0.21	52.9	19.1	35.0	12.6
S. capitata	*B. dic/S.cap.*	2.48	0.10	0.10	1.39	0.10	46.9	23.4	18.9	9.4
B. dic./S. cap.	*B. dic/S.cap.*	1.40	0.06	0.07	0.44	0.32	50.2	15.5	35.8	11.1
Site: Intro II										
B. dictyoneura	*B. dic.*	0.55	0.02	0.02	0.19	0.15	48.7	9.8	88.5	17.8
B. dictyoneura	*B. dic/C.a.*	0.38	0.01	0.02	0.20	0.17	48.3	8.2	127.1	21.6
B. dictyoneura	*B. dic/A.p.*	0.46	0.01	0.02	0.21	0.18	48.7	9.3	105.9	20.2
C. acutifolium	*B. dic/C.a.*	2.93	0.05	0.03	0.93	0.08	45.3	35.8	15.5	12.2
B. dic./C.a.	*B. dic/C.a.*	0.38	0.01	0.02	0.20	0.17	48.3	8.2	127.1	21.6
A. pintoi	*B. dic/A.p..*	2.35	0.11	0.07	3.57	0.21	45.6	33.9	19.4	14.4
B. dic./A.p.	*dic/A.p.*	1.41	0.06	0.04	1.89	0.19	47.1	21.6	33.4	15.3
Cassava	*B. dic.*	2.80	0.19	0.78	1.05	0.49	55.4	34.4	19.8	12.3
Maize	*B. dic.*	0.85	0.06	0.06	0.32	0.10	45.3	5.6	53.3	6.6
Rice	*B. dic.*	0.42	0.06	1.69	0.39	0.20	44.6	4.3	106.2	10.2
LSD $p < 0.05$		0.11	0.007	0.01	0.12	0.02	2.0	1.6	19.8	2.2

nutrients could be described by a single exponential decay function. The decomposition constants and litter half-lives for the loss of OM for all treatments are given in Table 2.

Loss of OM was slowest in the grass *B. dictyoneura* followed by the legume *C. acutifolium* with the crop residues from cassava, maize, and rice having a similar pattern to that of the legume *A. pintoi* (Fig 1). From an initial analysis of the relationships between initial litter/residue composition and half-lives, the best linear correlation was obtained between the lignin:N ratios and half-lives ($r = 0.62$). This was similar to that reported previously for forage grasses and legumes (TPP Ann Rpt 12-24, 1991).

Loss of the macronutrients N, P, and K followed a different pattern to that of OM (Fig 1). Cassava and *A. pintoi* released N at rates faster than the other litters and there was very little disappearance of N from litter and residues of *B. dictyoneura*, maize or rice. A similar pattern was observed with phosphorus (Fig. 1) but not for potassium where the disappearance of potassium was much greater in rice, followed by cassava compared with the other species. This was the result of a much greater initial concentration of potassium in residues of rice and cassava compared with the litter from other species.

Loss of calcium was greatest in *A. pintoi* compared with the other species (Fig. 2) whilst greatest amounts of magnesium were lost from cassava residues (Fig. 2). Again this was mainly the result of greater initial concentrations of calcium and magnesium in litter of *A. pintoi* and cassava respectively (Table 1).

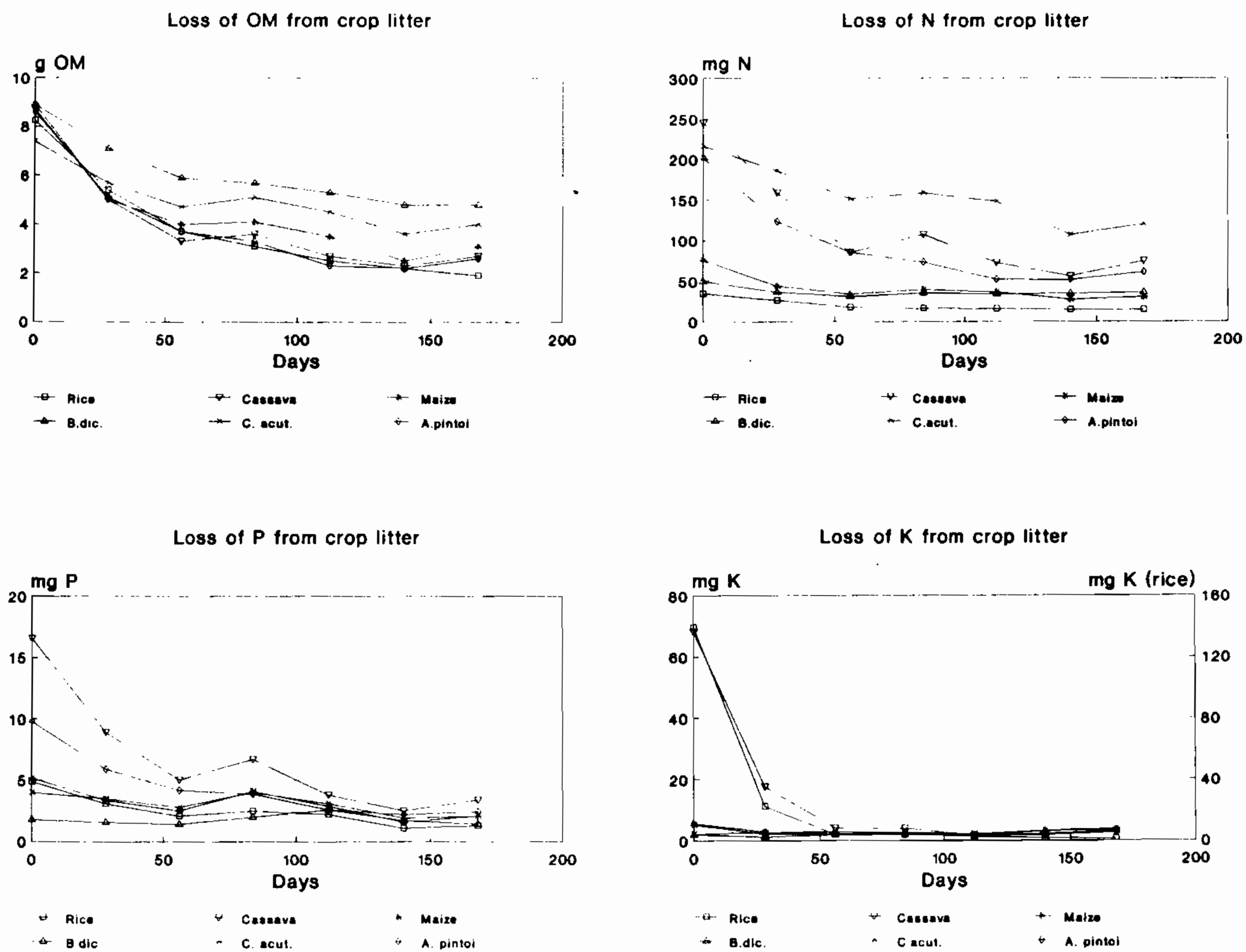

Fig. 1 Loss of OM, N, P and K from crop residues and forage litter

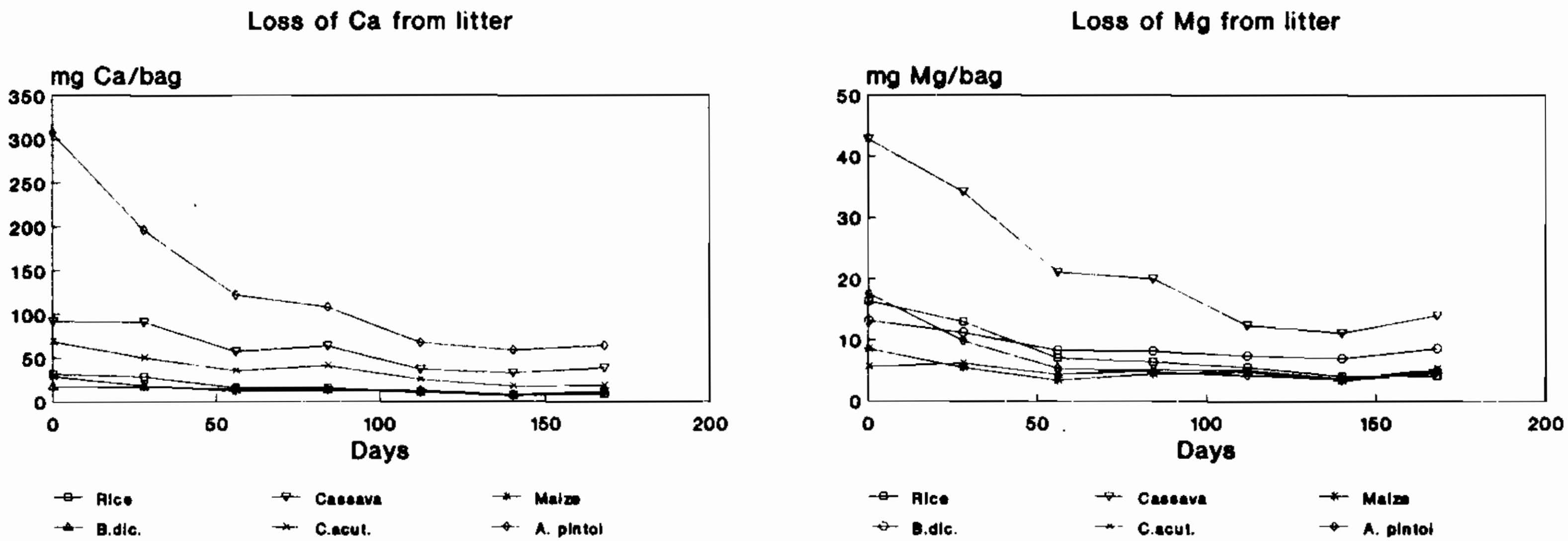

Fig. 2 Loss of Ca and Mg from crop residues and forage litter

Table 2. Decomposition parameters for loss of organic matter of forages and crop residues

Species	Pasture	k (day $^{-1}$)	Half-life $^{+}$ days
Site: Alegria			
B. dictyoneura	*B. dic.*	0.0014 $\pm$ 0.0002	179
B. dictyoneura	*B. dic./C.a.*	0.0017 $\pm$ 0.0002	148
B. dictyoneura	*B. dic./S.c.*	0.0018 $\pm$ 0.0002	144
C. acutifolium	*B. dic./C.a.*	0.0022 $\pm$ 0.0003	113
B. dic/C.a.	*B. dic./C.a.*	0.0020 $\pm$ 0.0003	118
S. capitata	*B. dic./S.c.*	0.0025 $\pm$ 0.0001	109
B. dic./S.c.	*B. dic./S.c.*	0.0020 $\pm$ 0.0002	127
Site: Intro II			
B. dictyoneura	*B. dic.*	0.0014 $\pm$ 0.0003	161
B. dictyoneura	*B. dic./C.a.*	0.0020 $\pm$ 0.0002	129
B. dictyoneura	*B. dic./A.p.*	0.0014 $\pm$ 0.0003	159
C. acutifolium	*B. dic/C.a.*	0.0014 $\pm$ 0.0003	164
B. dict./C.a.	*B. dic./C.a.*	0.0016 $\pm$ 0.0002	153
A. pintoi	*B. dic./A.p.*	0.0024 $\pm$ 0.0006	68
B. dic./A.p.	*B. dic./A.p.*	0.0020 $\pm$ 0.0005	86
Cassava	*B. dic.*	0.0023 $\pm$ 0.0006	68
Maize	*B. dic.*	0.0021 $\pm$ 0.0005	79
Rice	*B. dic.*	0.0027 $\pm$ 0.0005	71

$^{+}$ estimated from linear regressions of loge against time

There was a tendency for litter of *B. dictyoneura* collected from grass legume pastures at Alegria to decompose at rates faster than litter of *B. dictyoneura* collected from pure grass pastures (Table 2). This was probably due to better litter quality in terms of % N, lower lignin:N and C:N ratios in grass-legume pastures compared with pure grass pastures (Table 1). This was not the case at Intro II where there were little differences between the composition of litter of *B. dictyoneura* collected from pure grass or *B. dictyoneura/A. pintoi* pastures (Table 1) while grass litter in *B. dictyoneura/C. acutifolium* tended to decompose at a faster rate compared with the grass only pasture.

Effect of mixing grass and legume litter

At Alegria or IntroII a 50:50 mixture of grass and legume species, *B. dictyoneura/C. acutifolium*, *B.dictyoneura/S. capitata* and *B. dictyoneura/A. pintoi*, decomposed at rates equivalent to the values estimated from the mean parameters of each individual species (Table 2). Unlike the findings reported for temperate species there was no evidence for any synergistic or inhibitory effects of litter from legumes (high quality) on litter from grass (low quality). In the former a greater release of soluble metabolic C from high quality litter has been implicated in the observed synergistic effects. However in tropical species Century simulations suggest that metabolic C disappears too rapidly from leaf litter to have such a synergistic effect (Fig. 3).

The results obtained show that the rates of release of different nutrients will vary depending on the crop or forage residue/litter. Thus, depending on the cropping system or rotation used, there may be an opportunity to alter fertilizer inputs to avoid any nutrient imbalances or shortages. Further work on the recoveries of nutrients released from residues/litters by subsequent crops/pastures is needed to define the strategies for efficient nutrient management in agropastoral systems of the savannas.

Modelling litter decomposition

The decomposition data obtained in the field were compared with those predicted by the CENTURY model which utilizes % lignin, lignin:N ratios and climate data as modifiers of litter decomposition. In general, agreement between predicted patterns of decomposition and observed were good (r^2 = 0.92) and examples are shown in Fig. 4. The fit between observed and predicted values were poorest with *A. pintoi* and cassava and these species had noticeably higher concentrations of some nutrients compared with others e.g., Ca, P and K (Table 1).

These initial studies are encouraging for the widespread applicability of the CENTURY model for tropical agroecosystems.

Decomposition of roots

The decomposition of roots of forage grasses, legumes and rice was studied using litter bag techniques in boxes of soil from Carimagua under glasshouse conditions at Palmira. In addition a field experiment was initiated using a system of inverted clay pots in an attempt to match more closely actual conditions in the field.

Glasshouse study

Roots were separated into fine (<2mm) or coarse (>2mm) roots and air-dried material was incubated in nylon litter bags with and without soil. All bags were buried to a depth of about 10cm in large boxes of a clay loam soil and sampled at intervals over 15 weeks. As for leaf litter and residues a single exponential decay function was fitted to the decomposition data and a results summary is presented in Table 3. As for above ground litter, roots of legumes generally decomposed at faster rates than grasses with fastest decomposition occurring with roots of *A. pintoi.* Coarse roots of the grasses decomposed at faster rates than fine roots but the opposite was noted for legume material. Percent lignin, lignin:N and C:N ratios were the chemical indicators which best correlated with rates of decomposition. In terms of a ranking of species with respect to relative rates of decomposition the order was similar to that reported for leaf litter (Thomas & Asakawa, 1993) with the exception that roots of *A .pintoi* decomposed faster than roots of *S. capitata* i.e. vice versa to leaf litter.

Field experiment

Preliminary work in Carimagua on root decomposition using a litter bag technique showed that legume roots decomposed faster than grass roots. This litter bag approach used dried roots which may affect the initial fast decomposition of sugars, proteins, etc., in addition the root density in the rootbags may be higher than that in the field, which may affect the accessibility of OM for the decomposer community and soil fauna were excluded from the root bags by using a netting of small (1.5 mm) mesh size. Therefore the experimental set-up was changed, so as to create conditions to closely resemble those of the undisturbed soil. Ceramic plant pots (water permeable) were filled with a mixture of fresh roots and soil at a root density approximately equal to 2 g dry roots per kg moist soil. The pots were covered with a 6 mm mesh size netting and buried upside down in the soil. They were harvested at regular intervals and dry root weight were determined.

Results show that relative dry matter loss of *B. decumbens* during the initial 35 days was much slower than that of *C. acutifolium* and of *A. pintoi*, the latter losing weight at the highest rate (Fig. 5). An exponential decay curve ($Y_t = Y_0 e^{kt} + R$) was calculated through the data, explaining between 66 and 92% of the data variation. The decomposition constant k was 0.051, 0.063 and 0.066 d^{-1}, respectively. The residual material R, consisting of organic material which does not decompose within the time frame of a few months, represents the root input of slow plus passive organic material to the soil. Since for *C. acutifolium* and *B. decumbens* the residual material

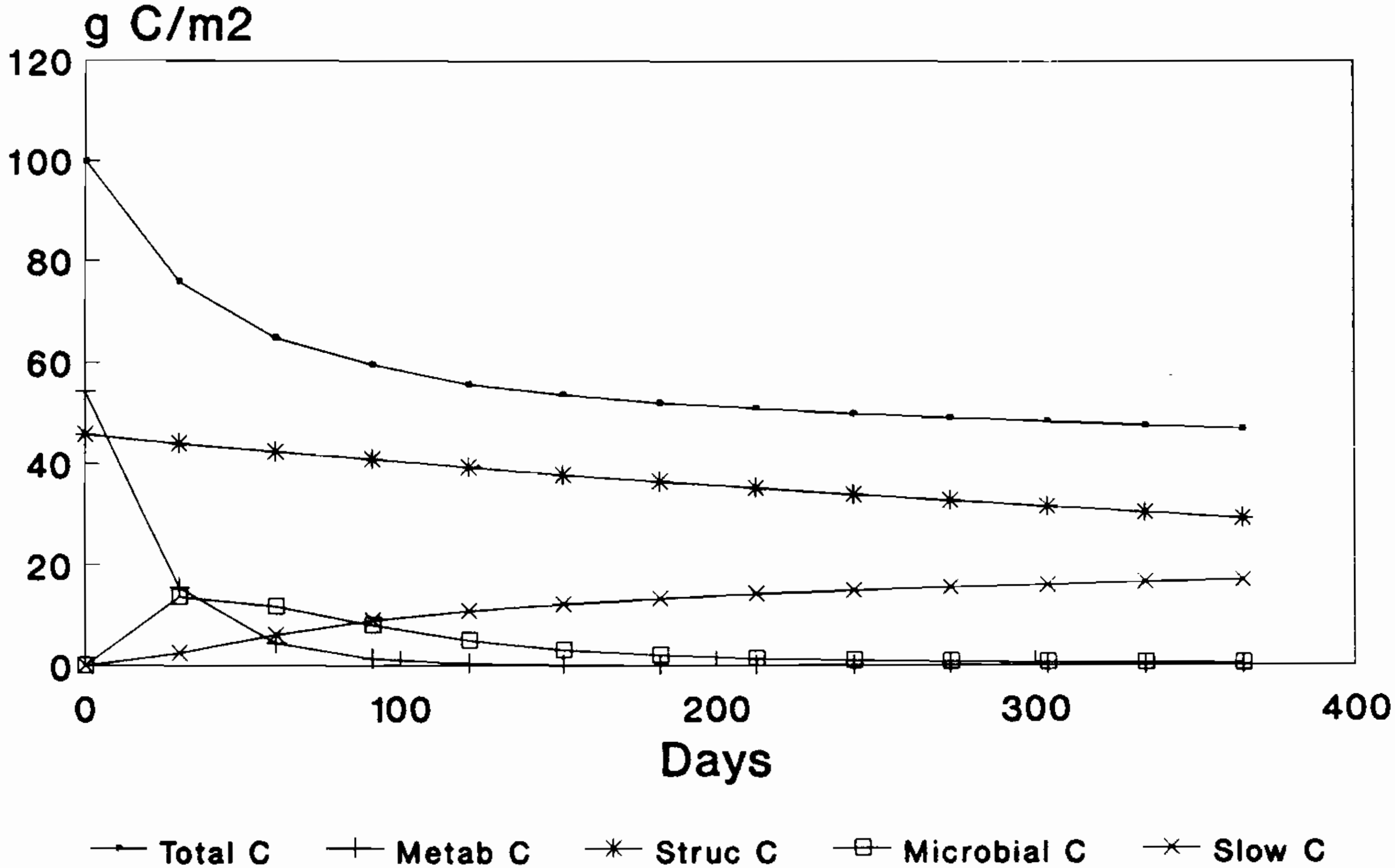

Fig. 3. Decomposition of A. pintoi leaf litter - C pools

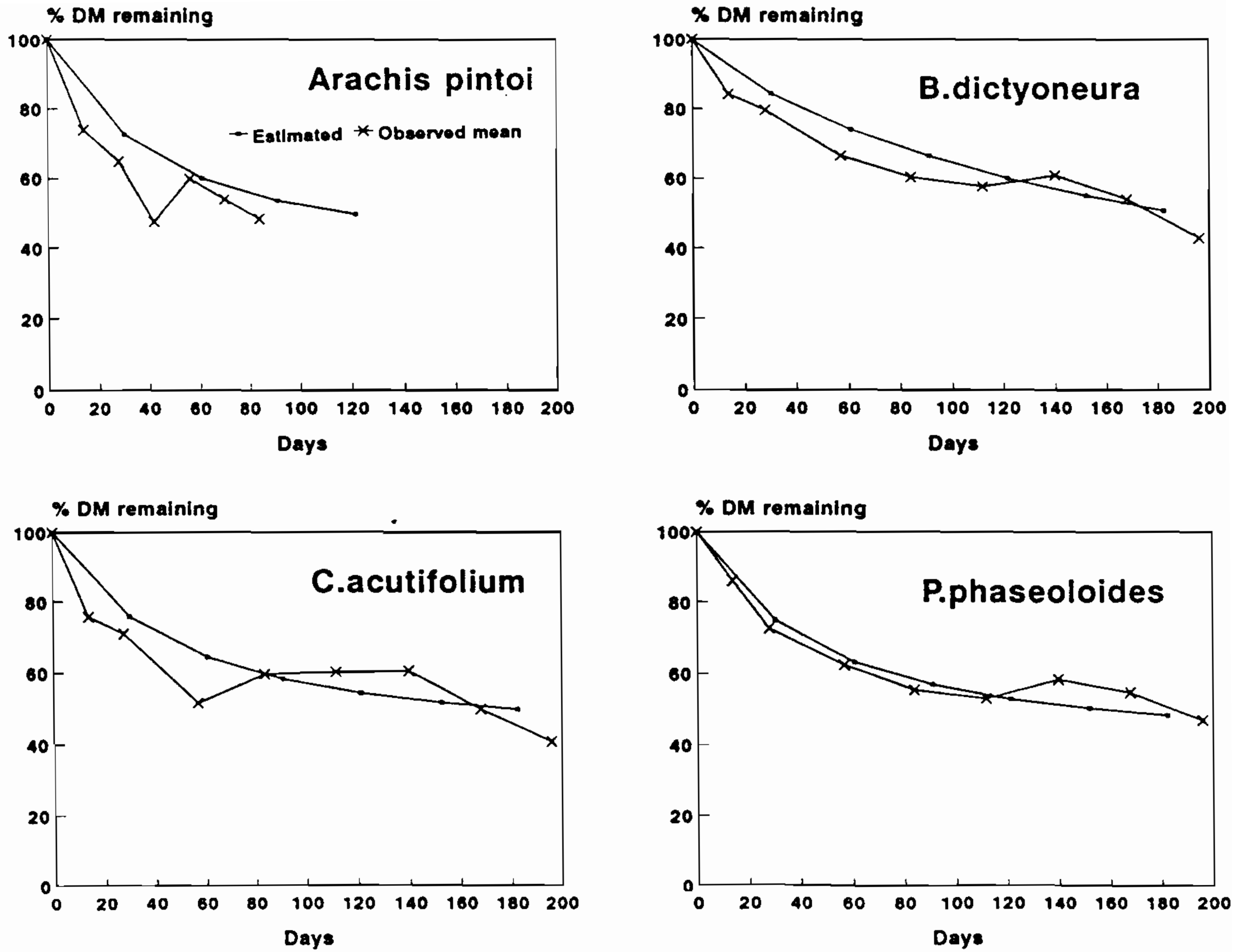

Fig. 4. Decomposition of leaf litter

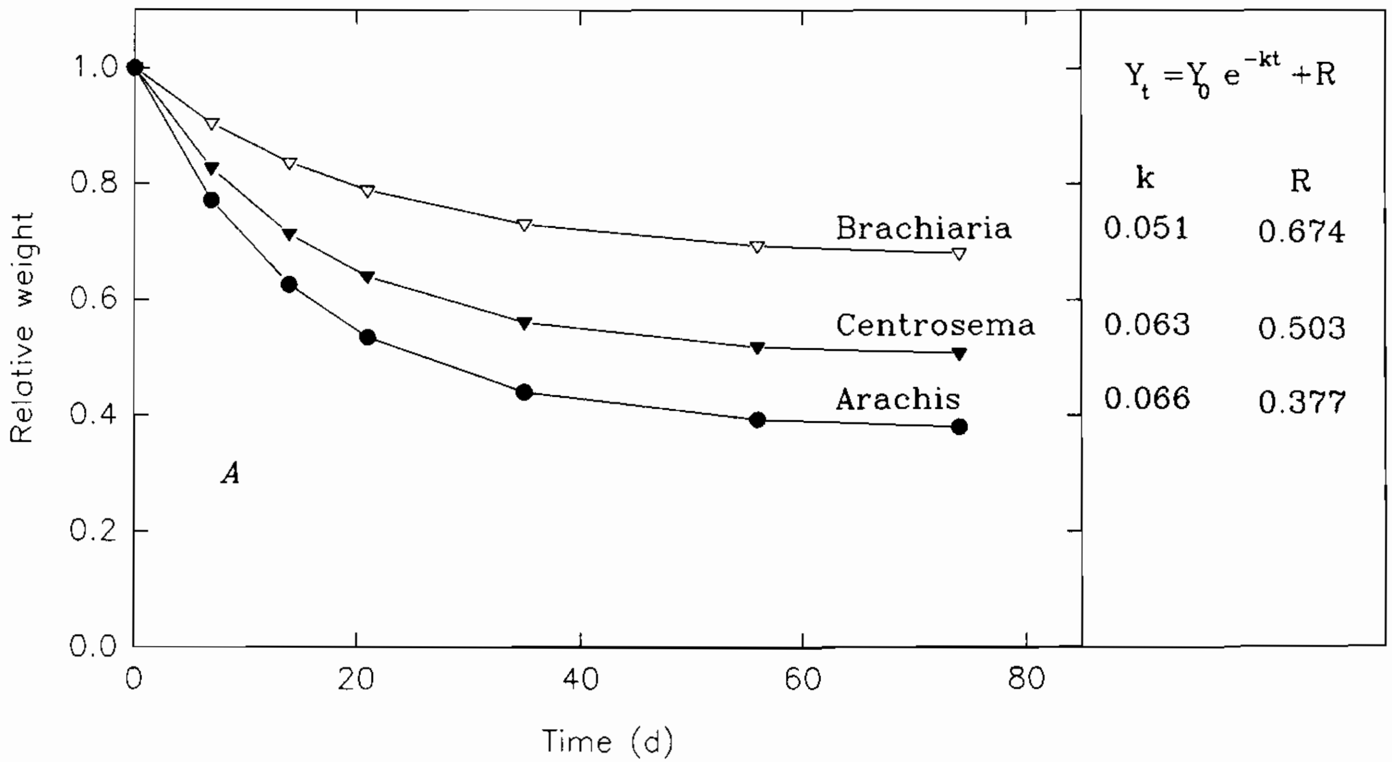

Fig. 5. Decomposition of roots

Table 3: Decomposition rate constants (K) and half-lives of roots

Species	Treatment	Decomposition Constant K	Half life (day)
Grasses			
B.humidicola	Coarse roots	0.0057 ± 0.0013	94
	Fine roots	0.0041 ± 0.0009	142
	Coarse roots + soil	0.0059 ± 0.0017	81
	Fine roots + soil	0.0059 ± 0.0011	98
B.dictyoneura			
	Coarse roots	0.0053 ± 0.0014	98
	Fine roots	0.0051 ± 0.0009	114
	Coarse roots + soil	0.0075 ± 0.0012	78
	Fine roots + soil	0.0061 ± 0.0019	74
B.brizantha			
	Coarse roots	0.0062 ± 0.0012	90
	Fine roots	0.0045 ± 0.00114	124
	Coarse roots + soil	0.0064 ± 0.00189	73
	Fine roots + soil	0.0043 ± 0.0016	115
O.sativa			
	Coarse roots	0.0048 ± 0.001	119
	Coarse roots + soil	0.0084 ± 0.0014	67
Legumes			
S.capitata			
	Coarse roots	0.0044 ± 0.00067	44
	Fine roots	0.0058 ± 0.00076	102
	Coarse roots + soil	0.0069 ± 0.00072	89
	Fine roots + soil	0.0075 ± 0.0015	70
C.acutifolium			
	Coarse roots	0.0050 ± 0.00060	122
	Fine roots	0.0052 ± 0.0013	105
	Coarse roots + soil	0.0056 ± 0.0007	109
	Fine roots + soil	0.0085 ± 0.0026	47
A.pintoi			
	Coarse roots	0.0143 ± 0.0023	39
	Fine roots	0.0139 ± 0.0035	33
	Coarse roots + soil	0.0210 ± 0.0018	30
	Fine roots + soil	0.0205 ± 0.0033	25

±,S.E.

made up more than 50% of the initial root weight, no decomposition half-life times could be calculated using this type of analysis. The experiment did not last long enough to determine the half-life time of the slow organic matter decomposition. For *A. pintoi* roots the half-life time during the fast decomposition was 25 days. This value was equal to that obtained with fine roots of *A. pintoi* incubated in litter bags with soil and is simliar to the range (25-39 days obtained with the other litter bag treatments (Table 3).

Relative carbon loss was similar to the relative weight loss, However, for lignin and nitrogen results were highly variable and no conclusions could be drawn. The experiment will be repeated during both the dry and the wet season and in two soil types (sandy and clayey).

Activities in the core experiment on grass/legume pastures at Carimagua

Litter production and nutrient cycling in grazed pastures

In tropical pastures with relatively low rates of pasture utilization the returns of nutrients to the soil via litter are greater than those via excreta (Thomas, 1992). In addition the return of litter in grazed pastures is continuous and can be managed in terms of quality, via plant species selection, and quantitatively via grazing management whereas returns of excreta are impossible to control in time and space.

This study reports the production and amounts of nutrients cycling via the litter of grass and legume based pastures on two soil types grazed with three stocking rates.

Pasture establishment and management

B. dictyoneura CIAT 6133 was sown in June 1990 alone or with *C. acutifolium* cv. Vichada or *S. capitata* cv. Capica at the sandy site. The same pastures were sown on the heavier soil with the exception that *A. pintoi* replaced *S. capitata*. All pastures were fertilized with either (kg/ha): - 20 P, 20 K, 50 Ca, 20 Mg, 12 S and trace elements (low fertility) or three times the amounts above (high fertility). In May 1991 and before grazing began, the average legume content of the *B. dictyoneura/ C. acutifolium* pasture was 22% and 29% in *B. dictyoneura/S. capitata* pastures on the sandy soil. On the heavier clay loam the legume content was 23% for *C. acutifolium* and 6% for *A. pintoi*.

Plots were grazed from May 1991 on a 7/21 day grazing/rest schedule, rotating the cattle among each of four paddocks per replicate treatment. Treatments were duplicated and stocking rate on the pure grass pasture was 1.5 an/ha (medium) while grass-legume pastures were grazed at 1 (low), 1.5 (medium) or 2 (high) an/ha at Alegria. *B.dictyoneura/C.acutifolium* pastures had corresponding stocking rates of 1.5 (low), 2.0 (medium) and 2.5 (high) at Introit while *B.dictyoneura/A. pintoi* was stocked at 2.0, 2.5 or 3 animals/ha.

Litter production

Litter was collected monthly from five permanently located 0.5 m^2 quadrants per replicate (10 per treatment), dried at 60°C, weighed and analyzed for total C, N, P, K, Ca, Mg, lignin and ash content.

Figures 6-10 show the monthly rates of litter production gDM/m^2 over two seasons at both sites. Initial litter biomasses at the commencement of grazing at Alegria were much greater in the grass-legume pastures compared with the grass only pasture (Figs 6&7) due to the presence of large amounts of legume litter from *C. acutifolium* (mean 45 g DM/m^2) and *S. capitata* (mean 72 g DM/m^2). By August however monthly litter production was similar both between grass and grass/legume pastures and between the stocking rate treatments of the grass-legume pastures (Figs 6&7). There were little or no differences in rates of litter production with varying stocking rates on either *B. dictyoneura/C. acutifolium* or *B. dictyoneura/S. capitata* pastures at Alegria (Figs 6&7). Similarly the effect of higher fertility on litter production soon disappeared (Fig 8).

At Intro II initial amounts of litter were greater in *B. dictyoneura/C. acutifolium* pastures than in the pure grass pasture (Fig. 9) but there were no differences between the pure grass pasture and treatments containing *A. pintoi* because of the low legume populations (Fig. 10). High stocking rate tended to reduce litter production in pastures of *B. dictyoneura/C. acutifolium* during the first dry season (Dec 1991) and thereafter but there was no difference between low and medium stocking rate treatments (Fig. 9). Increased stocking rates had little effect on litter production on the *B. dictyoneura/A. pintoi* pastures. As at Alegria the effect of higher fertility on litter production of *B. dictyoneura/C. acutifolium* pastures soon disappeared (results not shown).

Fig. 11 shows the average % N of the litter during the measurement period for all pastures at both sites. Of note are the 3-4 fold greater initial concentrations of N in litter of grass-legume pastures compared with grass only pastures (except with *A. pintoi* due to the low legume population). Concentrations of P and Ca were also greater in grass/legume pastures compared with grass only pastures but not K or Mg (Thomas et al., 1993).

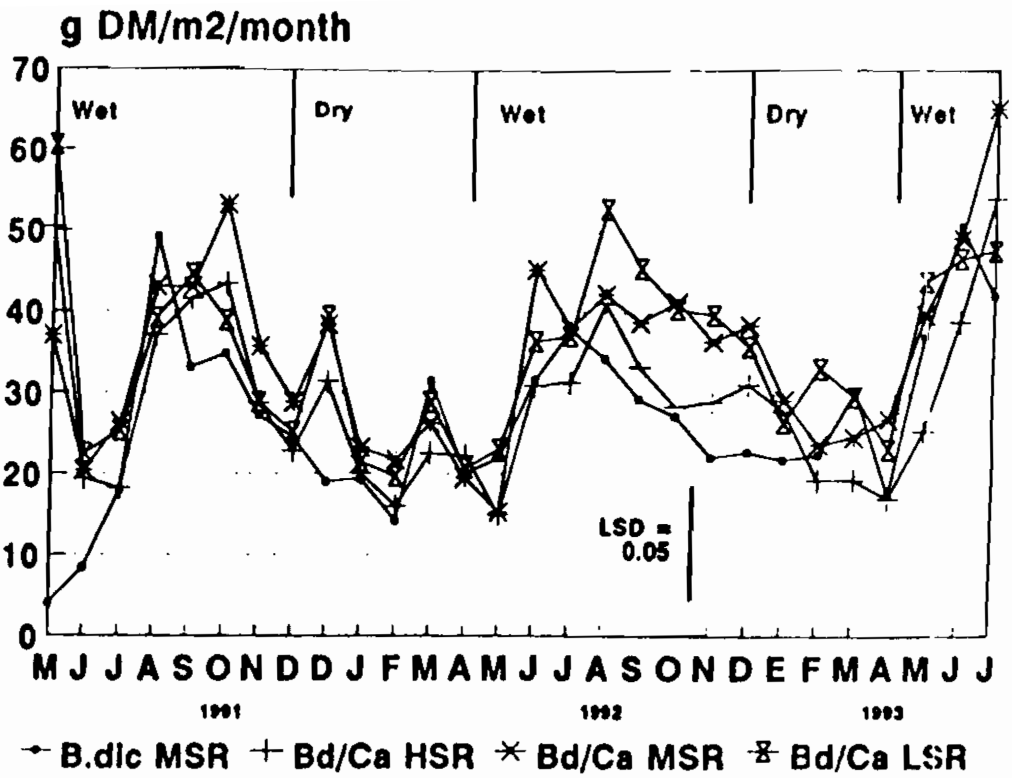

Fig. 6. Litter production at Alegría - Effect of SR on Bc/Ca pastures

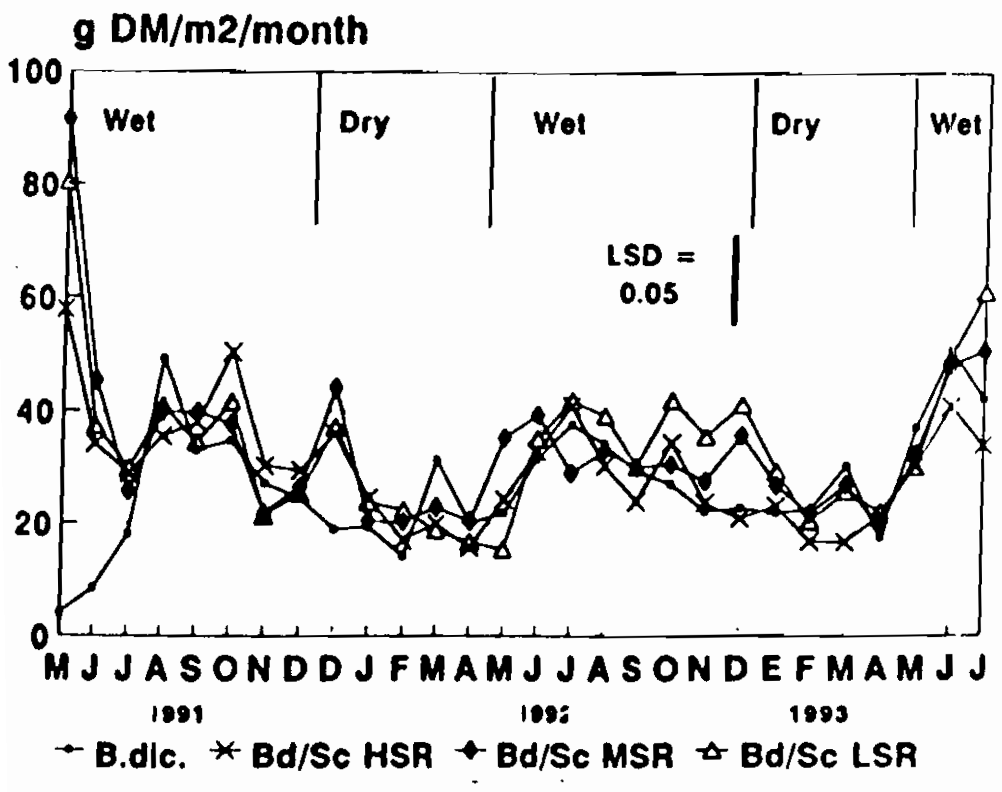

Fig. 7. Litter production at Alegría - Effect of SR on Bd/Sc pastures

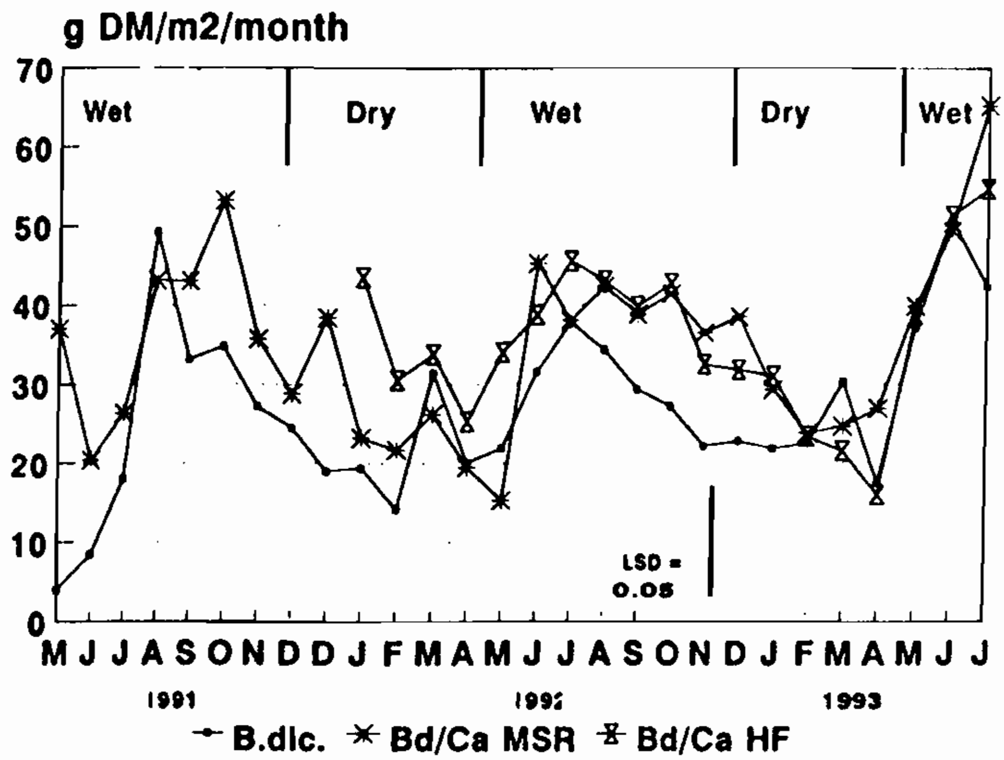

Fig. 8. Litter production at Alegría - Effect of HF on Bd/Ca pastures

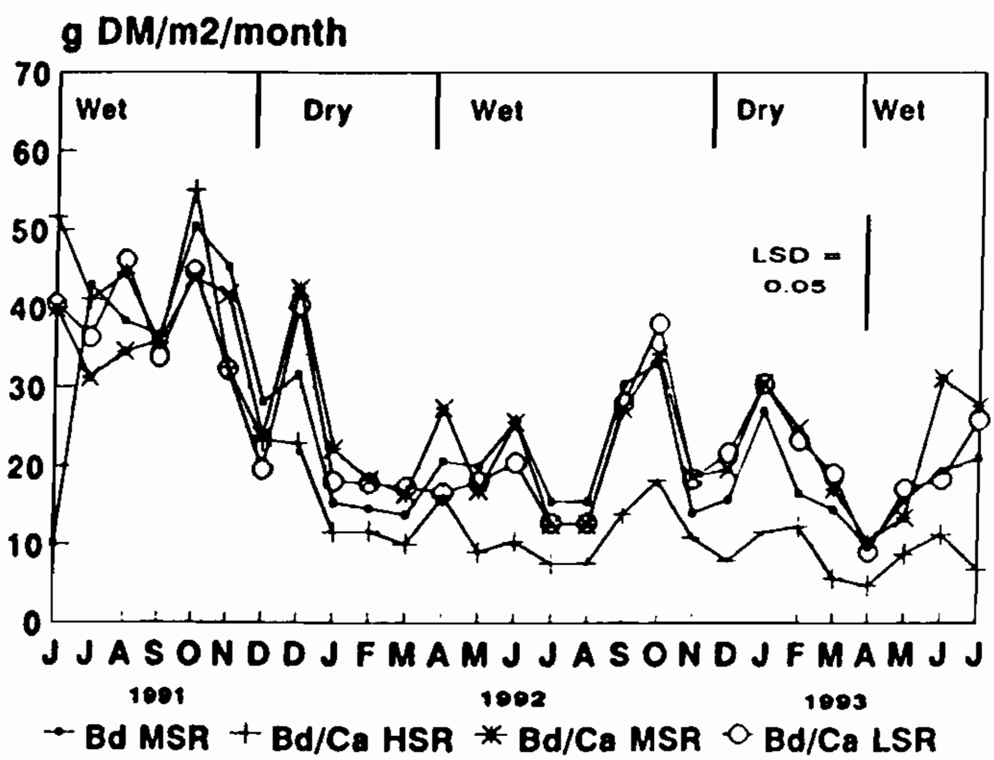

Fig. 9. Litter production at Introduction II - Effect of SR on Bd/Ca pastures

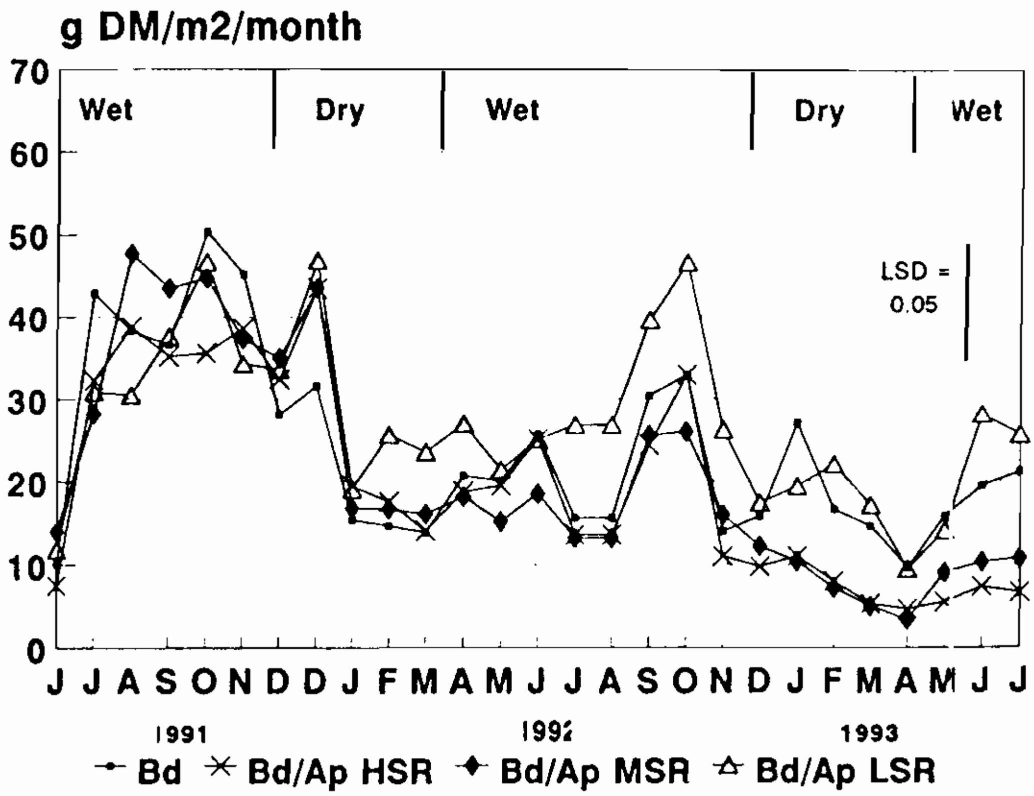

Fig. 10. Litter production at Intro II - Effect of SR or Bd/Ap pastures

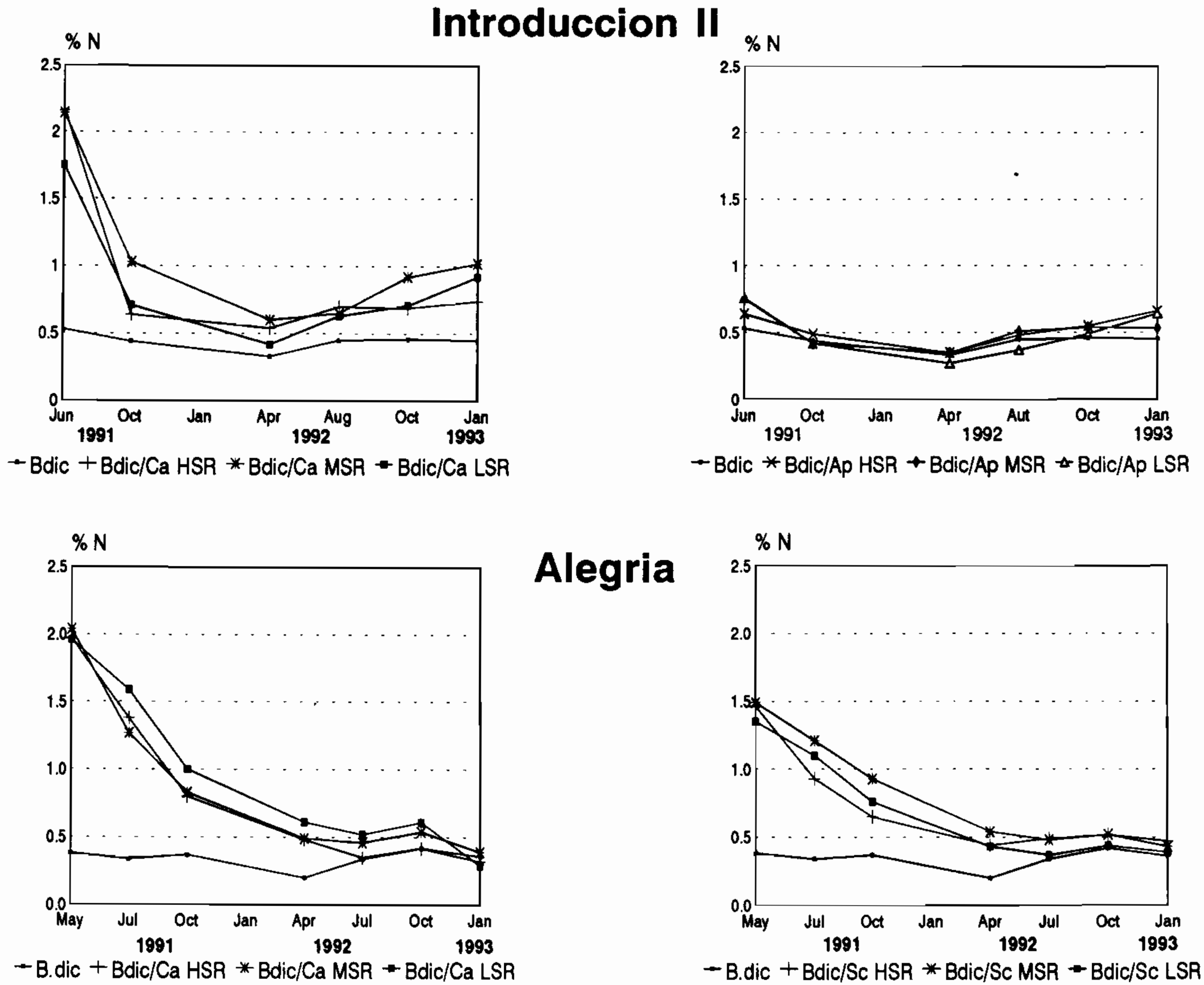

Fig. 11. % N in litter

By April 1992 there were little or no differences between the % N in litter of grass/legume pastures and in grass only pastures, probably reflecting the loss of the legume.

Thus although the introduction of a legume into a grass pasture resulted in a 3-4 fold increase in the amounts of N and Ca, and an increase in P returning to the soil via plant litter over the first 7-month measurement period, with the rapid loss of the legume these differences quickly disappeared.

Rates of N_2 fixation in *A. pintoi*, *C. acutifolium* and *S. capitata*

Forage legumes have been selected for adaptation to the infertile acid-soils of Latin America together with their appropriate *Bradyrhizobium* strains for use in pastures and agropastoral systems. Nitrogen fixation has rarely been measured in the field under conditions relevant to these agroecosystems. Here we report rates of nitrogen fixation and % N derived from fixation (%Ndfa) in three forage legumes grown in pastures on an oxisol in Colombia.

The legumes *A. pintoi* CIAT 17434, *C. acutifolium* cv. *Vichada* and *S. capitata* cv. *Capica* were sown on a sandy loam (Alegria) and a clay loam (Introll) at Carimagua with the grass *B. dictyoneura* CIAT 6133 in triplicated $10m^2$ plots. Similar areas of both native savanna and *P. maximum* ecotype KK16 were chosen as additional non-fixing controls. One half of each plot received a low fertility treatment of, kg/ha, 20P, 20K, 50Ca, 20Mg, 12S, micronutrients and no N (pasture fertility level of the core experiment). The other half received three times this level of fertilizer (high fertility treatment of the core experiment, appropriate for a crop).

Nitrogen fixation was measured by isotope dilution by applying 5 kg $(NH_4)_2SO_4$-N/ha (5% atom excess) in solution with cane sugar. Plants were harvested after 8-13 weeks. Results are means of two measurement periods during the wet seasons of 1991 and 1992. Data for 1993 are not yet available.

The amounts of nitrogen fixed over 12 weeks varied from 1-40 kg/ha with higher rates of fixation at high fertility levels on both soil types, especially with *A. pintoi* (Table 4). However when the data are expressed per unit legume dry matter it is evident that fertility had little effect on N_2 fixation (Table 5). Thus the low rates of fixation per unit area in pastures receiving low (pasture) fertility are mainly explained by the low legume contents compared with pastures receiving high fertility (Table 4). The %Ndfa was usually greater than 80% for all legumes and treatments and averaged 89.2%. Fertility had little or no effect on the %Ndfa (Table 5).

The data demonstrate that when in competition with a grass, legumes derive a large proportion of their N from the atmosphere on differing soil types and fertility levels appropriate for pasture or agropastoral systems in Latin American savannas. Given the high and relatively constant % of legume N derived from fixation (89%) it should be possible to estimate inputs of fixed-N by a simple estimate of legume content in the pasture. Furthermore the data verify the value of 90 %Ndfa used in the model to determine the optimum legume content in pasture for sustainability in terms of N (Thomas, 1992).

N mineralization potentials of soils under grass or grass/legume pastures.

Soils from different pastures were tested for N mineralization potentials using an anaerobic incubation method described earlier (TPP Ann Rpt 12-26, 1991). The 13 yr old *B. decumbens* alone and *B. decumbens*/kudzu pastures were included as examples of soils known to vary in their capacity to supply a subsequent rice crop with nitrogen and were contrasted with soils of the core experiment.

Table 6 shows the potential N mineralization rates of 0-20 cm soil profiles sampled in May 1991. Both soil from the 9 yr old pure kudzu pasture and 13 yr old *B. decumbens*/kudzu pasture had greater potential mineralization rates compared with the 13 yr old *B. decumbens* only pasture. For the core experimental sites there were no differences among grass and grass legume pastures or fertility levels at either site.

The pastures were re-sampled 4 months later and soil profiles were separated into 2 cm horizontal profiles to 6 cm depth. The results are presented in Table 7. Greater potential mineralization rates were measured in the 0-2 cm profile but not 2-4 or 4-6 of the *B. decumbens*/kudzu pasture compared with the *B. decumbens* only pasture.

Table 4. Amounts of N_2 fixed over 12 weeks Kg N/ha and % legume content in pastures

		A. pintoi		*C. acutifolium*		*S. capitata*	
Site	Fertility	1991	1992	1991	1992	1991	1992
Sandy	Low	0.8a (4.0)	-	1.7a (5.0)	0.3a (1.4)	21.0a (46.3)	4.4a (6.3)
Loam	High	7.4b (17.7)	-	2.5a (4.5)	0.8a (2.3)	40.0b (44.2)	2.2a (16.5)
Clay	Low	0.9a (1.9)	0.7a (2.8)	3.5a (4.6)	2.4a (6.6)	14.8a (27.0)	4.7a (24.0)
Loam	High	6.8b (10.0)	4.4b (14.8)	5.2a (5.4)	4.6a (9.4)	31.0b (32.3)	6.0a (21.6)

Numbers in brackets are % legume contents in the pastures.

Table 5. Amounts of N_2 fixed Kg N/t legume DM and %Ndfa

		A. pintoi		*C. acutifolium*		*S. capitata*	
Site	Fertility	1991	1992	1991	1992	1991	1992
Sandy loam	Low	18.7a (81.5)	-	25.3a (88.9)	23.52 (64.5)	27.1a (85.6)	17.9a (87.5)
(Alegria)	High	24.4b (87.1)	-	33.1b (91.7)	20.39 (96.3)	31.0a (90.2)	17.4a (88.0)
Clay loam (Intro II)	Low	19.7a (71.7)	15.3a (81.4)	29.1a (91.4)	20.3 (92.1)	21.6a (79.7)	16.6a (87.9)
	High	22.8b (85.6)	17.9a (68.3)	29.1a (92.9)	25.5 (95.4)	22.4a (89.1)	16.0a (92.2)

Numbers in brackets are the % Ndfa.

Table 6. N mineralization rates of soils under different pastures

Soil	Pasture	μg N/g soil/day (0-20 cm soil)
Intro II	*B. decumbens* (13 yr old)	4.42 ± 0.18
	B. dec./kudzu (13 yr old)	6.10 ± 0.26
	Kudzu (9 yr old)	5.33 ± 0.36
Intro II-core	*B. dictyoneura* (1 yr old)	1.45 ± 0.33
	B. dic./C. acutifolium - pasture fertility (1 yr old)	2.16 ± 0.37
	B. dic./C. acutifolium - high fertility (1 yr old)	1.59 ± 0.25
	B. dic./A. pintoi - pasture fertility (1 yr old)	1.69 ± 0.38
	B. dic./A. pintoi - high fertility (1 yr old)	1.59 ± 0.40
Alegria - core	*B. dictyoneura* (1 yr old)	2.36 ± 0.20
	B. dic./C. acutifolium - pasture fertility (1 yr old)	2.57 ± 0.29
	B. dic./C. acutifolium - high fertility (1 yr old)	2.56 ± 0.21
	B. dic./S. capitata - pasture fertility (1 yr old)	2.76 ± 0.84

Means of 10 estimates ± S.E. sampled in May 1991 from 0-20 cm profile

Table 7. Potential N mineralization rates of soils under different pastures at different soil depth

Soil	Pasture	Depth (cm)	μ N/g soil/day
Intro II	*B. decumbens* (13 yr old)	0 - 2	8.90 ± 1.46
		2 - 4	5.98 ± 0.39
		4 - 6	4.98 ± 0.42
	B. dec./kudzu (13 yr old)	0 - 2	10.25 ± 0.46
		2 - 4	5.18 ± 0.88
		4 - 6	5.44 ± 0.12
Intro II - core	*B. dictyoneura* pasture fertility	0 - 2	6.89 ± 0.28
		2 - 4	5.77 ± 0.17
		4 - 6	6.62 ± 0.35
	B. dic./C. acutifolium pasture fertility	0 - 2	6.79 ± 0.26
		2 - 4	5.99 ± 0.45
		4 - 6	6.69 ± 0.41
	B. dic./A. pintoi pasture fertility	0 - 2	6.67 ± 0.62
		2 - 4	6.70 ± 0.60
		4 - 6	6.57 ± 0.35
Alegria - core	*B. dictyoneura* pasture fertility	0 - 2	2.80 ± 0.07
		2 - 4	2.75 ± 0.21
		4 - 6	2.95 ± 0.26
	B. dic./C. acutifolium pasture fertility	0 - 2	2.62 ± 0.30
		2 - 4	2.41 ± 0.33
		4 - 6	2.78 ± 0.38
	B. dic./S. capitata pasture fertility	0 - 2	3.51 ± 0.22
		2 - 4	2.90 ± 0.11
		4 - 6	2.96 ± 0.26

+- S.E. n = 5, sampled Sept, 1991.

In the core experiment at Intro II (clay loam) there were no differences between grass or grass/legume pastures at any particular depth. At Alegria greatest rates of mineralization were observed in the 0-2 cm depth profile of *B. dictyoneura/S. capitata* pastures compared with the corresponding profiles from *B. dictyoneura* alone or *B. dictyoneura/C. acutifolium* pastures.

The soils under a long term pasture of *B. decumbens/kudzu* consistently show higher potential rates of N mineralization when compared with the grass only pasture (Tables 6&7) thus indicating the usefulness of the method for detecting differences in soil fertility. In the core experiment although there were visible and measurable differences in the N content of grass/legume pastures compared with grass only pastures at Alegria, the only differences detected in potential rates of N mineralization were in soil from the *B. dictyoneura/S. capitata* pastures in the 0-2 cm profile (Table 7). This suggests that for this methodology periods greater than 1 or 2 years are required to detect differences in soil fertility resulting from the presence of the legume.

Dynamics of soil organic matter/soil physics

A lab for soil organic matter and soil physics research has been equipped and methods for the characterization of soil organic matter (SOM) fractions and the determination of soil aggregate characteristics have been compiled from the literature or developed. A lab manual has been written for the analysis of the respective parameters; fine soil litter, microbial biomass, particulate OM (POM), light fraction, passive SOM, soil aggregate size distribution, wet aggregate stability, dispersability of clay in aggregates and hot-water extractable carbohydrate content of aggregates.

<u>Soil organic matter and soil physical characteristics under grass-only and grass/legume pastures.</u>

Soil samples were taken from clay loams under three long-term grass-only and grass-legume pastures at IntroII and III Carimagua, *viz,* 1) *B. decumbens +/- P. phaseoloides* (15 years old), 2) *B. humidicola +/- A. pintoi* (6 years old) and 3) *B. dictyoneura +/- A. pintoi* (6 years old). A nearby savanna control plot was also included. As these pastures have existed for a number of years, it was expected that possible changes in soil characteristics would be more pronounced here than in pastures of a younger age. Therefore, a detailed analysis of soil organic matter content and soil structural characteristics of these pastures was made, involving the following determinations:

- organic matter fractionation (active, slow, passive SOM; hot-water extractable carbohydrate content)
- aggregate size distribution
- aggregate stability at low and high disruptive force
- dispersibility of clay during soil disruption
- bulk density
- penetrometer resistance
- pore size distribution, water-retention characteristics
- water infiltration

Presently, most measurements have been finished, but only the data on soil aggregation and clay dispersion in relation to the carbohydrate content (as a glueing agent) of the soil have been analysed.

The methods used are described in the available laboratory manual. The size distribution of the aggregates shows that the soil was well aggregated. Irrespective of treatment and soil layer, more than 60% (w:w) of the soil consisted of particles larger than 1 mm, whereas about 90% was found in the macroaggregate size class (*i.e.* >250 μm). Clay- or silt-sized particles (*i.e.* <53μm) made up less than 2% of the soil. Differences among treatments were therefore small and were accounted for by shifts from large appears to having been too low to cause aggregate disruption. This method did not reveal any differences between treatments or soil depths.

Applying a higher disruptive force (wet shaking) resulted in a much greater breakdown of aggregates. Between 20 and 35% (w:w) of the aggregates which were initially between 1 and 2 mm were broken down to microaggregate- or clay-sized particles (i.e. <250 μm). Since after soil disruption the aggregates were collected on a to small macroaggregates, with no differences in initial microaggregation.

Determination of aggregate stability with the wet sieving method showed that around 90% (w:w) of the 1-2 mm aggregates stayed intact in all soil samples (Table 8). Variation among replicates was very small (coefficient of variation < 4%). For this highly aggregated soil, the level of soil disruption finer mesh than used for selecting them before the treatment (250 μm versus 1 mm), the fraction of aggregates broken down to particles smaller than the original 1 mm may have been considerably greater.

The aggregate distribution under native savanna did not differ from that under pastures. Inclusion of a legume component in a pasture did not affect the aggregate distribution (Figure 12), but did increase the aggregate stability at high level of soil disruption, be it that this effect was largely restricted to the 0-2.5 cm layer of the soil ($P<0.01$; Figure 13). In the deeper layers this effect also existed for the *B. decumbens* +/- *P. phaseoloides* treatments, but was not clear for the others. The stability of the native savanna soil was relatively high in all soil layers under investigation. The lack of a legume effect on aggregate distribution contrasts with data reported by Thomas *et al.* (1993), who found forthe same *B. decumbens* +/- *P. phaseoloides* experiment a much better soil aggregation in the grass/legume pasture than in the grass-only pasture, both being better aggregated than the savanna. However, even the best aggregated soil in this data (with 33% of the aggregates >0.5 mm) still had a much poorer aggregation than any soil in the present data (about 85% greater than 0.5 mm), which difference in fact is even bigger since in the latter analysis also aggregates >4 mm were included. Although part of this difference may be explained from the fact that the data refer to the distribution of water-stable aggregates only (pers. comm., M.A. Ayarza), it seems that either sample treatment has been different, or aggregation strongly varied with time of sampling.

Not surprisingly, stocking rate was negatively correlated with average aggregate size (Figure 12), as an increased trampling by the animals is likely to have destroyed part of the larger aggregates. For all soil depths and across all treatments, the smallest mean aggregate diameter was found in those pastures which supported 4 animals per hectare. For *B. humidicola* +/- *A. pintoi* (2 versus 4 an/ha) this decrease was significant ($P<0.05$) in all soil layers and could be ascribed to a reduction in the fraction aggregates greater then 2 mm (from 38.3% to 33.6%; $P<0.001$). For *B. dictyoneura* +/- *A. pintoi* (2 versus 3 an/ha) the difference never was significant. Aggregate stability at the higher of the two levels of disruption was also lower at higher stocking rate (Figure 13). In the layer 0-2.5 cm this was significant ($P<0.05$) in both stocking rate experiments; in the deeper layers only for the *B. dictyoneura* +/- *A. pintoi* experiment. The effect of stocking rate did not differ between grass-only and grass/legume pastures.

Table 8. Wet aggregate stability (WAS) of aggregates from 3 soil layers in various grass-only and grass/legume pastures at the low level of soil disruptive force (standard deviation in brackets)

Treatment	WAS (%)		
	0-2.5 cm	2.5-5 cm	5-10 cm
Bdec	91.5 (2.9)	92.4 (1.8)	92.5 (3.1)
Bdec/Pp	91.6 (3.0)	93.6 (0.7)	92.9 (1.9)
Bhum+2	90.8 (1.7)	91.7 (1.4)	93.7 (1.4)
Bhum/Ap+2	90.3 (1.5)	91.1 (1.3)	93.9 (0.6)
Bhum+4	87.1 (1.7)	90.7 (1.2)	92.2 (1.6)
Bhum/Ap+4	88.1 (2.1)	89.9 (1.2)	91.9 (1.4)
Bdic+2	86.8 (2.8)	91.1 (2.5)	89.9 (2.5)
Bdic/Ap+2	91.2 (1.8)	89.6 (2.1)	91.5 (2.0)
Bdic+3	88.4 (2.1)	92.2 (1.6)	91.4 (1.9)
Bdic/Ap+3	90.1 (1.8)	90.5 (2.4)	92.7 (1.1)
Sav	89.7 (1.8)	91.6 (1.8)	91.0 (2.1)

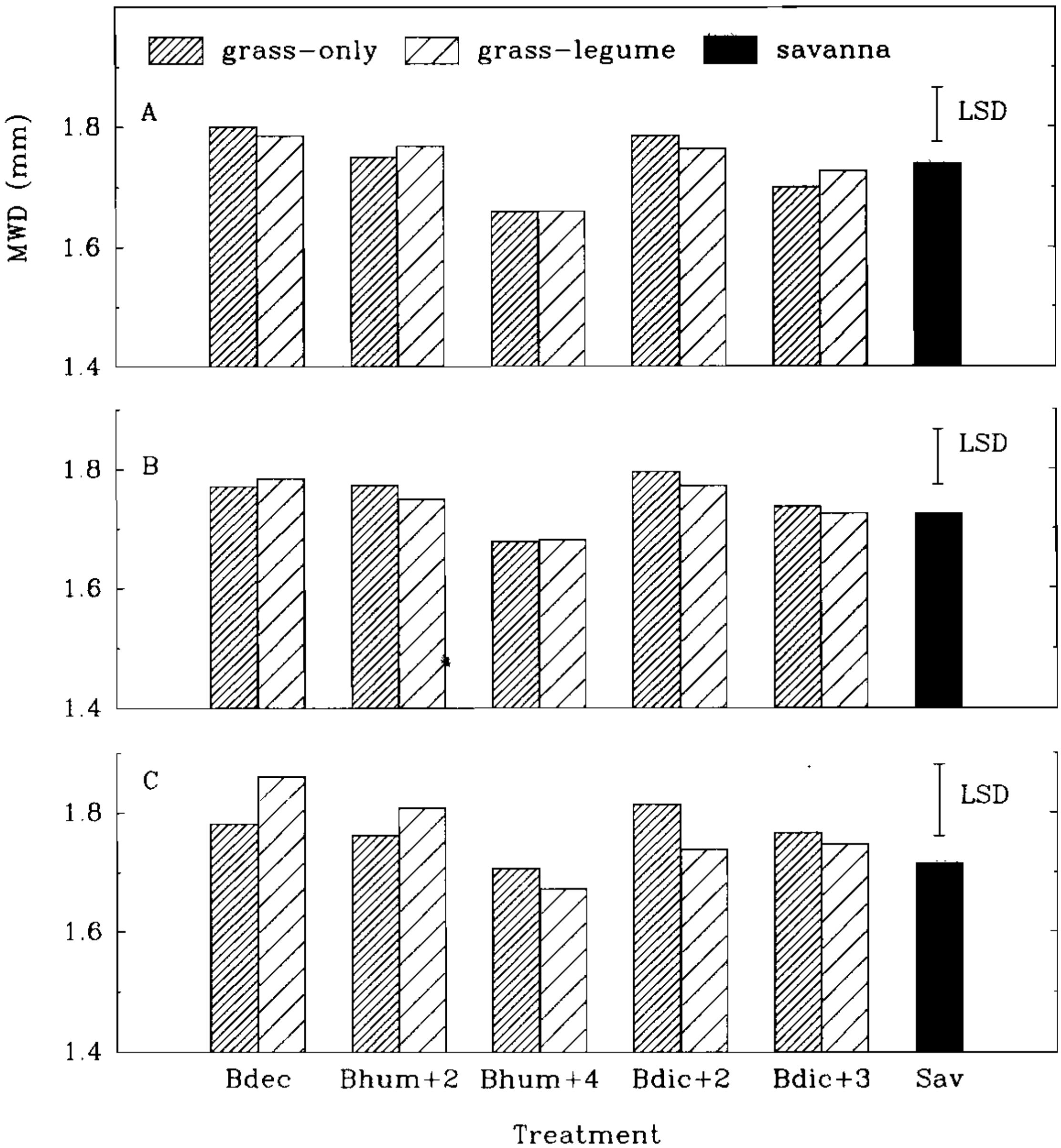

Fig. 12. Initial mean weight diameter of soil aggregates a) 0-2.5 cm b) 2.5-5 cm c) 5-10 cm

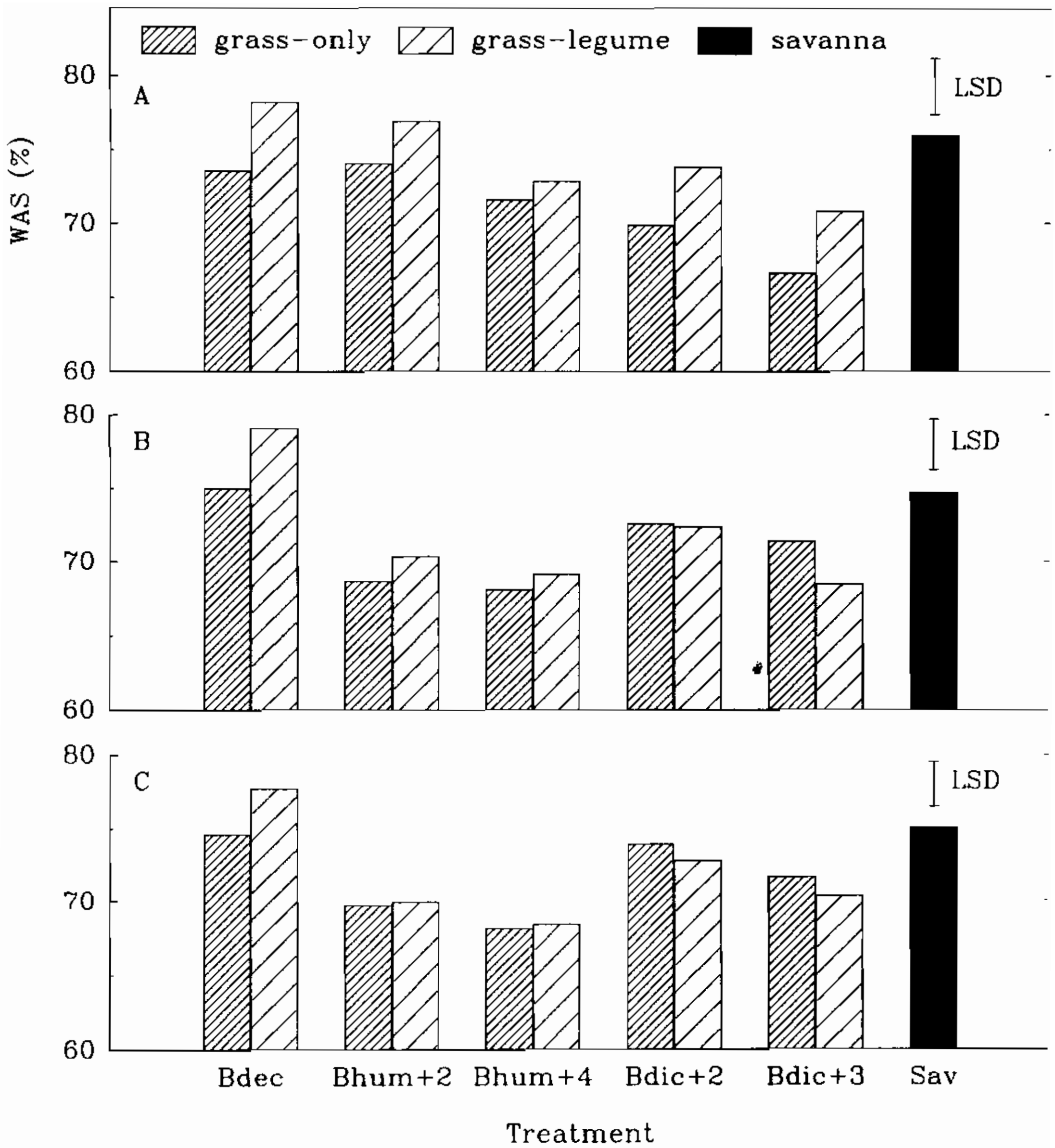

Fig. 13. Wet aggregate stability of soil aggregates a) 0-25 cm b) 2.5-5 c) 5-10 cm

The instability of microaggregates was determined by measuring the dispersion of clay particles after disruption of the soil. The results showed that this phenomenon hardly occurred in these soils. For all treatments and all soil layers only between 2.1 and 3.1% of the total sample weight (DC) or between 5.1 and 8.2% of the clay content (DCF) was dispersed. No differences existed between treatments or soil depths. It can thus be concluded that microaggregates were highly stable.

Differences in species composition of the pasture (grass-only vs grass/legume) are likely to affect the size and composition of the microbial population and thus the production of microbial gums, which form a major gluing agent in the aggregation process. The generally high level of aggregation in this soil, however, suggests that this did not lead to a noticeably different aggregate MWD. The composition of the more humified soil organic matter may differ considerably between grass-only and grass/legume pastures, as earlier shown by delta-13C work of Rao *et al.* for the *B. decumbens* +/- *P. phaseoloides* experiment. As humified SOM plays a central role in the stabilization of aggregates, this difference may explain the better aggregate stability of the soil under grass/legume. Increased trampling at higher stocking rates not only leads to a breaking up of aggregates and thus a smaller MWD, it also leads to aggregate deformation, increasing the intra-aggregate tension in the remaining aggregates, thus making them vulnerable for collapse. The stability may be further affected by a less thorough macro-aggregate stabilization by the root-hypha-humus complex, as root density may decline in response to the increased bulk density due to trampling and the more severe removal of plant tops.

It has been suggested that a certain carbohydrate pool, possibly hot water extractable carbohydrates, equates with the microbial polysaccharides which glue together soil aggregates. Figure 14 shows that even though the range of aggregate stability values is small, still a clear positive correlation existed between WAS and hot water extractable carbohydrate content. This confirms the hypothesis above. Moreover, the relatively large range in carbohydrate values (400-1200 μg/g) compared to the range in stability values (60-80%) indicates that the method may prove useful to detect small differences in aggregate stability, even if these differences are not that clear yet in the stability measurement itself. However, the larger variability in carbohydrate data than in the stability data (CV's of 3-22% and 2-6%, respectively) may put a limit to its applicability.

In conclusion it can be said that in this soil the inherent stability of the soil structure under native savanna was high and only slightly changed under pasture. Differences in both initial aggregate distribution and aggregate stability were small among all treatments. Still their potential importance may be found in the fact that in the wet season extensive flooding of the soil frequently occurs, leading to a washing away of part of the top soil, as Spain and Gualdrón (1988) mentioned soil compaction and erosion among the principal causes of pasture degradation in the eastern Colombian savannas. Small differences in aggregation or aggregate stability may have their impact on the soil's erodability. In future research attention should be paid to the water infiltration characteristics of the soil and to the fate of soil aggregates when pasture is rotated with crops (esp. rice), as it is known that a decline in soil structure may occur under crop cultivation.

Other activities

Modelling. The application of the CENTURY ecosystem model to determine likely trends in SOM dynamics is at a preliminary stage and work is continuing on its modification to Carimagua conditions.

Minirhizotron. The purchase of a video camera minirhizotron system will allow estimates of root growth and turnover under field conditions after preliminary work has been made to adjust the equipment to Carimagua conditions.

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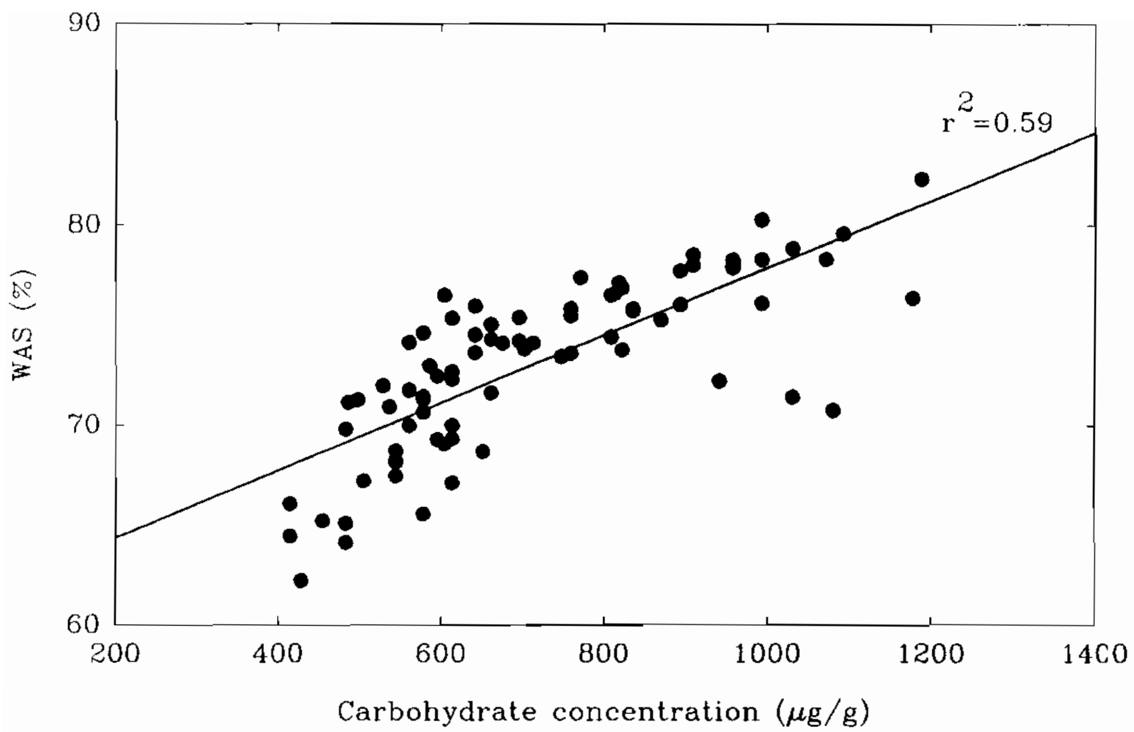

Fig. 14. **Correlation between wet aggregate stabilitu (WAS) and hot water extractable carbohydrate concentration (μg glucose/g soil)**

CHAPTER III

ECOPHYSIOLOGY

INTRODUCTION

The period 1992-1993 marked the creation of the new Savannas Program, and the transition from the work carried out within the old Tropical Pastures Program to address the objectives of the new Program. Some work, particularly the collaborative studies with colleagues in the new Tropical Forages and the Savannas Programs has continued, but other new initiatives have been undertaken. In particular, there has been increased emphasis on the competitive relations between grasses and legumes, on soil biology, and on mathematical modelling. The on-going rice-pastures project was completed in 1992, and the area was resown to the original pastures.

Competitive relations between grasses and legumes

The lack of persistence of the legume component in mixed grass-legume swards is one of the biggest problems faced in sustainable improvement of the savannas. Obtaining the target legume content is a delicate balancing act between the many factors that affect legume persistence, such as competition with the associated grass for light, water and nutrients, in addition to grazing preference.

Field studies

In 1991, it was observed on the sandy soil site of the collaborative "Core" experiment that the contribution of the legumes, particularly in the leaf component, in both associations was declining (Figures 1a and b). There was no regeneration of seedlings in *Centrosema acutifolium* cv Vichada (seed set in this cultivar in grazed pastures at low latitudes has long been recognized as a problem), but in *Stylosanthes capitata* where germination was satisfactory, the seedlings lacked vigor. In most cases the plants grew very little after the second or third trifoliate leaf stage.

This is not an uncommon observation in *S. capitata*-based pastures in Carimagua, but it has never been satisfactorily resolved. Valencia (1981) showed that there was root competition between mature plants of *Andropogon gayanus* and seedlings of *S. capitata*, and that if the competition was eliminated by enclosing the seedlings in plastic tubes driven 30 cm into the ground, then they grew normally. In another experiment, she concluded that the plants were competing for K. Nevertheless, applications of K to *A. gayanus*/*S. capitata* swards did not lead to enhanced persistence of the legume in field trials (CIAT, 1986).

A micro-plot experiment was undertaken in the second half of 1991 in which 16 matched groups of seedlings of *S. capitata* in each of two replicated paddocks of the medium stocking rate were selected and assigned at random to one of four treatments with four internal replicates. The treatments were a factorial between protected from root competition or not, and open to grazing or protected by cages. Protection from root competition was provided by PVC tubes 10 cm in diameter driven 30 cm into the soil, with the upper end flush with the surface, contrasted with PVC rings 10 cm in diameter and 5 cm deep placed in the soil, also flush with the surface.

Plant height and vigor were monitored each four weeks for four months in 1991, and again at the start of the wet season in 1992, but there was no evidence of any response to the treatments. At the start of the wet season in 1992, *C. acutifolium* disappeared from most of the plots in the experiment, and at mid-year, symptoms of K deficiency were recognized in leaves of *S. capitata*. A further group of micro-plot study was undertaken in which application of K fertilizer was contrasted with removal of the grass plants (the chopped up removed material was returned as mulch), simulated cultivation, or mowing the grass each four weeks to a stubble height of 5 cm. In this experiment there were clear responses in both height and vigor of the *S. capitata* plants to added K and lesser responses where the grass was removed.

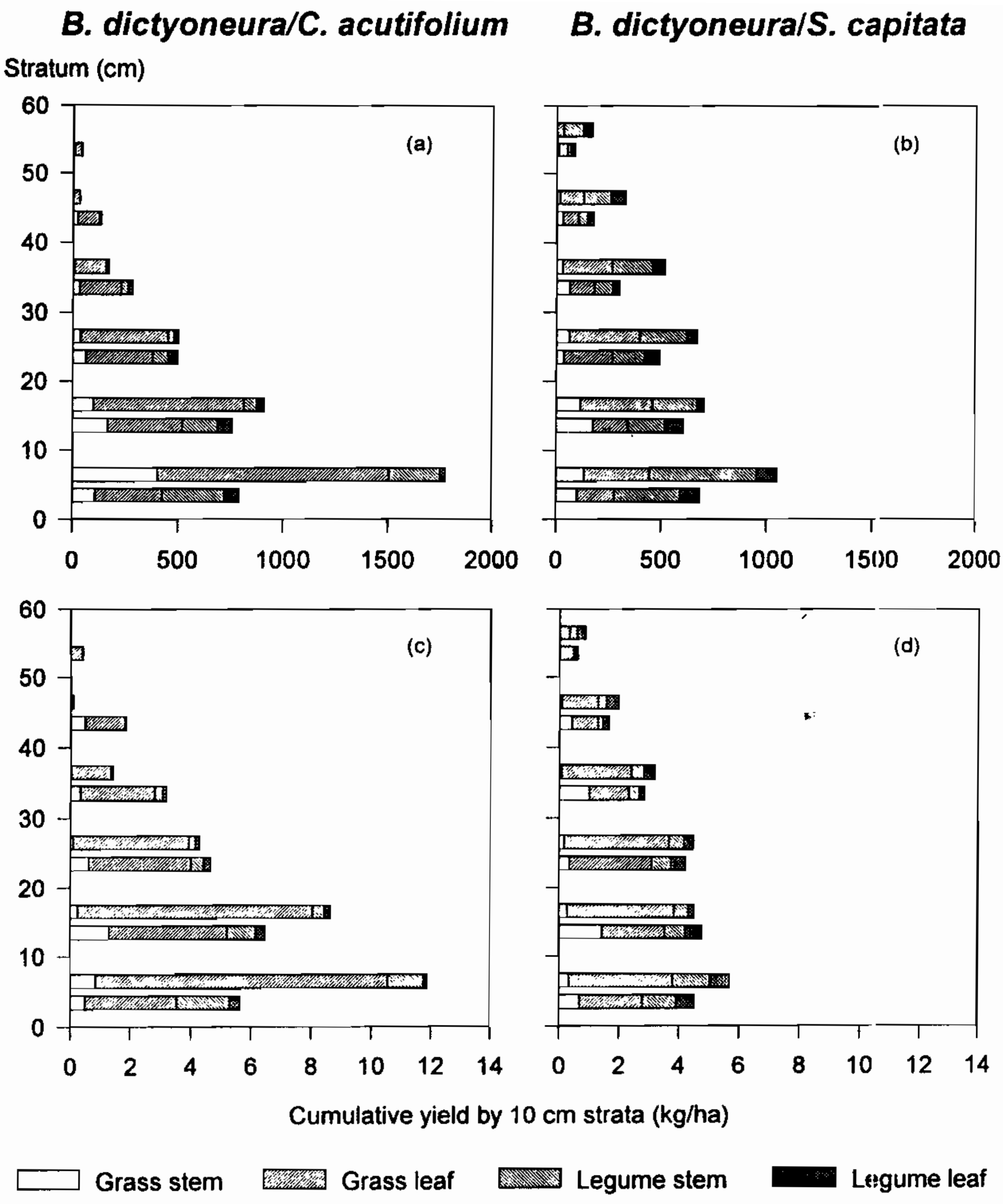

Figure 1. Distribution of dry matter and potassium in height strata in two associations on the sandy soil site in 1991.

Concurrent analysis of plant tissue samples taken in April and August, 1991, showed that the legumes in both associations had tissue K concentrations about half or less the commonly accepted critical value of 0.95-1.05% (Table 1), and considerably less than in the associated grass.

On the basis of the responses to K in the micro-plot experiment and the low tissue concentrations of K, 100 kg/ha K was applied to each paddock in the *S. capitata*-based treatments in early in the 1993 rainy season, leaving a 5-m strip without K in the center of each paddock. The effects of the fertilizer were monitored during the subsequent five months. The influence of cultivation and defoliation were also evaluated, both in the fertilized areas and the unfertilized strips, to determine the effect of other management options.

Table 1. Concentrations of K in tissue of the components of two associations grown on the sandy soil on two occasions in 1991.

Association	Component	Stems	Leaves	Total shoots
April, 1991.		**Tissue K concentration, %**		
C. acutifolium[1]/	Grass	0.80	1.10	1.03
B. dictyoneura[2]	Legume	0.59	0.51	0.57
S. capitata[3]/	Grass	0.94	1.18	1.10
B. dictyoneura	Legume	0.38	0.63	0.46
August, 1991.				
C. acutifolium/	Grass	0.22	0.94	0.81
B. dictyoneura	Legume	0.54	0.56	0.54
S. capitata/	Grass	0.26	1.05	0.89
B. dictyoneura	Legume	0.23	0.64	0.32

[1] cv. Vichada; [2] cv. Llanero; [3] cv. capica.

In one paddock of each of each replicate of the three stocking rate treatments, nine matched quadrats were chosen in both the fertilized area and the unfertilized strip. These were allocated at random to three replicates of three treatments: simulated cultivation, defoliation each four weeks to a stubble height of 5 cm, and a control. The controls evaluate the effect of K on its own, while the others evaluate the interaction of K with other management options. On the unfertilized strip a further three matched quadrats were allocated to a treatment to which 40 kg/ha K was applied in two split dressings four weeks apart. The treatments are summarized in Table 2.

The treatments were imposed two weeks after the K fertilizer was applied, and ten legume plants were marked in each quadrat. Measurements of plant height, together with visual scores of vigor and color were made for each marked plant at the end of each three-week regrowth period (the experiment is grazed in a 7/21 day rotation) for four months. In addition, representative samples of stem, young leaf and old leaf of both grass and legume were obtained at three-week intervals for mineral analysis. At the end of the four month period each quadrat was harvested at ground level for dry matter yield.

Table 2. Treatments superimposed after application of 100 kg/ha K on the sandy soil site in 1993.

Without K	With K
Simulated cultivation	Simulated cultivation
Mowing to 5 cm	Mowing to 5 cm
Control	Control
20 + 20 kg/ha K	

The results show that *S. capitata* indeed responded in both yield (Table 3) and in K content of the younger leaves (Figure 2) to application of K fertilizer. Although there were indications of an interaction between stocking rate and treatment in the yield data, because of the variability in grazed field experiments such as this one, it failed to reach significance. Partitioning of the factorial between K and management treatment similarly failed to reach significance for either main effects or interactions. Nevertheless it is likely that where K is applied, treatments that reduce the competitiveness of the grass may enhance legume growth.

Table 3. The influence of stocking rate, management treatments and K on the dry matter yield of *S. capitata* four months after application of K fertilizer. The plants were located in pastures grazed in a 7/21 day rotation.

Stocking rate	High		Medium		Low		Mean	
Treatment	-K	+K	-K	+K	-K	+K	-K	+K
			Dry matter yield, g/10 plants					
Cultivation	6.2	8.4	6.5	15.6	3.2	14.3	5.3	12.4
Mowing	2.5	7.5	9.5	11.5	3.9	14.2	5.3	11.0
Control	3.9	7.3	5.4	8.8	7.5	4.9	5.0	7.0
20 + 20 kg/ha K	3.2	-	4.4	-	6.5	-	4.7	-
Standard error			3.27 ns[†]				1.89 *	

[†] ns = P>0.05; * = P<0.05.

It is worrying that the K concentrations fell so rapidly in the legume leaf tissue after initial large increases. It is noteworthy that by the time K was applied, the *S. capitata* populations were far less than considered desirable (Table 4). The possibility of some form of recuperation treatment, such as burning to which *S. capitata* is tolerant (Alejo et al 1986), is an obvious option.

Greenhouse studies

Given that *S. capitata* does indeed suffer from competition from the associated grass, the obvious question is, is it possible to select grasses that are less aggressive for K? Anecdotal evidence suggests that *Brachiaria decumbens* is a more benign companion grass for *S. capitata*, and there are records of farm pastures in which a satisfactory proportion of *S. capitata* has been maintained for more than ten years.

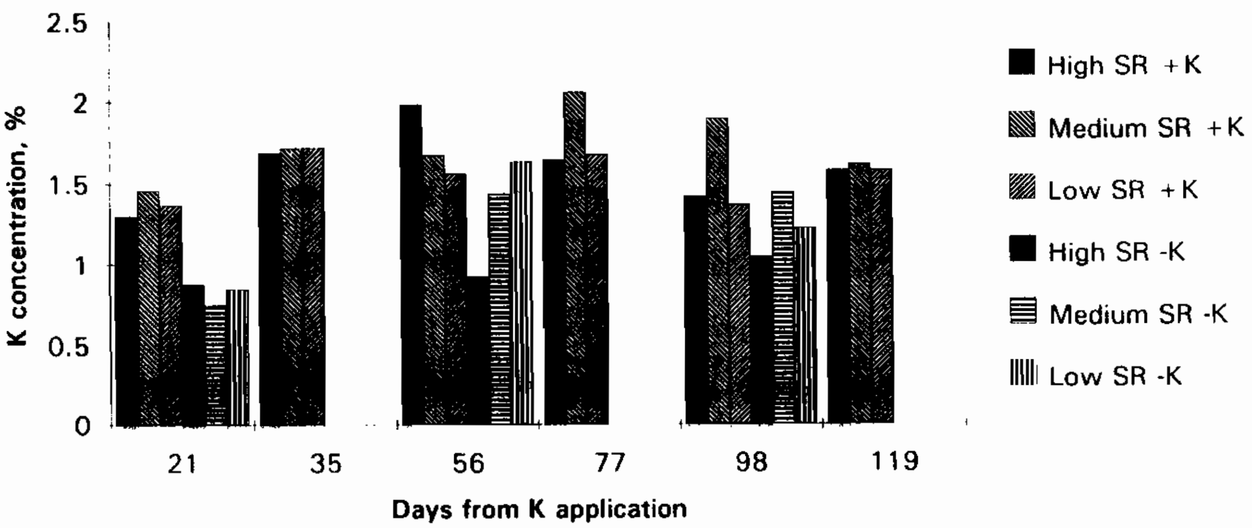

Figure 2. K concentration in young leaves of S. capitata at three stocking rates.

Table 4. The mean yields of dry matter of grass, legume and litter four months after the application of K on the sandy soil site.

Stocking rate	High		Medium		Low		Mean	
Treatment	-K	+K	-K	+K	-K	+K	-K	+K
				Dry matter yield, g/m^2				
Grass	136.7	142.3	135.9	202.8	127.3	213.3	5.3	12.4
Litter	157.4	121.6	180.2	237.4	264.6	320.9	5.3	11.0
Legume	1.3	2.5	0.5	1.0	0.2	1.4	5.0	7.0
Standard error			3.27 ns[1]				1.89 *	

Hall (1975) proposed an extension of the replacement series design (de Wit 1960) to allow closer definition of competition for mineral nutrients, specifically for K. Clearly, if it can be shown that variation exists for competitiveness for K, the prospects for selecting for grasses that are more compatible with legumes may be considerably enhanced. An experiment was conducted in the greenhouse in pots using Carimagua soil in the second semester of 1993 to investigate this hypothesis.

A factorial combination of three legumes and two grasses, each at two levels (low and high) of added K, was grown in a replacement series experiment of six establishment ratios (0.0/1.0, 0.2/0.8, 0.4/0.6, 0.6/0.4, 0.8/0.2, and 1.0/0.0 for grass and legume respectively). The grasses were *B. decumbens* cv. Basilisk and *Brachiaria dictyoneura* cv. Llanero, and the legumes were *S. capitata* cv. capica, *C. acutifolium* cv. Vichada and *Arachis pintoi* CIAT 17434. The experiment was only recently harvested, and because complete analysis of the data requires nutrient composition of the plant tissue, which are not yet available, only some preliminary observations can be made. The behavior of the legumes in the pots was remarkably similar to the field, with *S. capitata* in association with the grasses showing typical stunting at the low level of K, and foliar symptoms of K deficiency. *B. decumbens* appeared to be less vigorously competitive with the legumes than *B. dictyoneura*.

Rice pastures

In 1989, CIAT experimental rice line 3 was sown after ten-year-old pastures of *B. decumbens* alone and *B. decumbens* in association with *Pueraria phaseoloides* (Kudzu) and contrasted with a native savanna. A simple factorial between three levels of N (0, 40 and 80 kg/ha) and two levels of P (25 and 50 kg/ha) fertilizer was superimposed. The yields obtained (Table 5) showed that the legume-based pasture provided the equivalent of 80 kg/ha N to the subsequent rice crop, that there were no responses to P over 25 kg/ha on the old pastures, and that on the savanna only with 80 kg/ha N and 50 kg/ha P were the yields satisfactory.

The Section repeated the experiment on the same plots with the same treatments for a further three years to document what problems were likely to be encountered in an essentially mono-crop system. In 1991, a commercial variety of acid-soil tolerant upland rice, Oryzica Sabana 6, was released, and it was used in place of Line 3. In the final year, 1992, the plots were split to both Oryzica Sabana 6 and Line 3, and a study made of the development of the yield components. The rice was under-sown with the original pasture species, and the pastures allowed to regenerate.

No weed control was undertaken apart from during land preparation before the crops were sown, and it was clear that weeds became an important factor in the later years. Because of the increasing competition from a suite of broad-leaved weeds, rice yields declined with time (Table 6). There was still some residual value from the legume-based pasture in the second year, but the effect was not seen in the third year. It was especially evident that Oryzica Sabana 6 was prone to lodging in contrast to Line 3 (Table 7). There were no significant differences between the two lines of rice in their yield components.

The pastures that have regenerated are excellent, and they have been returned to grazing (Table 8). These pastures, with 15 years of detailed history, represent a valuable resource for the investigation of sustainability issues.

Table 5. The influence of old grass and grass-legume pasture contrasted with a native savanna on the yield of upland rice at Carimagua in 1989.

Pasture	*B. decumbens* alone		*B. decumbens/P. phaseoloides*		Native savanna	
Phosphorus applied (kg/ha)	25	50	25	50	25	50
Nitrogen applied (kg/ha)			**Yield of paddy, kg/ha**			
0	1360	1340	3070	3210	1050	914
40	3080	2950	3130	3210	1740	1500
80	3570	3570	3540	3360	1770	1980

Crop-pasture rotations

The Section has contributed to the new initiative on sustainable crop-pasture systems by undertaking measurements of the phenological development of the crops (in 1993, rice), and their root, shoot and yield development. These data are key components for the modelling of crop performance (discussed in more detail below).

Rice (Oryzica Sabana 6) was planted, either alone or under-sown with a cocktail of legumes and *Brachiaria humidicola*, over some 7 ha directly from native savanna. Crop performance was excellent and yields were about 3.4 t/ha. The development of root biomass during the crop is shown in Figure 3. It is not clear why the yield of roots in mixture with the pasture was less than in the rice alone. There was no evidence of the difference having any influence on crop yield.

Table 6. Yields of paddy in the three years following the initial crops in 1989.

Pasture	*B. decumbens* alone		*B. decumbens*/ *P. phaseoloides*		Native savanna	
Phosphorus applied (kg/ha)	25	50	25	50	25	50
Nitrogen applied (kg/ha)			**Yield of paddy, kg/ha 1990 (Line 3)**			
0	1400	2120	2220	2610	-	-
40	2630	2520	2560	3530	-	-
80	2950	3630	3480	3860	-	1970
Standard error	292		238, P* N*			
			1991 (Oryzica Sabana 6)			
0	3370	3150	3080	3313	-	-
40	2870	3000	3290	3050	-	-
80	3320	2770	3180	2630	-	3910
Standard error			184, Pns Nns			
			1992 (both lines)			
0 (Line 3)	1730	1970	1920	2400	-	-
(O S 6)	1624	2030	1590	2150		
40 (Line 3)	1420	1530	1870	2250	-	-
(O S 6)	1250	1760	1330	2190		
80 (Line 3)	1200	1220	1740	2880	-	1360
(O S 6)	985	1270	1500	2160		890
Standard error	251, N***		189, N x P x lines*			

*** P<0.001, * P<0.05, ns P>0.05

Soil biology

In collaboration with Dr. Patrick Lavelle, ORSTOM, France and Dr. Ana Moreno, Universidad Complutense, Spain, studies are being undertaken on the influence of the various crop and crop-pasture systems on the biomass and diversity of the soil fauna, particularly earthworms. A preliminary survey has shown that crops virtually eliminated the soil fauna (classified as ants, termites, earthworms and others), while in long term pastures of *B. decumbens*/Kudzu the diversity was similar to the savanna but with greatly increased biomass of the earthworm component. The field work is being carried out by a post-graduate student enrolled in the Universidad Complutense.

Table 7. Scores of lodging in 1991 and 1992.

Pasture	*B. decumbens* alone	*B.decumbens/P. phaseoloides*	Native savanna
Nitrogen applied (kg/ha)		**Lodging scores, %** **1991 (Oryzica Sabana 6)**	
0	14		
40	24		
80	50		
		1992 (both lines)	
0 (Line 3)	2	6	
(O S 6)	11	34	
40 (Line 3)	6	8	
(O S 6)	24	42	
80 (Line 3)	25	15	
(O S 6)	43	63	

Table 8. Dry matter yields of weeds and regenerating pasture species at rice harvest, 1992.

Pasture	*B. decumbens* alone		*B. decumbens/P. phaseoloides*		
Nitrogen applied (kg/ha)	**Grass**	**Weeds**	**Grass**	**Legume**	**Weeds**
			Dry matter yield, kg/ha		
0 (Line 3)	1168	674	1399	708	2532
(O S 6)	1429	2312	1777	346	1359
80 (Line 3)	1268	2808	1035	286	1173
(O S 6)	2547	2499	1199	152	1073

Modelling

The modelling activities of the Section take two forms, the application of the crop models of the IBSNAT series (CERES for gramineous crops and GRO for leguminous crops), and the collaborative development of a model of grazed legume-grass pastures in the lowland tropics.

The IBSNAT models depend heavily on detailed understanding of the developmental physiology of the crop variety under consideration, in particular the interactions between heat-sum during vegetative growth and photoperiod in controlling the initiation of flowering, and the influence of heat-sum during grain fill. Whilst these 'genetic coefficients' are well known for many commercial varieties of temperate and sub-tropical crops, there is scant information available for the varieties of maize, rice, soybean and others of importance in the Latin American savannas. For this reason, detailed phenological information is being sought whenever possible in experiments in which the section is and will be collaborating.

Modelling the behavior of crop plants is relatively straight-forward, in that their physiological and agronomic reactions are both well-known and well-understood. Moreover, each crop starts from a well-defined point at planting, and proceeds to another well-defined point, harvest, and the outputs are simple, namely the grain yield. After harvest the plant dies, all residues return to the system, which is another simple system. Despite the apparent simplicity of annual crops, it has taken a great deal of concentrated effort to write realistic models, although this has now been achieved, notably with the IBSNAT models referred to above.

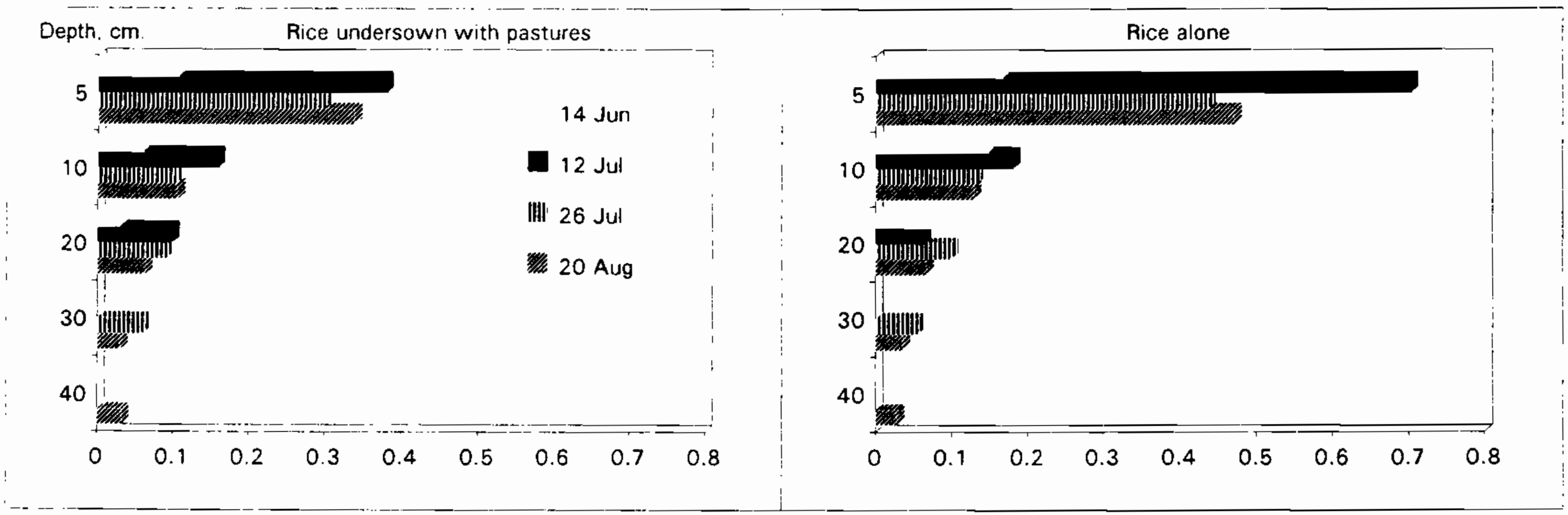

Figure 3. Distribution of root biomass in cores in rice alone and rice with pastures at Carimagua, 1993.

Compared with crops, pastures are much more complex systems, because the time scale involved is much longer, there is far less scope to manipulate the conditions of plant growth, several plant species are involved, usually with contrasting physiologies, and moreover, the grazing animal has such a profound influence. No model exists that describes the relations between the components of a tropical pasture. However, the Hurley pasture model, a model of a temperate pasture written by Dr J.H.M. Thornley, currently of the Institute of Terrestrial Ecology in Edinburgh, has been found to work well in southern England. Accordingly, we have evaluated with Dr Thornley its suitability for application to grazed grass-legume pastures in the lowland tropics.

The Hurley model is concerned with the dynamics of carbon and nitrogen pools and flows in a grazed ryegrass monoculture under temperate conditions, and to relate these to environmental and management variables. It has a number of deficiencies that prevent it being used directly for mixed grass-legume pasture, such as

- It does not represent phosphorus, a nutrient almost as important in the lowland tropics as nitrogen.
- It does not represent meristematic tissue growth, essential to represent the dynamics and persistence of grazed legume-grass pastures.
- An explicit representation of nitrogen fixation is needed for legume-based pastures.
- Animal selection between the grass and legume components is not represented.
- There is no representation of two species that compete for light, nutrients and water, and have different growth rates and digestibilities.
- The pastures are grazed by sheep, not cattle.

To take account of these added complexities, considerable *de novo* program development is needed. In collaboration with the CIAT plant-soil group, Dr Thornley has written a soil sub-model that takes account of phosphorus, nitrogen and potassium, and has written a prototype legume sub-model that includes meristematic tissue growth. Preliminary evaluations suggest that these sub-models perform sensibly. For example, the legume sub-model was interfaced to actual meteorological data for Palmira. The crop developed a realistic leaf area, and plant growth was more affected by the variations in solar radiation than by variations in temperature, both of which are reasonable. Wider testing of the sub-models will be undertaken in the coming year and further development of the appropriate sub-models is continuing (Figure 4).

Myles J. Fisher

Collaborators

CIAT Belisario Volverás
Luis Fernando Chávez

References

Alejo, A.P., Rodriguez, A.G., and Fisher, M.J. (1988). [Tolerance of *Stylosanthes capitata* to fire on the eastern plains of Colombia]. Pasturas Tropicales 10(1):2-7. (In Spanish).

CIAT (1986). Annual Report 1985, Tropical Pastures Program. Working Document No. 17, 1986. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 398pp.

Hall, R.L. (1974). Analysis of the nature of interference between plants of different species. II. Nutrient relations in a Nandi *Setaria* and Greenleaf *Desmodium* association with particular reference to potassium. Australian Journal of Agricultural Research 25:749-756.

Thornley, J.H.M., and E.L.J. Leverre (1990). A model of nitrogen flows in grassland. Plant, Cell and Environment 12:863-86.

Valencia, I. (1981). Root competition between *Andropogon gayanus* and *Stylosanthes capitata* in an oxisol in Colombia. PhD thesis, University of Florida, Gainesville (Diss. Abstr 45/07:1976b).

Wit, C.T. de (1960). On competition. Verslagen van Laandbouwkkundige Onderzoekingen 66. 82pp.

Theses supervised

Hans Imoff, pre-graduate student in Agriculture at the Federal Technological University, Zurich, Switzerland. Studies on the development of yield components in two varieties of upland rice.

Maria Claudia Lara Mena, pre-graduate student in Systems Engineering and Computing, Pontificia Universidad Javeriana, Cali. Signal monitoring and control in the measurement of photosynthesis.

Martin Vervoorn, pre-graduate student in Agriculture at the Agricultural University of the Netherlands, Wageningen. Studies on the effect of K fertilizer on an association of *Stylosanthes capitata* and *Brachiaria dictyoneura* under grazing.

Juan José Jiménez, post-graduate student in Biology at the Universidad Complutense, Madrid, Spain. The population biology of soil fauna on the eastern plains of Colombia under contrasting systems of management.

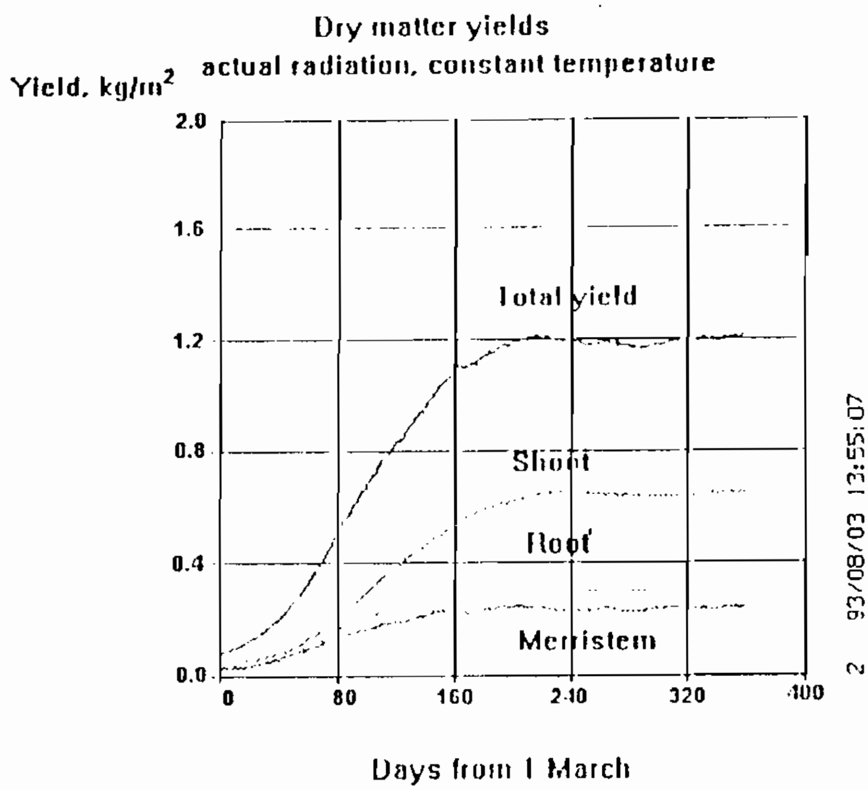

Figure 4. The influence of actual radiation at Palmira at constant temperature on the behavior of the legume sub-model.

CHAPTER IV

PROTOTYPE CROPPING AND FARMING SYSTEMS

INTRODUCTION

This report includes a brief summary of progress to date in research concerning the integration of various technologies in prototype cropping systems for the savannas, or Llanos, of Colombia and Venezuela, and their impact on soil conditions. Also, it includes progress on the on-farm evaluation of technological alternatives for system intensification initiated to estimate their impact on whole system performance.

In this report only partial results are presented since many soil physical and chemical measurements are still in progress, and plant and root samples are still being processed and analyzed. The work reported involves collaboration with ICA, the Universidad Tecnológica del Llano, Villavicencio, the Departamento de Biología of the Universidad Nacional de Colombia, Bogotá, and various members of the Savannas Program. Despite CIAT's budgetary constraints, which implied delays in processing of samples and data, a team approach followed with other Sections of the Program has permitted to compensate for some of the deficiencies.

Some of the trials have been planned as long term experiments, and in fact two of them are now 5 years old. It is anticipated that a full analysis for the initial 5-year period will be carried out during 1994.

Some of the collaborative work within the Program (Cations and Phosphorus experiments in Carimagua station and in Matazul and La Florida farms), and with the Rice Program (Silica trials in Matazul and La Florida farms) are dealt with in other reports. Work on pastures seed production in rice-pasture systems in Matazul farm with the Tropical Forages Program is partly reported here and partly in their report. The rest of the work reported here relates to the experiments (continuous rice monocrop, long term rice-pasture systems, and recuperation of degraded *Brachiaria humidicola* with rice) and other activities.

LONG TERM EXPERIMENTS

Rice-pasture systems (Matazul farm, Llanos Orientales, Colombia, 1989-1993).

This experiment was the pioneer trial that gave rise to the now well known "rice-pastures" system used to establish grass-legume pastures interseeded with upland rice on unimproved savanna soils. It will be recalled that the system is characterized by the use of acid-soil-adapted germplasm of upland rice and forages that do not require liming to adjust soil pH.

The experimental site is located in land system No. 201 (Figure 1) as defined by Cochrane et al. (1985) characterized by well drained and flat lands with slopes <8%, and haplustox soils of intermediate to heavy textures, covering 424,000 ha (Fairbairn and Jones, 1987). The majority of this land system has good access roads as described by Jones (1991), and is in fact the current target area for intensification of farming systems in the Colombian savannas. A much larger area, land system No. 202 with 1,447,800 ha, is essential identical to No. 201 but is located much further east (Fairbairn and Jones, 1987) and at the present time completely lacks infrastructure.

The rice-pastures experiment started in 1989 with 3 treatments: rice line 3 (R) + *Andropogon gayanus* (*Ag*) + *Stylosanthes capitata* (*Sc*); R + *Brachiaria dictyoneura* (*Bd*) + *Centrosema acutifolium* (*Ca*); and R monocrop, in 1 ha plots with 3 replications.

In summary, in 1989 rice yields were on average 2 t per ha without statistical differences between treatments, and there was excellent establishment of the interseeded pasture species. Ever since, the experiment has been grazed with high animal weight gains in the first 2 years but with a decline to lower levels in 1992 characteristic of traditionally established pastures. The rice monocrop treatment was sown to *Bd* without a legume in 1990. By the end of 1992 the legumes in the grass-legumes had almost disappeared and

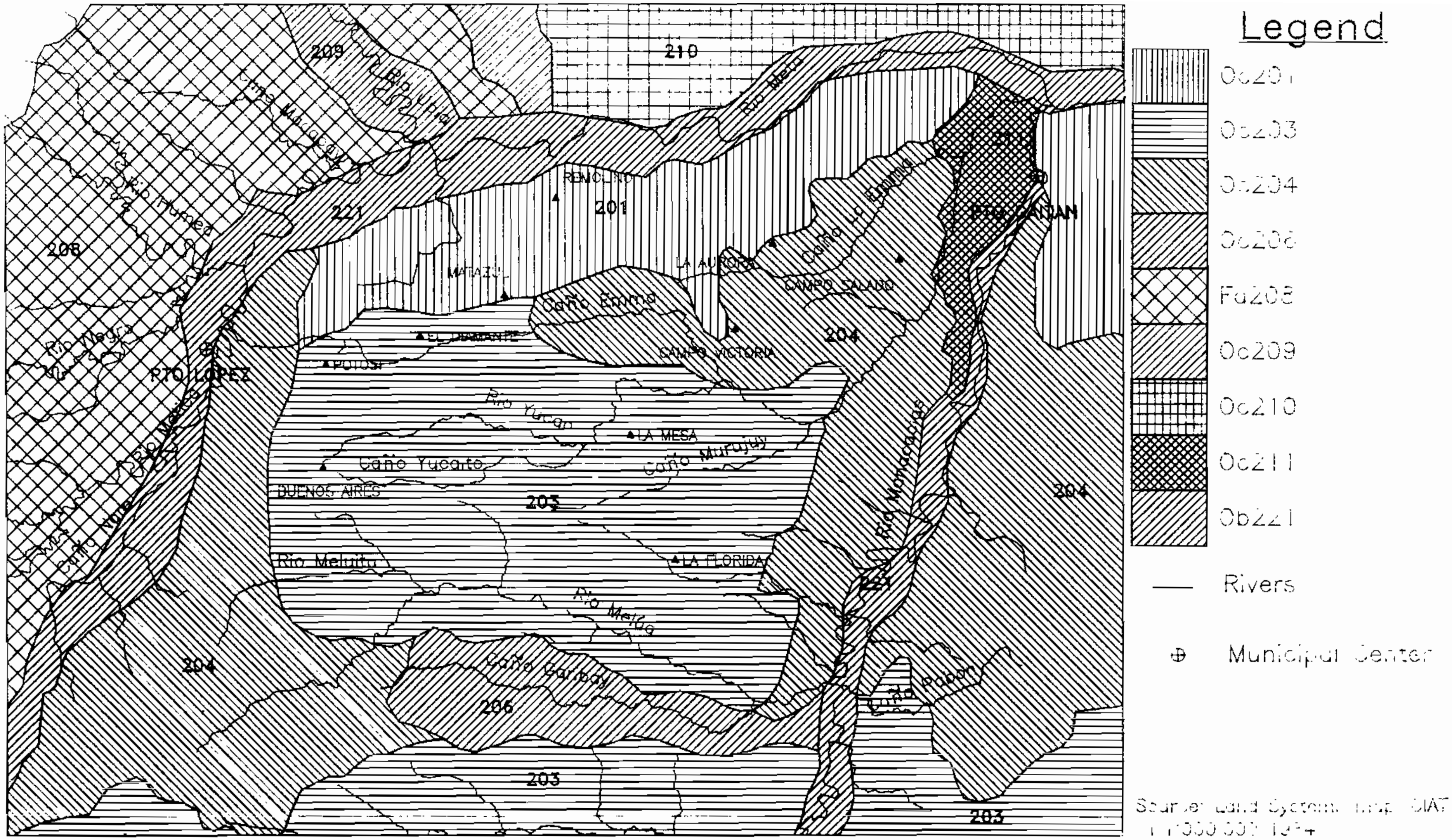

Fig. 1. LAND SYSTEMS FOR THE PTO. LOPEZ – PTO. GAITAN ZONE.

CIAT. Land Use Program

Scale: 1:700.000

the decision was taken to recuperate half of each 1 ha plot through rice (Line 3 and Oryzica Sabana 6) planted in early 1993 while preserving the other half as grazed pastures controls. At the same time the original 1989 experiment was repeated on a smaller scale to have a replication in time and a direct comparison with the plots under recuperation. The 1993 replicate of the initial experiment included rice line 3, the original line used in 1989, as well as cv. Oryzica Sabana 6, commercially released in 1991.

Figure 2 shows that the savanna-based 1993 replication of the 1989 experiment significantly out yielded the results observed in 1989. Nevertheless, the differences between treatments remained basically unchanged. This probably shows year to year differences and improved agronomic management of the system but the results reconfirm the initial findings.

With regard to the performance of rice following the pastures originally established in the 1989 trial, yields following *Bd*-alone were significantly less than after either of the grass-legume pastures. Although not strictly comparable in statistical terms, rice yields after native savanna were higher than after a 3-year old pasture of *Bd* alone.

An additional treatment to reconfirm the benefit of early land preparation (results from 1990 not tested in 1989 and therefore neither in the replicate in 1993) showed a drastic increase in rice yields with this practice (burning and ploughing at the end of the rainy season before the planting).

At the end of 1992, after one rice crop and 3 years of grazing of the resulting pastures, soil nutrient contents were comparable to, or slightly higher, than the original levels found in the native savanna soil (Table 1). This shows that no degradation of the existing soil chemical properties has taken place under the studied systems.

Table 1. Soil analyses in long-term rice-pasture systems. Matazul, Llanos Orientales, Colombia. 1989-1992.

	P (Bray II) (ppm)	K	Ca	Mg	Al	pH 1:1(H_2O)	MO (%)	Sat.Al (%)
		(meq 100 g^{-1})						
1989								
Native savanna	1.60	0.07	0.17	0.06	3.70	4.44	3.96	94.0
1992								
Native savanna	2.72	0.06	0.11	0.05	2.47	4.82	4.72	92.0
Rice	4.58	0.10	0.33	0.10	2.63	4.67	3.96	83.0
Rice + *A.gayanus* - *S.capitata*	4.69	0.11	0.39	0.15	2.53	4.77	4.88	79.5
Rice + *B.decumbens* - *C.acutifolium*	5.89	0.08	0.43	0.12	2.23	4.78	4.55	66.9

Regarding soil physical properties, samples from collaborative work with scientists from ICA-La Libertad are being processed in the Soil Physics laboratory at La Libertad by both CIAT and ICA staff, and data are being analyzed. As a preliminary example, on 10 December 1992 and after two years of intensive grazing, bulk density (g/cm^2) for the top unploughed 10 cm was 1.41 in *Bd* + *Ca*, 1.34 in *Bd*, 1.32 in *Ag* + *Sc*, and 1.35 in native savanna. On 30 April 1993, resistance to penetration (kg/cm^2) was determined in *Bd* + *Ca* under grazing, in *Bd* + *Ca* ploughed for recuperation with rice, and in native savanna under grazing. In grazed *Bd* + *Ca* resistance was 11.0 in the top 3.5 cm and 23.9 at 20 cm depth. In the ploughed *Bd* + *Ca*, resistance to penetration was respectively 1.4 and 18.2 for the same depths, and 15.6 and 18.4 for native savanna. It seems that grazing, particularly *Bd* + *Ca* produces some compacting, mainly below the top few cm, but native savanna has a greater resistance to penetration at the surface (3.5 cm). Ploughing for renewing the grass by using a rice crop completely reverses the resistance to penetration at 20 cm to values similar to those of the native savanna. These data are preliminary and need to be further

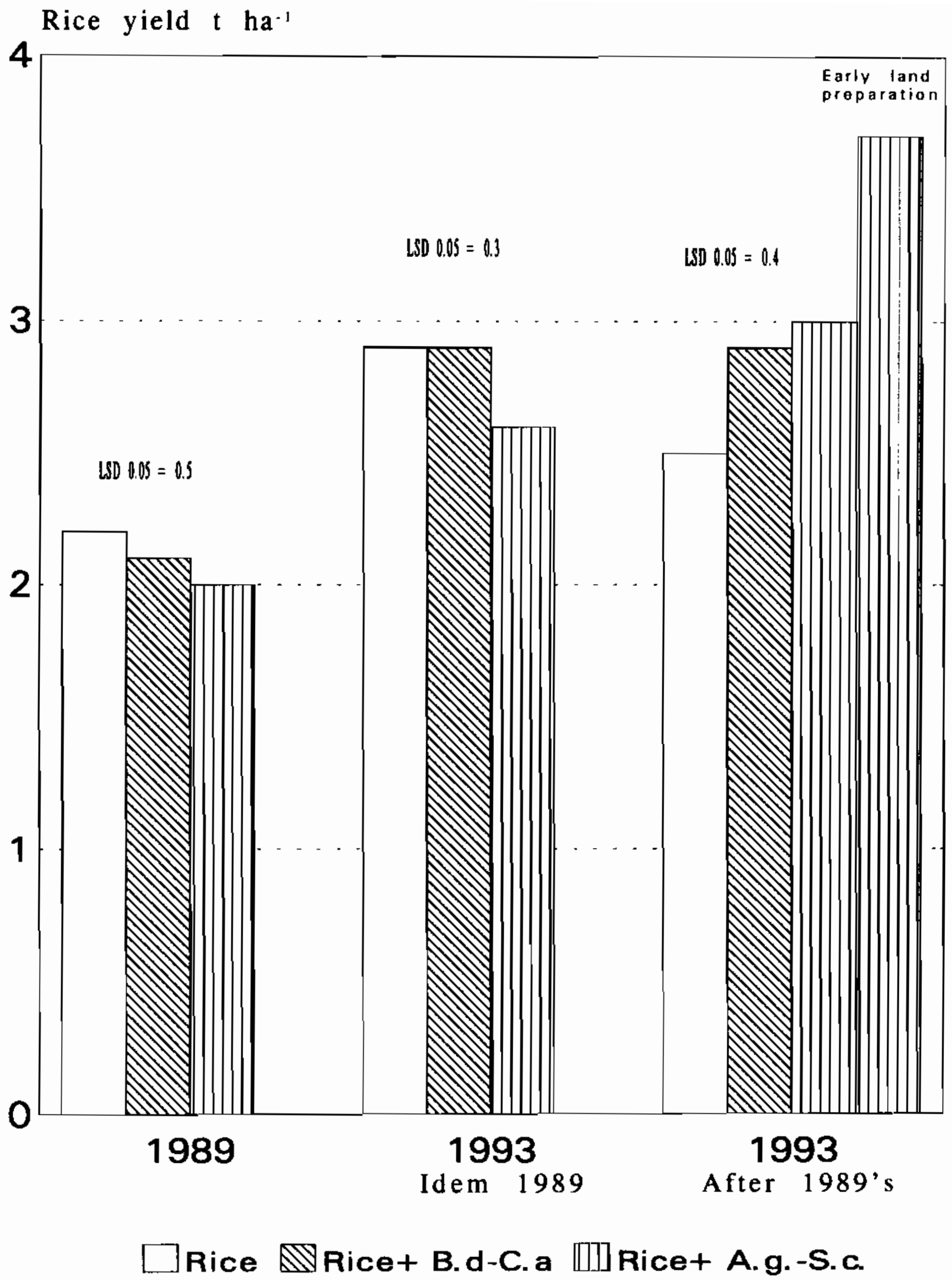

Figure 2. Rice production (Line 3) in long term rice-pasture systems. Matazul, Llanos Orientales, Colombia. 1989-1993.

analyzes together with other soil physical parameters such as aggregate size and stability and infiltration rates before conclusions can be drawn.

Continuous rice monocrop (Matazul farm, Llanos Orientales, Colombia, 1989-1993)

The introduction of upland rice varieties for the savannas of Colombia, although intended to form part of rotations with pastures, raises also the possibility of continuous rice cropping.

A continuous rice trial (3 rice lines: line 2, line 6, and Oryzica sabana 6), has being carried out since early 1989, to test the hypothesis that this practice is associated with decreasing yields with time in Oxisols, as well as soil degradation. Fertilizer inputs were adjusted at yearly intervals to maintain appropriate soil nutrient concentrations. The remaining agronomic practices were standardized as per current recommendations for the rice crop, including early land preparation with chisels followed by disk harrowing.

Figure 3 shows a continuous linear decline in yields for Oryzica Sabana 6 from 1989 to 1992 ($r^2=0.96$), at a rate of nearly 400 kg/ha despite the correction of nutrient imbalances in the soil. The comparison between soil chemical analyses before starting the experiment in 1989 and at the end of 1992 (Figure 4) shows a notorious balanced increase in nutrient elements, in pH, and large decreases in Al concentration and saturation level. It is therefore unlikely that the observed decrease in rice yields can be associated with a decline in chemical soil fertility. On the other hand, a large build up of weeds over time was observed, which by the end of 1991 accounted for a large amount of biomass and for much of the nutrients taken up by plants in the system (Table 2). The large volume of weeds biomass regularly ploughed under, together with the increased aeration due to yearly tillage should account for the unanticipated increased level of soil organic matter (Figure 4). It should also be noted that elements such as K and Ca were taken up in greater amounts by the weeds than by the crop itself. The experiment was modified for the cropping season of 1993 to test the hypothesis that rice yields could be recuperated with improved agronomic practices.

Two treatments were compared : a) the currently recommended early land preparation system based on the use of chisels and heavy disk harrowing, followed by the use of post emergent herbicides, and b) early land preparation using mould board plough, and disk harrowing, but without the use of herbicides. Only one rice cultivar, Oryzica Sabana 6, was used as the test crop.

Table 2. Nutrient uptake by rice and weeds in continuous rice monocropping. Matazul, Llanos Orientales, Colombia. 1991.

		N	P	K	Ca	Mg	S	Zn
		Uptake in above ground biomass, kg ha^{-1}						
Line 23	(3.1)*	45	9	71	6	7	3	1.0
Weeds	(1.7)**	18	5	75	10	4	2	0.1
Line 2	(2.7)	43	7	31	10	8	3	1.0
Weeds	(1.2)	10	3	31	5	2	1	0.1
Line 6	(2.2)	37	6	63	10	8	3	1.0
Weeds	(1.7)	22	6	70	12	6	0.1	0.2

* Rice grain yield (t ha^{-1})
** Weeds dry matter (t ha^{-1})

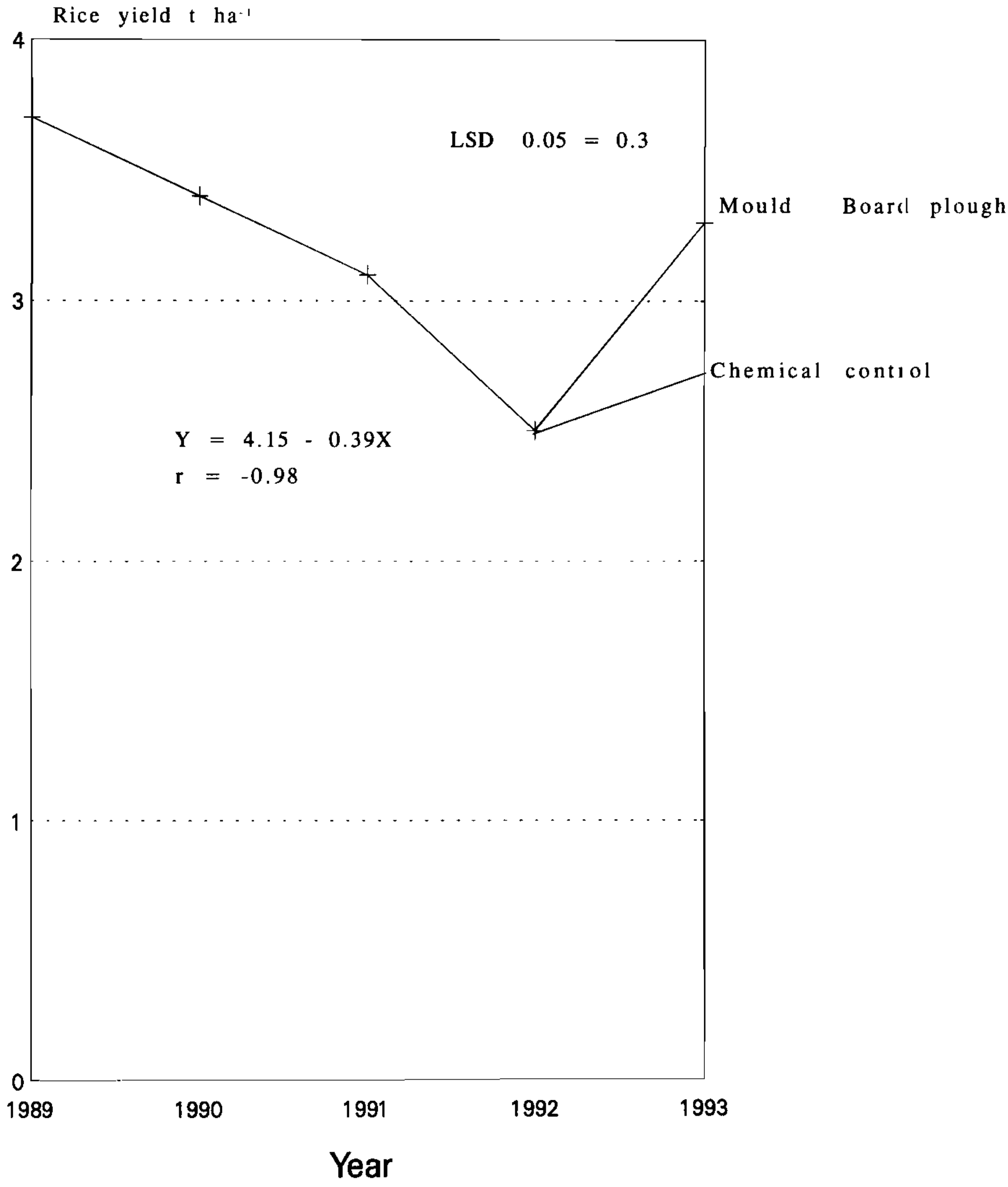

Figure 3. Continuous rice (Oryzica Sabana 6) monocrop production in acid savanna soils. Matazul, Llanos Orientales, Colombia, 1989-1993.

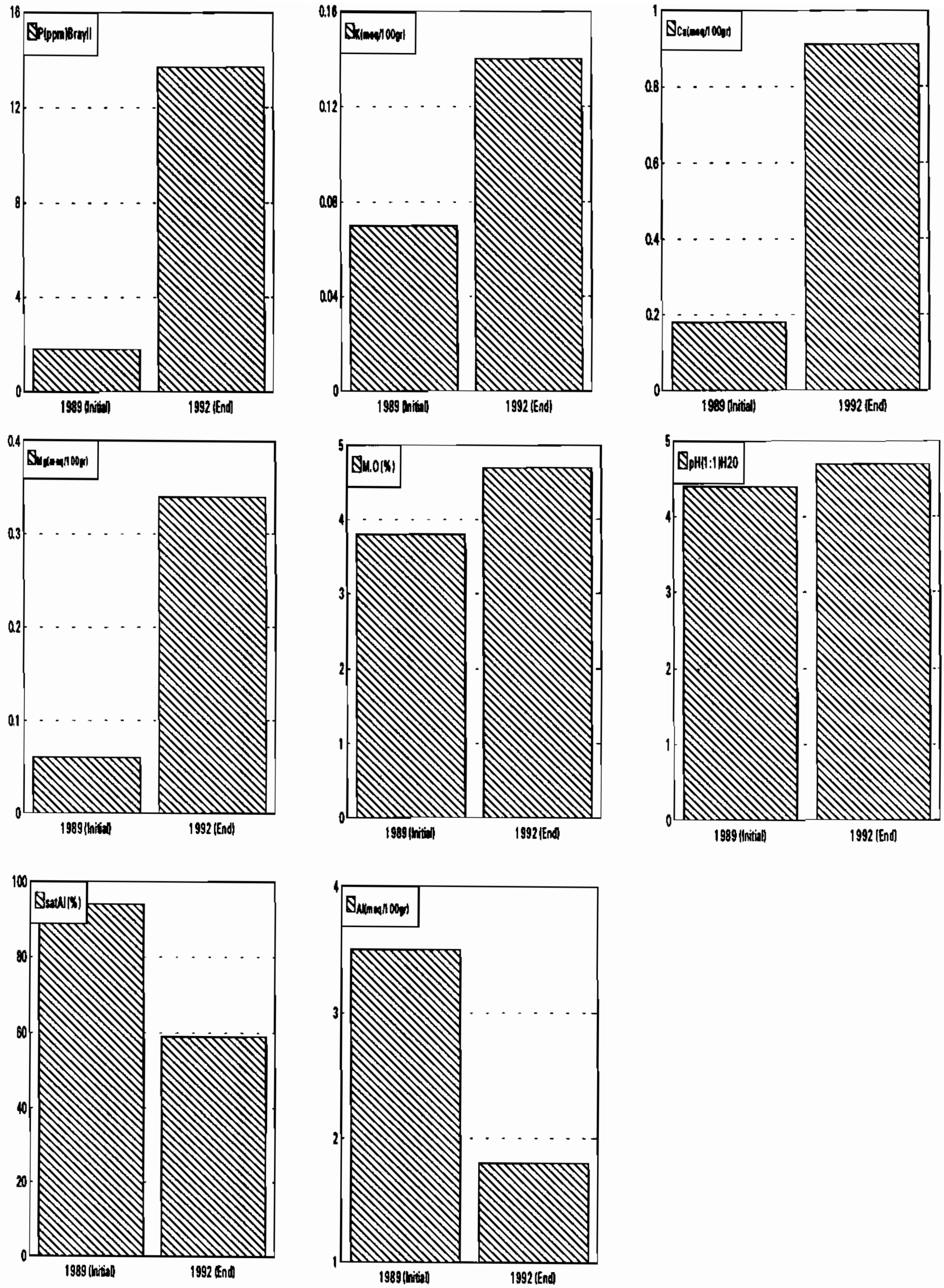

Figure 4. Soil analyses in continuous rice monocrop in acid savanna soils. Matazul, Llanos Orientales, Colombia, 1989-1993.

Results for these treatments (Figure 3) indicated a modest increase of about 300 kg/ha for chemical control and a further 400 kg/ha (total 700 kg/ha) increase for the mechanical control in comparison to the year immediately before i.e. 1992. The mould board treatment actually raised yields to a level similar to that obtained in the second year of monocropping. The difference between both treatments was significant ($P<0.05$). These results need to be interpreted with caution, particularly in relation to herbicide use, since no research has been carried out so far on appropriate dosages, timing, etc. Complete and detailed nutrient balance sheets are being elaborated at this writing; similarly, soil physical parameters have been estimated and are being analyzed. Although there is no visual evidence of erosion, soil losses have not been estimated. Conditional to the results of these variables, and assuming that no new problems arise, it would appear then that rice monocropping assisted by sound agronomic practices may be a viable practice at least for the soil type used in the present study.

SHORT TERM EXPERIMENTS

A number of variations around the initial rice-pastures prototype system have been explored with the aims of diversifying it, increasing its economic attractiveness, and to determine whether the system is technically viable in lands already intervened, as an alternative to areas still covered by native vegetation. With reference to the latter, it should be recalled that in the Colombian llanos alone there are approximately 150,000 ha of sown, grass-only, pastures. Of course, much larger areas have suffered anthropogenic disturbances in Venezuela and Brazil. A survey carried out in 1991 by the former Tropical Pastures Program had pointed out that grass pastures in the Colombian llanos are regularly disked at intervals of 4 or less years in an effort to recuperate their productivity, thus offering the opportunity to use rice, and eventually other crops, to achieve much higher levels of grain and cattle production.

Pastures seed production in rice-pasture systems (Matazul farm, Llanos Orientales, Colombia, 1992 and 1993).

As already mentioned in the introduction, detailed results on the pasture species seed production are dealt with in the Annual Report of the Tropical Forages Program. The hypothesis testec is that the rice-pastures system allows successive harvesting of the rice crops itself, followed by seed harvests of the pasture components, prior to the initiation of grazing, even if the latter has to be ceferred for some months.

The experiment was based on a rice (O. Sabana 6)-*B. dictyoneura* (*Bd*)-*S. capitata* cv. Capica (*Sc*) association subjected to various treatments as follows: a) dates of planting the pastures after the rice (0, 15 and 30 days; b) broadcast versus drilled pastures, and c) drilled rice at 34 and 51 cm between rows, with 3 replications. Seed density for Capica was increased to 4 kg/ha and that of Bd was 3 kg/ha, to assure an adequate plant population of the forages for seed production. Rice seed density remained at the recommended 80 kg/ha.

This report only deals with some aspects of rice production and some of the economics of the overall system (rice + *S. capitata*), before the grass seed was harvested. Assistance in the analyses was obtained from the Economics section of the Rice Program.

Table 3 shows the results for drilled rice at the conventional 34 cm row spacing, with drilled and broadcast pastures planted simultaneously with rice, and compared with the rice monocrop. Rice yields were significantly reduced because of the competition with pastures with increased seed densities. Nevertheless, even with the modest Capica seed yields realized in these treatments and without considering the subsequent seed yield of Bd, the system appears economically very attractive and with current relative prices, superior to rice monocropping. The tradeoff involved is the probable loss of approximately 2 months of grazing to allow harvesting Capica after the rice harvest. Capica was affected by clipping by the combine harvester at rice harvesting. Its yields were higher in the 15 days planting treatment after sowing the rice (See T. Forages' A. Report) but the 0 days planting could have been ideal if the cutting height for rice with the harvester had been higher and had not damaged the Capica plants which were the most vigorous in these treatments. These results therefore suggest that future adaptive research, hopefully carried out by other institutions and seed producers, on this prototype may make even more attractive.

Table 3. Rice grain and forage legume seed production in rice-pasture systems. Matazul, Llanos Orientales, Colombia. 1992-1993.

Drilled rice with	Rice yield ($t\ ha^{-1}$)	*Stylosanthes capitata* Yield ($kg\ ha^{-1}$)	*Stylosanthes capitata* Rice equivalent ($t\ ha^{-1}$)	Break even point ($t\ ha^{-1}$)	Net income (US$ ha^{-1})
Drilled *S. capitata* (+ *B. dictyoneura*)	2.9 b	31.5	2.4	3.8	225
Broadcast *S. capitata* (+ *B. dictyoneura*)	2.7 b	30.2	2.3	3.9	165
Rice monocrop	3.4 a	-	-	2.9	75
LSD 0.05	0.4				

Renovation of *Brachiaria humidicola* (*Bh*) with rice (O. Sabana 6) and *Arachis pintoi* (*Ap*) or *Desmodium ovalifolium* (*Do*) and different types of land preparation (Matazul and Santa Cruz farms, Llanos Orientales, Colombia, 1992-1993)

As indicated above, large areas of sown grass pastures in various stages of degradation are available throughout the lowlands of tropical America. The current experiment involved pastures of *B. humidicola*, as prototype of the most aggressive species presently available.

Two *Bh* pastures were selected for this trial, namely one in Matazul in good condition and the other one in Santa Cruz quite degraded and on a lighter textured soil. The experiment was based on the assumption that regardless of treatment, *Bh* would recover from existing soil seed stocks and remaining stolons and other vegetative parts. All treatments involved early land preparation. Treatments included: a) introduction of *Ap* or *Do* versus no legume and b) land preparation treatments of varying depths and intensities (burning of the pasture + crossed pass of a heavy disc harrow; single pass of the disc harrow; crossed pass of disc harrow; cross pass of chisel plough; cross pass of chisel plough + single pass of disc harrow, and cross pass of chisel plough + cross pass of disc harrow).

The two trials had 3 replications each. As with all the other experiments above, complete data were taken on soil physical and chemical parameters. The biomass of each of the component species was measured and their chemical composition analyzed to estimate balance sheets for different nutrients. These sets of measurements were aimed at quantifying the variables that may be related to the processes of pasture degradation and rehabilitation via an annual crop.

Figure 5 shows only the treatments of rice with and without *Ap* for the soil prepared with fire + harrow, cross harrowing, cross chiseling, or cross chisel + cross harrow in the two experiments. It is clear that in the treatments with shallow land preparation i.e. harrow with or without fire, rice production is virtually impossible, being even 0 kg/ha in fire + harrow in Santa Cruz. When deep land preparation is introduced with a chisel plough, *Bh* is de-rooted and rice was able to establish, compete successfully, and yield more than 2.5 t/ha in Matazul and over 2 t/ha in S. Cruz. Chiseling followed by harrowing led to a better seedbed associated with a further significant increase in rice yields. The rice yield differences between the two sites might be due to the more degraded condition in S. Cruz before starting but a definite explanation has to wait for the data being processed. Regardless of the situation, these experiments have shown that it is definitively possible to apply the rice-based system even with highly aggressive pasture species, if appropriate agronomic practices are employed.

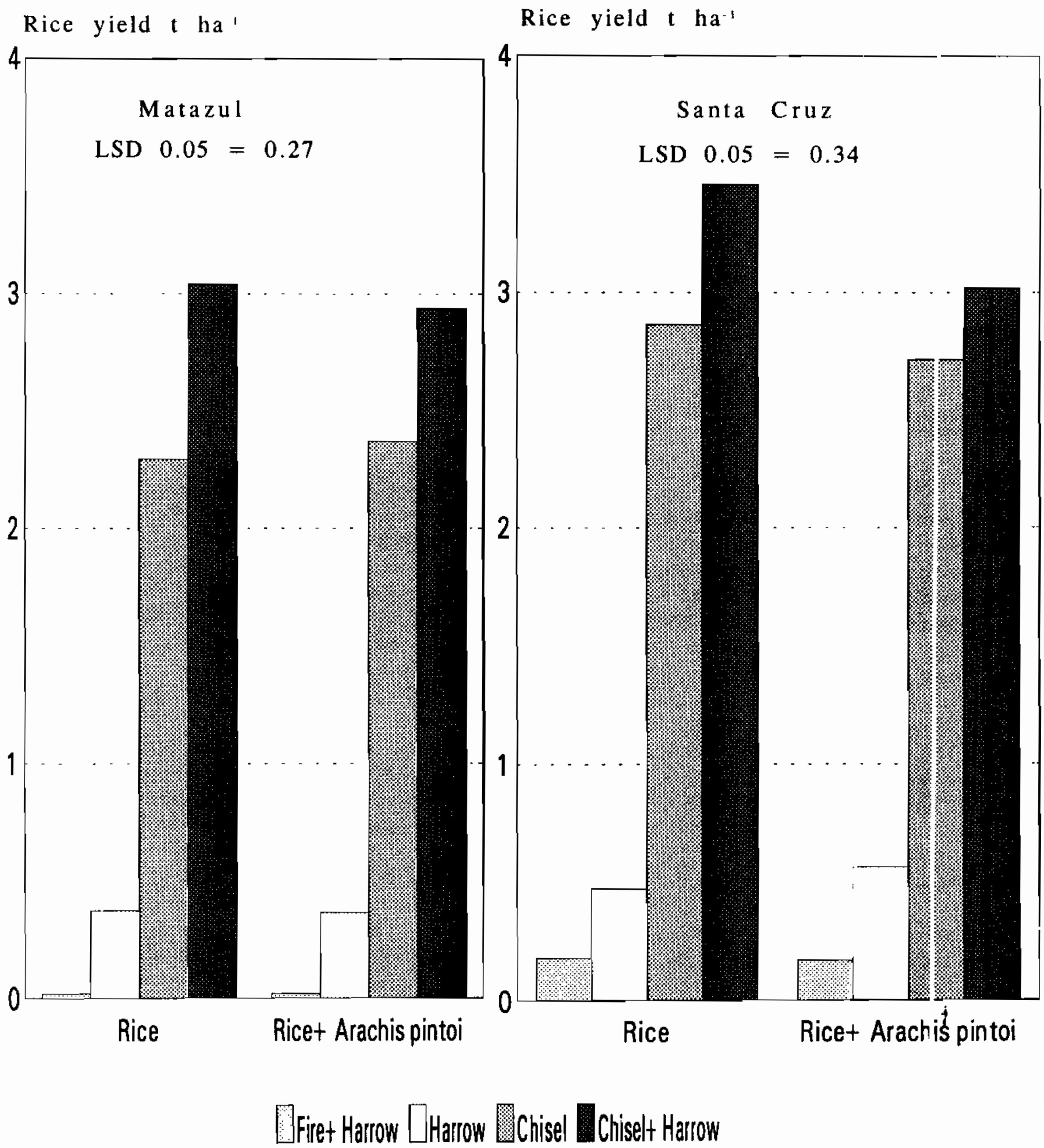

Figure 5. Rice yields during the recuperation of degraded *B. humidicola* pastures with rice (Oryz ca Sabana 6) and forage legumes (*A. pintoi*). Matazul-Santa Cruz, Colombia, 1992.

Characterization of land use in contrasting farming systems

Farms located in contrasting land systems of the Llanos differ significantly in the use of resources. Some of these differences are associated with variations in landscape, relative distance from markets and resource endowment. It has been hypothesized that at least some of the differences in land use between farms mimic changes that will take place over time, so that a cross-sectional study can represent also their temporal evolution. If this were indeed the case, relatively short-term studies would be an admittedly imperfect proxy for much longer term longitudinal studies.

A set of seven contrasting farms in terms of size, location, and production system(s) are being monitored in the two main land systems of the Colombian Llanos, currently subject to increasing pressure, namely systems No. 201 and 203 which cover 424,000 and 1,200,000 has of flat and rolling-slope topography respectively. It should be noted that further east, class 201 has an exact equivalency in land system 202 with 1,447,800 has, and that, at least preliminarily, many of the findings in class 203 could apply to a total area of 5,038,400 has (sum of classes 203, 204, 205 and 206).

Soil chemical parameters are essentially similar in all of the above classes, but there are differences in texture and topography. The set of monitored farms ranges from extensive, savanna-based ranching systems in hilly, fragile, lands of light texture to a continuous cropping system intensive in the use of machinery and chemical inputs based on flat lands of heavier texture.

Whole farm inputs and outputs will be monitored over at least one full year. Within each farm, fixed points located in different areas of the landscape, and subject to different uses, have been identified. As a minimum, and conditional to relative intensity of use, soil samples are obtained twice a year for detailed physico-chemical characterization with the objective of relating present use to soil parameters. An attempt at characterizing soil biological activity will be made in cooperation with the Universidad Tecnológica de los Llanos (UT). Similarly, in those areas under native vegetation or introduced pastures, surveys are made of botanical composition, and stocking density and grazing, again with the cooperation of UT.

In collaboration with the Land Use Program (LUP), the Instituto Geográfico Agustín Codazzi (IGAC), and possible the Ministry of Agriculture, it is expected to characterize in more detail the whole area under study using the limited (secondary) socioeconomic information available, so as to complement the classification previous referred to by Cochrane et al., and which was based exclusively on physical parameters at a scale of 1:1,000,000. Since land facets were not mapped it still lacks precision for identifying farm sites within them (Fairbairn and Jones, 1987); thus, with the aid of satellite images and a semi-detailed soil map that IGAC is expected to develop, a rather precise definition of land systems and facets will be possible together with a characterization of farming systems. Other sources of data that will be gradually incorporated into the respective database refer to descriptions of typical *soil* profiles, results of previous farm surveys conducted by CIAT (see below), and others. This dynamic database will serve, among other purposes, to better delimit domains of extrapolation for technological components, and prototype cropping and farming systems. Used together with GIS-based simulation models of land use, it will allow eventually the spatial simulation of alternative land uses and to evaluate their impact on the region.

Reference was made above to surveys regularly conducted in the region. The former Tropical Pastures Program regularly conducted such surveys to characterize cattle production systems in the Llanos, and information on their evolution is available since the late 70s. More recently, the introduction of upland rice varieties for the region prompted the interest of CIAT's Rice Program in estimating the progressive impact of the new cultivars. Early in 1993, a new survey was conducted jointly by CIAT's Forages, Rice and Savannas Programs on a total of 78 farms, to assess the latest trends in changes in the farming systems of the region of the Llanos located closest to markets and other infrastructure, along the axis of the main road connecting Puerto López and Puerto Gaitán. This area corresponds mostly to land systems 201 and 203, and to a lesser extent, 211 and 204. Despite unfavorable rice prices in the 1991 and 1992 planting seasons, upland rice is been increasingly adopted farmers in the Llanos, and the initial trend of adoption appears to be closely related to its use as a pioneer crop in establishing or in rehabilitating pastures.

It is also apparent that the rate of planting for pastures is entering the exponential phase. Out of a total area of 1,025,984 hectares, 172,839 (16.8%) have been sown to pastures. The total areas planted in 1992 amounted to 5715 hectares, and were heavily dominated by new *B. humidicola* pastures equivalent to 4243 hectares (74%). An indication of the dynamism of the farming systems is the fact that over the period 1979-1992, the yearly growth rate in the area planted to pastures was 14.17%, whereas for the period 1989-1992 it increased to 23.75%. The effect of a large number of independent variables on the total area planted was examined. It was concluded that the significant factors contributing to the expansion of the area *planted in* the period 1979-1992 included: a) beef prices received by farmers; b) the number of forage cultivars available; c) paving of the road between Puerto López and Villavicencio, and d) the price of triple superphosphate, whereas negative factors included a) the price of urea and b) credit costs.

On farm performance of system's components

Within the set of farms alluded to above, the biophysical performance of some selected systems components has been the subject of monitoring studies initiated well before the Savannas Program was created. The emphasis until then had been on the contribution of sown pastures to animal productivity in farms and ranches located mostly in land systems 203, 204 and 211 (Figure 1), characterized by more extensive systems associated with poorer natural resources, hilly topography and limited infrastructure, where intensification via the development, adoption of agropastoral systems is unlikely in the short term.

It is hypothesized that in those relatively more extensive systems, the introduction of sown pastures would have the greatest impact on system (animal) performance given the larger disparity between the anticipated carrying capacity and potential productivity of sown pastures versus native savanna vegetation than is the case in land system 201. It is also in those systems where long term pasture persistence is relatively more important.

Some of the above points are illustrated in the study cases that follow. The El Amparo farm located in land system 211 is based on soils that are over 70% sand, where native pastures typically have a carrying capacity of 0.1 AU/ha and have below average overall productivity, thus representing the most extreme situation found in the Llanos. Soil-wise there are approximate equivalencies in the Llanos of Venezuela and Cerrados of Brazil. Table 4 shows data for two pastures based on the extremely persistent *B. dictyoneura* associated with a legume of lesser persistence, *C. acutifolium*. The legume was replanted in year 3, and the results show that as long as it persists, animal productivity is rapidly increased. These results are comparable to those observed in the "core" experiment at Carimagua on a similar soil (reported elsewhere), and point to the need for a long term persistent legume in these systems.

Table 4. Animal performance on *B. dictyoneura* alone or associated with *C. acutifolium*. Farm El Amparo, land system 211.

Period	*B.dic./C.a.*			*B. dictyoneura*		
	AU/ha	g/hd.d	kg/ha	AU/ha	g/hd.d	kg/ha
YEAR 1 Jun89-Sep90	1.27	521	212	1.27	465	193
YEAR 2 Sep90-Ag91	1.32	481	232	0.54	155	93
YEAR 3 Jul91-Apr92	1.50	-160	-38	1.38	-174	-38
Pasture renovation						
YEAR 4 Nov92-Jul93	1.46	575	186	0.97	52	11

A very similar trend was observed in Guayabal farm (Table 5) also located on very fragile soils of land system 204, where again the legumes were effectively lost during the third year of grazing and had to be replanted; the impact of their reintroduction (see year 4) is immediate and substantial.

In these extensive systems located in marginal areas, very low-input-demanding and resilient grasses like *B. humidicola* continued to be adopted (see results of 1992 survey, above) despite their lower performance relative to other grasses (Table 6).

The contribution to these pastures of a legume of equally low demands like *D. ovalifolium* can be important in terms of animal production as shown in Table 7, where the legume was contributing approximately 40% of the forage on offer.

Table 5. Animal performance on *B. dictyoneura* alone or associated with *C. acutifolium* and *S. capitata*. Farm Guayabal, land system 204.

Period	*B.dic.-C.a.-S.c.*			*B. dictyoneura*		
	U/ha	g/hd.d	kg/ha	AU/ha	g/hd.d	kg/ha
YEAR 1	1.22	594	304	1.25	599	305
YEAR 2	0.86	585	95	0.98	446	91
YEAR 3	1.39	522	150	1.46	436	206
YEAR 4*	2.00	718	238	1.45	600	147

* Partial data

Table 6. Animal performance on *B. dictyoneura* versus *B. humidicola*. La Primavera farm, land system 203.

Period	*B. dictyoneura*			*B. humidicola*		
	AU/ha	g/hd.d	kg/ha	AU/ha	g/hd.d	kg/ha
First year	1.70	558	392	1.50	301	184

Table 7. Animal performance on *B. humidicola* alone or associated with *D. ovalifolium* CIAT 13089. La Primavera farm, land system 203.

Period	*B. humidicola*			*B.h./D.o.*		
	AU/ha	g/hd.d	kg/ha	AU/ha	g/hd.d	kg/ha
YEAR 1	1.54	192	176	1.79	284	290
YEAR 3 *	1.42	319	151	3.03	381	352

* Year 3 is the year following accidental burning of all pastures.

An accidental fire that burnt all the pastures during the dry season (February) of 1992 allowed an opportunity to assess the residual contribution of the legume to grass productivity after one year of grazing. Table 7 shows these effects in terms of animal performance. Residual effects in terms of biomass production were evaluated by establishing a small-plot, factorial, experiment to measure the effect of 4 rates of N (0, 50, 100 and 200 kg/ha) and two rates of a basal application of P (0 and 22 kg/ha) on the regrowth of the grass after the fire. Since the small plot experiment was set up only at the beginning of the rainy season (April 14, 1992), already a substantial regrowth had accumulated in the time elapsed since burning (Table 8).

Table 8. Regrowth of *B. humidicola* alone or associated with *D. ovalifolium* CIAT 13089, between February (fire) and April 1992. Farm La Primavera, land system 203.

Pasture	Height, cm	Yield, kg DM/ha
B. humidicola	6.50	995
B.h./D.o.	9.08	1792
s.e.	1.32	881
P<	0.0001	0.001

Over a period of 190 days of the rainy season, there was a highly significant and linear response to N, and interaction with the basal fertilizer in both pastures in terms of soil cover, pasture height and yield (Table 9).

From the respective regressions equations it can be calculated that in absence of the basal application of P, the grass-alone pasture would require an input of 75 kg N/ha to achieve the same regrowth as that of the associated grass, and 58 kg in the presence of basal P. These quantities coincide reasonably well with more direct estimates of N fixation obtained under experimental conditions in Carimagua.

Other activities

Besides the activities in the Colombian Llanos with LUP, a similar initiative is being explored with the Ministerio del Ambiente and FONAIAP in Venezuela, with the purpose of retrieving, organizing and mapping biophysical and socioeconomic information relative to the Venezuelan Llanos.

In terms of specific research projects on agropastoral systems, frequent interaction with the Universidad Experimental de los Llanos "Ezequiel Zamora", UNELLEZ, and FONAIAP, led to the initiation in the Venezuelan Llanos of a small number of exploratory trials involving crop-pastures "best bets", around maize, sorghum, rice and forages. Nevertheless, these activities suffered in 1993 due to institutional uncertainties in that country.

Table 9. Linear regression of accumulated forage yield (kg DM/ha) on N (kg/ha). Farm La Primavera, land system 203.

Pasture	Basal fertilizer	Intercept	Regression coefficient	r^2
B. humidicola	-	4050	8.72	0.87
B. humidicola	+	4824	18.50	0.92
B. h.- D. o.	-	4700	10.03	0.75
B.h. - D. o.	+	5888	19.68	0.97

Seminars and meetings

II Seminar on Agropastoral Systems for Savannas and Cerrados Ecosystems (13-22 March 1993)

The purpose of this seminar was to interact with crops and pastures researchers of Brazil (CNPAF, CNPGC, CPAC, CNPMS, and soybeans' centers), Colombia (ICA, FEDEARROZ), Venezuela (FONAIAP, RE-UNELLEZ); and to identify future priorities of crop-pastures research in Cerrados and Savannas.

The three involved countries are actively participating in crops pastures research, and expressed the need for CIAT to link their activities as well as to conduct long-term strategic research on agropastoral systems.

Coordinators of agropastoral activities in different regions were chosen and Venezuela was selected for the III seminar in mid 1994, when an international network on agropastoral systems is expected to be created.

Workshop on "Managing Acid Soils, MAS"

Scientists of the Savannas Program actively participated in the workshop of the consortium for management of acid soils in Latin America. For further information see document produced as a result of the meeting.

Slash and Burn planning meeting

Members of the Savannas Program also participated in the planning meeting of S&B in Acre and Rondônia (Brazil) last 24 October-6 November, where CIAT's participation was important in terms of identifying research priorities for those crops on which the Center has developed considerable expertise.

Planning meetings with CIMMYT's team at CIAT, ICA, and FENALCE

The Savannas Program participated with the above mentioned institutions in the planning of research on maize for acid savanna soils in Colombia. The main outcome apart from the planned experiments was the agreement on working in coordination with CIAT's Savannas Program. This was agreed to avoid duplication of results and to fit within the Program's strategy of addressing the overall ecosystem and the variety of cropping systems that are adequate for the existing different soil types and other diverse conditions found in the Savanna ecosystem. CIMMYT has produced a document on the research to carry out from 1994.

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CHAPTER V

SUSTAINABLE AGROPASTORAL SYSTEMS FOR THE CERRADOS

INTRODUCTION

During the last 25 years the Cerrado has evolved from almost exclusive extensive cattle ranching activities to a mosaic of intensive and extensive management systems, traditional and innovative farmers and large and small properties, all arranged in varying landscape positions. This dramatic change has been the result of a rapid area expansion and occupation stimulated by government incentives.

However, in the last ten years, incentives have been reduced and farmers are now facing the challenge to use land and resources more efficiently. Improvement of efficiency will be possible if alternative production systems are developed.

Conventional crop and pasture management systems are causing serious problems of soil degradation accompanied by losses in productivity.

The Section was created in 1992 with the objective to contribute to the development of sustainable agropastoral systems that increase productivity and enhance the resource base conditions.

This objective fulfills the general goal of the Savanna Program. Since its creation the Section evolved towards an increasing involvement in on-farm activities. Emphasis was given to the following activities: 1) selection of the research study areas in the cerrados, 2) characterization of the present land use systems, 3) testing of crop and pasture components for improved agropastoral systems and 4) strategic research on soil processes undergoing in crop-pasture integration systems. This report describes the main achievements in these areas and the plans of the Section for next few years.

SELECTION OF RESEARCH STUDY AREAS

The Section devoted a great deal of effort on the process of selection of the site(s) where the Savannas Program will conduct collaborative research with EMBRAPA in the Cerrados. Site selection process started with the agroecological characterization of 12 potential research sites (Jones et al., 1992). Uberlândia, Rio Verde, Campo Grande and Rondonópolis were placed as the top four candidate regions on the bases of their greater agroecological representativity, higher land use intensity, demand for technology and strength of local institutions (Figure 1).

The process continued with the analysis of the secondary information available for each of those four regions (Rivas and Pereira, 1992), followed by a Rapid Rural Appraisal conducted by a multidisciplinary group of researchers from several institutions (Table 1).

Preliminary results of the rural appraisal

A final report of the results obtained from the rural appraisal is not yet available. However several observations can be reported.

Land use

There appears to be a consistent land use pattern across the four regions. The flat areas with medium to clay soil texture, known as "chapadões" are mostly used for grain production; the rolling landscapes and sandy soils for extensive livestock production and the transition areas for dairy production systems.

Pockets of high fertility soils were also observed in all four regions. This land use pattern is also accompanied by a different group of people devoted to each activity. The "gauchos" who are mostly from the south of Brazil are almost exclusively dedicated to produce grains and the people from the region are devoted to extensive livestock and milk production in small farms.

Problems of sustainability

All production systems found in the four regions have problems of degradation. There is an increasing pressure of weeds and nematodes in the continuous soybean cropping systems and visible problems of soil erosion and compaction in cropping and pasture the land and the poor management of the pastures.

Grain producers, especially those from more distant regions such as Rondonópolis are also facing difficulties cope with the increasing production costs of conventional technology. On the other hand traditional livestock producers do not have the machinery nor the knowledge to reclaim pastures. Dairy producers, who in most cases are small farmers, are facing severe problems of production during the dry season.

Use of improved technologies

Only the most advanced farmers and livestock producers are using crop rotations, minimum tillage, and deep subsoiling to reduce soil degradation problems. However most of these practices are expensive and require specialized equipment. There is also an increasing interest on the integration of crops and pastures. In some cases farmers are integrating the two activities, but maintained in separated areas.

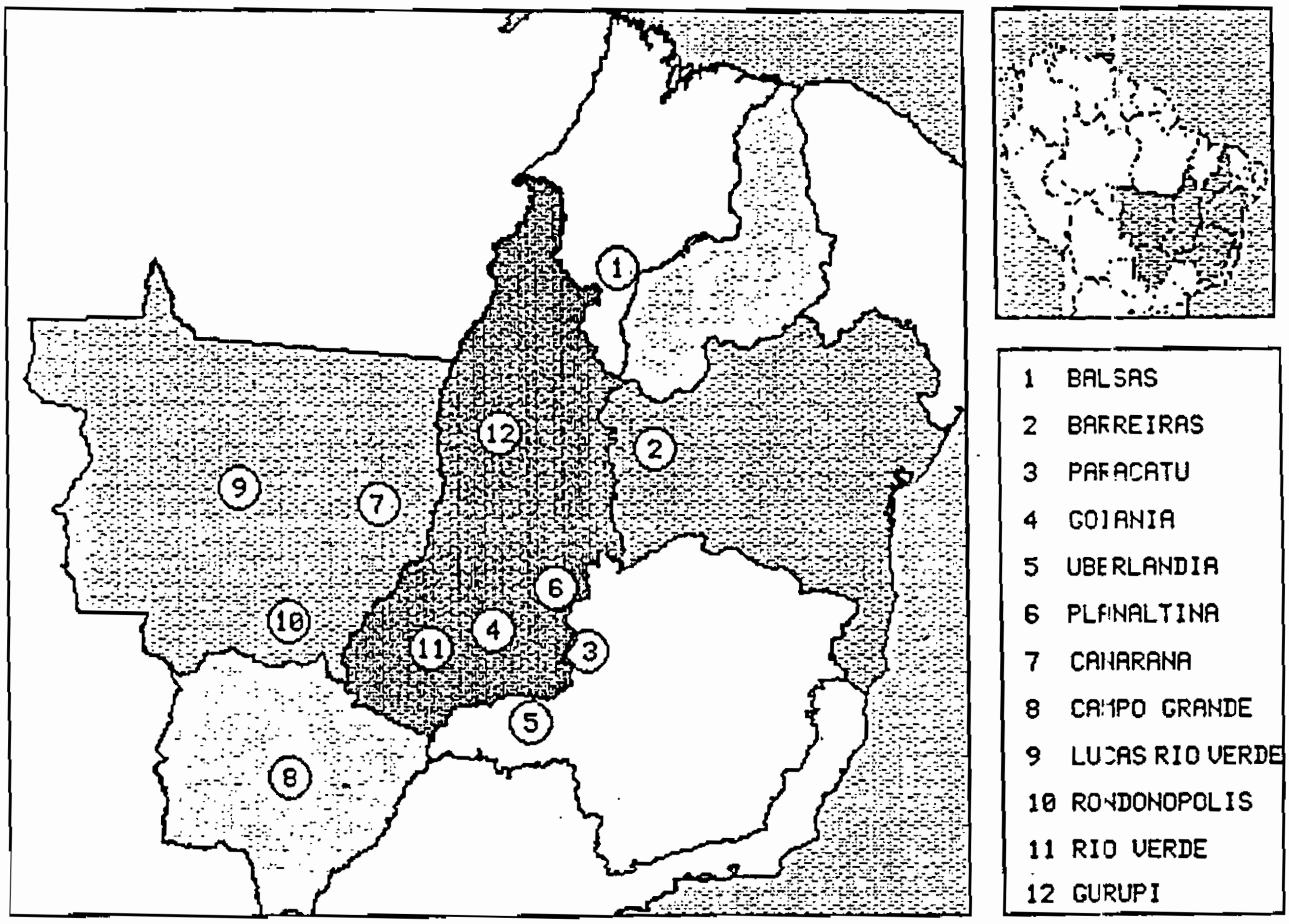

Figure 1. Savannas study areas.

Table 1. List of institutions participating in the rapid rural appraisal of the four candidate research sites in the Cerrado.

Region	Date	Institute	Total
Rio Verde	Dec 92	CPAC (3), CIAT (1), NCSU (1)	5
Uberlândia	Feb 93	CPAC (2), CIAT (2), CNPGL (1), CNPAF (1), CNPMS (1)	7
Campo Grande	Apr 93	CPAC (2), CIAT (2), CNPGC (1), CNPAF (1), CNPMS (1), CNPSO (2), CPAO (1), NCSU (1)	11
Rondonópolis	Apr 93	CPAC (2), CIAT (1), CNPGC (1), CNPAF (1), CNPMS (1), CNPSO (2), CPAO (1), NCSU (1)	10

CPAC: Cerrados Agricultural Research Center (EMBRAPA); CIAT: Centro Internacional de Agricultura Tropical; CNPAF: National Center for Rice and Beans (EMBRAPA); CNPGC: National Center for Beef Livestock (EMBRAPA); CNPMS: National Center for Corn and Sorghum (EMBRAPA); CNPSO: National Center for Soybeans (EMBRAPA); CPAO: West Agricultural Research Center; NCSU: North Carolina State University.

Potential of each region to become a research site

Any of the four regions might well be a research site for the Savannas Program in Brazil. However, considering the logistics aspect Uberlândia appears to offer the best potential to become one of the research sites for the Savannas Program. Six of the agroecological classes described by Jones et. al. (1992) are present in that region. In addition, all the dominant production systems are present in the region at a close distance from each other. From the point of view of logistics it is relatively close to several EMBRAPA centers and has a strong University with expertise on environmental issues.

Visit to alternative research sites

Three frontier regions were also visited during the last year with the objective of making a rapid assessment of their potential as contrasting regions to be included in the future expansion of the activities of the Program.

Canarana (Mato Grosso), Barreiras (Bahía) and Gurupí (Tocantins) were visited. These three regions were developed during the 70's part of colonization projects supported by the government. Each of these three regions have specific characteristics. Barreiras is located on extremely fragile sandy soils, Canarana in a transition zone between the cerrados and the forest amazon and Gurupí on diverse soil types and landscapes.

Problems of sustainability

Most of these areas were opened to plant crops, especially rice. However during the last ten years rice has been replaced by other crops and pastures due to the low price in the market. The common main constraints found in these regions is the long distance from the market and the increasing production costs of conventional technology. In many cases, grain producers are unable to pay back bank loams to plant crops.

From the institutional point of view all the three regions have similar problems: 1) weak Cooperatives, 2) limited activities of the extension and research institutions and 3) problems of economic and biological sustainability of the current production systems.

During next year, Lucas de Río Verde and Balsas will be visited with the same purpose. After the analysis of the information collected and the availability of funds one of these region will be chosen as the second research site.

CROP-PASTURE INTEGRATION IN INTENSIVE PRODUCTION SYSTEMS

A characterization study

Rice has traditionally been used to plant pastures in the Cerrados. Farmers plant upland rice after clearing the native vegetation and establish the pastures when the crop is harvested.

Recently, CNPAF-EMBRAPA has developed a system known as "Barreirão", in which upland rice is planted simultaneously with *Brachiaria brizantha* to reclaim degraded pastures. There is, however, an increasing interest in the potential role of crop-pasture integration in intensive production systems based mainly on soybeans and corn. In 1992 a characterization study was initiated on a farm near Uberlândia (MG) where this type of integration has gradually evolved over the last 10 years. The farmer has maintained yearly records of: 1) land use, 2) rainfall, 3) tillage practices, 4) fertilization, 5) crop yields and 6) planted pasture species. This information has been used to characterize the dynamics of the crop-pasture integration and to document the impact of crop and pasture cycles on productivity and soil chemical and physical properties.

Description of the area

The farm "Fazenda Santa Terezinha" is located 30 km south of Uberlândia on the highway to Uberaba. The soils in the area are classified as Red Yellow Latosols. They are sandy (70-80% sand) and have a low inherent fertility (Table 2). However due to the use of lime and fertilizers for crops, soil fertility has increased dramatically over the years (Table 3). The total farm area is about 1240 ha, 10% remaining as native cerrado. Pasture establishment, was initiated in 1978 and by 1983 the whole farm area was planted with improved pastures comprised of *Brachiaria decumbens, Brachiaria humidicola* and *Andropogon gayanus*. Because of the decline in pasture productivity over time and due to the availability of credit and subsidies for cropping activities, the farmer decided to gradually replace planted pastures with crops followed by new improved pastures to be rotated with crops. By 1991 all originally planted pastures had been replaced by crops-pastures sequences (Figure 2). At present sixty percent of the area is planted to soybeans and corn. The remaining area is in pastures comprised of several species of *Panicum* planted after 3-4 years of crops.

Table 2. Soil chemical and physical properties of a native cerrado area. Santa Terezinha farm, Uberlândia (mean of 16 composite samples).

Depth	Sand	Clay	pH	Al	Ca+Mg	K	Al+H	P	Bsat	MO
(cm)	%			meq/100g				(ppm)	%	
0-10	82	13	5.4	0.38	0.41	0.04	1.90	1.6	19	0.97
10-20	79	15	5.2	0.36	0.19	0.04	0.78	0.6	23	--
20-30	74	13	5.2	0.33	0.16	0.03	0.69	0.4	22	--
30-40	--	--	5.2	0.31	0.13	0.02	0.70	0.3	18	--

Methods: P and K (Mehlich 1).

Effect of the pasture cycle on crop production

The farm records showed that soybean yields varied from year to year. However there was a tendency toward yields increasing with the age of the planted pasture. Yield data obtained from fields with increasing length of pasture cycle showed a net benefit equivalent to 50 kg soybeans/ha for every year under pastures (Figure 3). However, due to the limited number of observations available for most periods, results must be considered as only preliminary.

Table 3. Changes in soil chemical properties after four years of continuous cropping in a sandy latosol of Uberlândia (mean of four samples).

Parameters	Depth (cm)	Native cerrado	After four crops	Increase
pH	0-10	5.4	6.3	0.9
	10-20	5.2	5.9	0.7
	20-30	5.2	5.6	0.4
	30-40	5.2	5.0	0.2
Base saturation[1] (%)	0-10	19.1	82.7	63.4
	10-20	22.6	84.6	62.0
	20-30	21.9	69.5	47.6
	30-40	17.7	52.0	34.3
P (ppm)	0-10	1.6	26.4	24.8
	10-20	0.6	0.4	-0.2
	20-30	0.4	0.3	-0.1
	30-40	0.3	14.0	0.0

P_2O_5: 547 kg/ha; Lime: 6.75 t/ha

1 Calculated as sum of Ca+Mg+K/CEC (Ammonium acetate Ph 7.0)

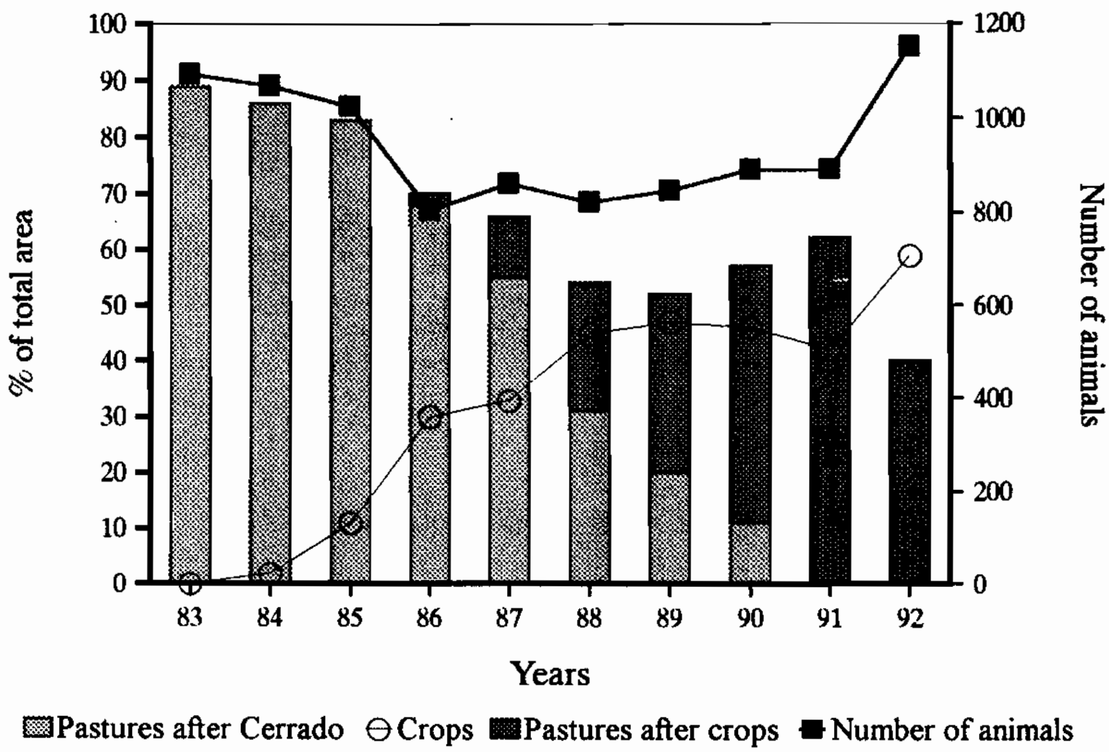

Figure 2. Changes in the crop and pasture area over time in a farm located in Uberlândia (M.G., Brazil).

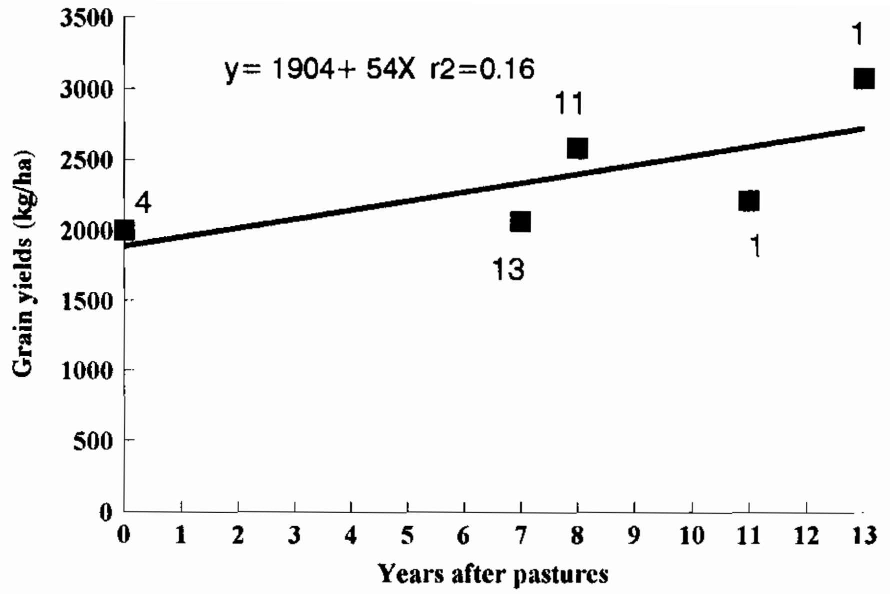

Figure 3. Grain yield of soybean planted in fields with several years under pastures.

Corn has been used by the farmer in rotation with soybeans. More recently it has been used as a companion crop to establish pastures. The corn and the pasture are planted simultaneously.

Comparison of yield data when corn was planted alone and in association with grasses showed that production was not affected when planted with *Andropogon* but it was reduced by 14% when the corn was planted with *Panicum* species (Table 4).

Table 4. Effect of the companion grass on corn yields when both components were planted simultaneously (mean of several crops).

System	Yields (kg/ha ± STD	% Yield reduction
Corn alone (5)	6718 ± 43	-
Corn + *A. gayanus* (2)	6520 ± 537	2
Corn + *B. brizantha* (2)	5953 ± 866	11
Corn + *P. maximum* (2)	5790 ± 127	14

Number in brackets correspond to the number of crops used in the calculations.

Effect of crop cycle on pasture production

The introduction of crops in the farm has resulted in the reduction of the planted pasture area by 60% and the replacement of originally planted pasture by more productive and higher quality grasses (e.g *Panicum maximum* cv. Vencedor). These pastures were consistently well established by corn harvest time and ready for grazing by the beginning of the dry season. This was particularly advantageous in 1992 when there was sufficient high quality forage for the farm herd during the dry season, and enough excess to finish 150 heifers that were sold at the end of the dry season.

The most impressive result of the synergistic effect between crops and pastures planted after crops has been the striking increase the carrying capacity of the farm in spite of the reduction in pasture area (Table 5).

Table 5. Evolution of the area under pastures over time in the Fazenda Terezinha - Uberlândia (MG).

Year	Pasture after cerrado	Pasture after crops	Total area	Herd size	Stocking rates
	----------ha----------				(head/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	2.8

Effect of crop and pasture cycles on soil properties

In addition to the expected increase in soil fertility over time due to intensive cropping, there have been several important changes in soil physical properties. Soil samples taken from areas with increasing time under crops showed an almost linear decrease in the proportion soil aggregates > 2mm (Figure 4). This is attributed to the cumulative effect of plowing, disking and disk harrowing of the soil to plant crops. This effect appears to be counteracted when crops are rotated with pastures. Samples taken from a pasture planted after four years of crops showed an increased proportion of aggregates > 2mm after four years.

The effect of planted pastures, native cerrado and continuous cropping on the organic matter content in the 0-10 cm soil layer can be seen in Table 6. The highest OM levels were observed in the pasture planted after crops.

During the present year the farmer is introducing no-till planting on the farm. Land preparation was limited to planting milleto (*Pennisetum* sp). He is planning to use the existing pastures of *Andropogon* and *B. brizantha* as cover crops to plant corn and soybeans. Pastures will be controlled with herbicides at planting and during crop development. However the farmer expects to graze them after the crop is harvested.

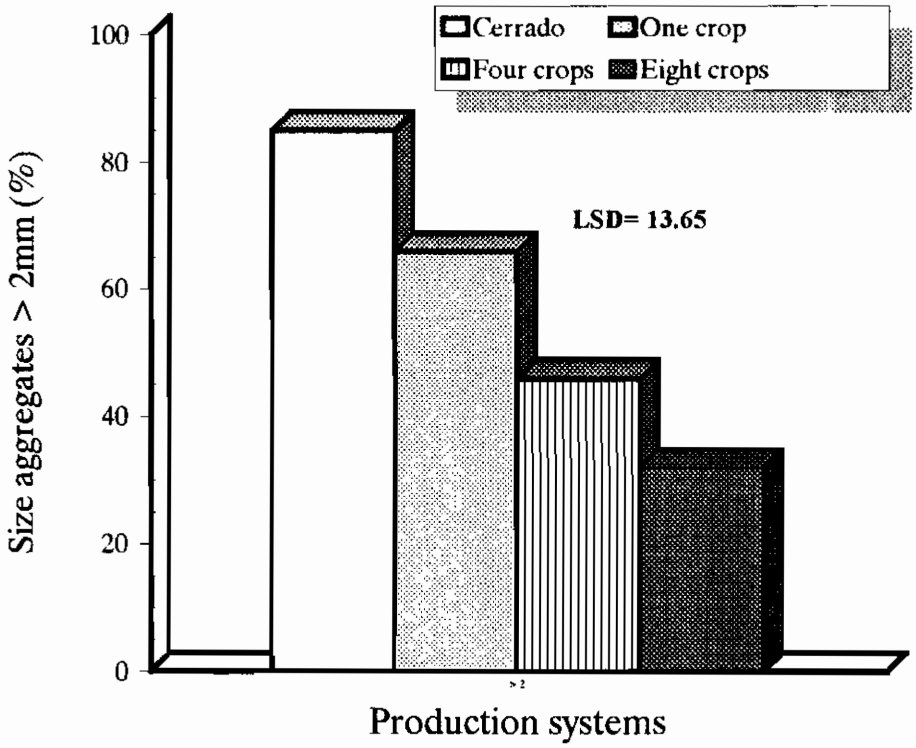

Figure 4. Effect of management on soil aggregate stability of loamy sand soil of Uberlândia, Minas Gerais, Brazil.

Table 6. Effect of management on chemical properties of the 0-10 cm topsoil of a latosol of Uberlândia (values are mean of four composite samples).

System	pH	Al	Ca+Mg	K	OM	P
		meq/100 g			%	ppm
Native cerrado	5.4 a	0.4 a	0.4 a	18 a	0.97 a	1.6 a
After 1 crop	5.9 a	0.0 b	1.9 b	54 b	0.84 a	17.9 b
After 4 crops	6.3 b	0.0 b	2.4 b	99 c	0.94 a	26.4 bc
Crop/pasture rotation	5.7 a	0.0 b	1.8 b	22 a	1.23 b	44 bc

Values within columns followed by a different letter are statistically different according to the Tukey test ($P<0.05$).

Preliminary conclusions and work planned for next year

The present characterization is providing a new and unique information on the potential of crop pasture integration to improve the economical and biological sustainability of intensive management systems. Although the economic analysis of the whole enterprise is not yet available it is clear that overall productivity of the farm has improved by the introduction of crops while maintaining, or even increasing livestock production.

Preliminary data is confirming the potential of pastures to increase or restore organic matter levels and soil aggregation after deterioration during the crop cycle. These processes will be carefully characterized through a collaborative project with the University of Bayreuth in Germany and CPAC-EMBRAPA. Monitoring of the activities on the rest of the farm will be maintained to assess the potential of planted pastures as cover crops for direct crop planting. Opportunistic measurements will be also conducted to assess changes in the organic phosphorous fractions under crop and pasture cycles.

Although crop-pasture integration has a high potential to improve current production systems in the cerrados there are some constraints to be solved before further adoption by the producers. At the research level it is necessary to develop crop and pasture components agronomically compatible and potentially adapted to the different conditions of production systems in terms of landscape, soil types, and socieconomical conditions of the producers. More knowledge is also needed to maximize synergism between components and to enhance soil improving processes.

Integrated systems will probably require a different management than that developed to manage individual crop and pasture systems if farmers want to maximize benefits of the integration. This will require adjustments at the farm level and at the managerial level.

GERMPLASM TESTING FOR IMPROVED AGROPASTORAL SYSTEMS

One of the most important steps in the design of improved agropastoral systems is the development and testing of compatible crop and pasture components. Since last year, the section started field work to test the potential of several pasture species as components of agropastoral systems to reclaim degraded pastures or for rotation with crops under intensive management systems. The work is being conducted in four farms located in Uberlândia (MG) having contrasting differences in terms of land use and soil texture (Table 7).

Germplasm testing was carried out at two scales: 1) small plots (4 m^2) to test adaptation of several promising grass and legume species and 2) large plots (1 ha) to determine the long term effects of improved agropastoral systems on crop and animal production and soil conditions. Species included in the work were selected in collaboration with Forages Program of CIAT. Tables 8 and 9 show the species included in each trial.

Table 7. Initial soil characterization of the 0 - 20 cm topsoil of the selected areas in Uberlândia.

Production system	Clay	OM (%)	pH	Al	Ca+Mg	K	P (ppm)	Aggregate size >2m (%)
				-----meq/100g-----				
Intensive management	57	3.4	6.2	0.0	4.9	0.12	34	50
Intensive management	13	0.9	6.3	0.0	2.4	0.25	26	46
Degradated pasture	17	0.7	5.3	0.6	0.4	0.13	1.1	73
Degradated pasture	57	2.7	5.1	0.5	0.5	0.07	0.9	77

Table 8. Crop and pasture components of the agropastoral systems tested in the large plots.

Components	Degraded pasture		Intensive management systems	
	Sandy	Clay	Sandy	Clay
Crop	Rice	Rice	Corn	Corn
Grass	*B. ruziziensis*[1]	*B. decumbens*[2]	*P. maximum* Vencedor	*P. maximum* Vencedor
Legumes	*S. mineirão*	*S. mineirão*	*S. mineirão*	*S. mineirão*
	A. pintoi[3]	*A. pintoi*	---	---
	N. wightii	*N. wightii*	*N. wightii*	*N. wightii*
	C. mucunoides	*C. mucunoides*	*C. mucunoides*	*C. mucunoides*

[1, 2] Original grass species
[3] *A. pintoi* BRA 15263 B

Table 9. List of species included in the small plot work.

Order	Species	Identification
1	*Calopogonium mucunoides*	CIAT 18564
2	*Calopogonium mucunoides*	CIAT 7722
3	*Calopogonium mucunoides*	CIAT 8405
4	*Calopogonium mucunoides*	CIAT 18065
5	*Calopogonium mucunoides*	CIAT 9111
6	*Calopogonium mucunoides*	CIAT 822
7	*Pueraria phaseoloides*	BRA 000582
8	*Pueraria phaseoloides*	BRA 000612
9	*Pueraria phaseoloides*	BRA 000817
10	*Pueraria phaseoloides*	BRA 000761
11	*Arachis pintoi*	BRA 15263B
12	*Centrosema brasilianum*	CPAC 2510
13	*Centrosema brasilianum*	CIAT 5234
14	*Brachiaria brizantha*	BRA 003484
15	*Brachiaria brizantha*	BRA 004308
16	*Brachiaria brizantha*	BRA 003441
17	*Brachiaria decumbens*	CIAT 16484
18	*Panicum maximum* cv. Vencedor	
19	*Brachiaria decumbens* cv. Basilisk	
20	*Brachiaria ruziziensis*	
21	*Paspalum atratum*	BRA 9610

Pasture species included in the large plots were planted simultaneously with upland rice in the reclamation treatment and with corn in the intensive management system. Germplasm tested in the small plots work was planted in strips within the large plots.

Testing was carried out in the presence and absence of the crop and grass components of the system. After three months of planting they were cut to evaluated for dry matter production.

Results from the small plot work

Competition by the grass and the crop components affected the establishment of most of the legumes included in the trial. Only, *Arachis pintoi* was able to survive even under the conditions of the intensive management system. In absence of competition, legumes performed better under the low fertility conditions of the reclaimed pastures system than under the high fertility and stronger competition conditions of the intensive management systems (Table 10). Again in this case, *A. pintoi* was the best adapted species in terms of dry matter production.

In contrast to the performance of the legumes, most of the grasses planted in the non-competition treatment responded markedly to the improved fertility conditions of the intensive management system (Table 11).

Initial results in the large plots

Rice growth was severely affected by a combination of factors including deficient land preparation, a strong veranico after planting and by the competition of weeds and the reclaimed *Brachiaria* species. In contrast to this, pasture establishment was very good. Initial population counting showed an averaged population of 2-3 plant/0.5 m^2 of most of the legume species (Table 12). Survival of the vegetative material of *Arachis* was good (above 80%). However development was slowed down due to the aggressiveness of the grass. Establishment of the pasture components in the clay soil was initially affected by a heavy infestation of the weed *Mimosa pudica*. However, it improved dramatically after the beginning of the dry season when the *Mimosa* was destroyed by a natural predator.

Corn yields in the intensive management system were very good in spite of the vigorous growth of the grass (Table 13). Legume establishment under this condition, was very poor in both soil types. Growth was probably affected by competition by light with the crop and grass components.

Table 10. Dry matter yields of the legume forages included in the small plot work after three months of planting (mean of two reps).

		Degraded pasture (kg/ha)		Intensive management (kg/ha)	
Species	Identification	Sandy	Clay	Clay	Sandy
C. mucunoides	CIAT 18564	536	555	31.2	33
	7722	496	562	51.2	0
	8405	668	681	65.0	143
	18065	336	626	28.7	0
	9111	628	457	205	0
	822	177	825	52.5	0
P. phaseoloides	BRA 000582	525	530	0	0
	000612	760	170	0	0
	000817	752	115	0	0
	000761	551	148	0	0
A. pintoi	BRA 15263B	913	791	153	353
C. brasilianum	CPAC 2510	260	256	23	0
	CIAT 5234	287	542	0	0

Preliminary conclusions and future plans

Results obtained showed that in spite of the eficient land preparation that affected rice performance in the reclamation treatment forage legumes like Stylo mineirâo was very well established. The greater rusticity of forage legumes is of particular importance in traditional livestock production systems where the lack of appropriated machinery is a common problem.

The fact that all the legumes included in the experiment did not establish well under the conditions of the intensive management systems suggest that strategies different than the simultaneous planting are needed. Competition could be reduced planting the legume before than the crop or the grass. This hypothesis will be tested during the present year.

The long term evaluation of the improved agropastoral systems will start this year. In order to test the role of the legumes in the intensive management system the cocktail of legumes will be reintroduced in strips in the large plots this year. An intensive characterization in terms of soil and plant parameters will be conducted in the reclaimed and unreclaimed controls prior to initiate grazing. The changes in these parameters over time will be used to assess the duration of the benefit of improved pasture systems on animal production and soil conditions and to confirm their beneficial impact on crop production.

The small plot work methodology to test promising pasture species could be useful to test the adaptation of promising crop and pasture germplasm at early stages. However it will require some adjustments to avoid the problems observed during this year. Plot size and number of reps should be increased to improve the results.

Table 11. Dry matter yields of several promising grass species planted in two production systems and two soil types without competition.

Species	Sandy soil		Clay soil	
	Degraded pasture	Int.management system	Degraded pasture	Int.management system
	t/ha DM			
B. brizantha BRA 003484	2.0 ± 0.8	5.9 ± 1.2	1.3 ± 0.1	14.3 ± 4.7
B. brizantha BRA 004308	1.5 ± 0.8	10.9 ± 1.4	0.6 ± 0.1	10.3 ± 3.2
B. brizantha BRA 003441	1.6 ± 0.6	11.7 ± 1.4	0.6 ± 0.0	3 2 ± 0.5
B. decumbens CIAT 16488	1.6 ± 0.3	8.5 ± 0.8	0.7 ± 0.1	6 6 ± 0.9
P. maximum cv. Vencedor	1.5 ± 0.4	10.9 ± 2.3	0.9 ± 0.4	14 0 ± 3.7
B. decumbens cv. Basilisk	2.5 ± 0.5	6.1 ± 0.9	1.1 ± 0.2	8.6 ± 0.23
B. ruziziensis	2.0 ± 0.7	7.1 ± 4.3	0.5 ± 0.1	5.8 ± 0.4
P. atratum BRA 9610	1.5 ± 0.8	4.1 ± 0.3	0.2 ± 0.1	4.8 ± 0.6
mean	**1.8 ± 0.36**	**8.2 ± 2.8**	**0.8 ± 0.3**	**8.5 ± 4.1**

* mean of two reps.

Table 12. Plant population of several forage species determined after two months of planting (mean of planting (mean of 100 sampling points 0.5 m²).

Production system	Clay content (%)	Weeds	Grass	*Stylosanthes*	*Calopogonium*	*Neonotonia*
		number of plants/0.5 m²				
Degraded pastures	18	9 ± 6	11 ± 3[1]	2 ± 1	2 ± 1	2 ± 1
	57	20 ± 7	19 ± 6[2]	3 ± 1	2 ± 1	2 ± 1
Int.management system	13	6 ± 8	9 ± 3[3]	0 ± 0	1 ± 2	1 ± 1
	57	36 ± 18	4 ± 2[3]	0.2 ± 0.6	1 ± 1	1 ± 1

[1] *Brachiaria ruziziensis*
[2] *Brachiaria decumbens*
[3] *P. maximum* cv. Vencedor

Table 13. Grain yield and dry matter production of the components of the agropastoral systems tested.

System	Soil type	Crop	Grass	*Stylosanthes*	*Calopogonium* + *Neonotonia*	Weeds
		t/ha		kg/ha		
Degraded pastures	sandy	0.0	5.2	66	286	58
	clay	0.0	1.9	279	93	1212
Intensive management system	sandy	7.5	2.9	0.4	4.5	23
	clay	5.9	3.8	0.0	108	52

ON-STATION STRATEGIC RESEARCH

Activities at the Station level were concentrated in the participation in a long term experiment studying the effects of integrated and non-integrated crop-pasture systems on: 1) crop and animal productivity, 2) soil chemical, physical and biological properties and 3) agronomic efficiency.

The experiment was installed in 1991 on a Dark Red Latosol of CPAC with a high clay content and low fertility (Table 14).

Table 14. Chemical and physical properties of the 0-20 cm topsoil of an Oxisol (L.V.A.) used in the experiment (mean of 20 subsamples).

Parameters	Rep 1	Rep 2
pH (H_2O 1:2.5)	5.28 ± 0.02	5.44 ± 0.02
Ca+Mg (meq/100ml)	0.17 ± 0.06	0.16 ± 0.02
P (ppm-Melich-1)	1.29 ± 0.024	1.11 ± 0.055
K (ppm)	34 ± 1.1	35 ± 1.4
MO (%)	2.9 ± 0.07	2.97 ± 0.04
Al. saturation (%)	72.8 ± 0.6	71.2 ± 1.3
CTC at pH 7.0	6.87 ± 0.14	6.03 ± 0.09
Clay (%)	60.1 ± 1.2	54.3 ± 1.1
Silt (%)	11.2 ± 0.5	10.9 ± 0.3
Sand (%)	28.7 ± 1.6	34.8 ± 1.3

Integrated and non-integrated crop-pasture treatments were placed in the main plots of the experiment and the management variables (fertilization levels, land preparation methods and grazing intensity) were located in the subplots within each system (Fig. 5). Measurements are conducted by a multidisciplinary team of scientist from CPAC and CIAT (Table 15).

Before planting the experiment, all the native cerrado vegetation was cut and removed from the area and the lime treatments were applied and incorporated. Pastures were established in October 1991 planting *A. gayanus* as the common grass and a cocktail of legumes of *Stylosanthes guianensis* cv. Mineirâo (0.5 kg/ha), *Calopogonium mucunoides* (2,3 kg/ha) and *Neonotonia wigthii* (1,6 kg/ha) planted in rows. Grazing intensity was designed to maintain a contrasting amount of residues.

Soybeans was planted successively during the first two years of the experiment in the cropping treatments. However the varieties used each year were different. "Doko" was used the first year because its better adaptation to soil acidity and "Seriema" in the second year because its higher production potential.

Table 15. List of personnel who participate on the crop-pasture integration experiment.

Name	Institution	Activity
L. Vilela	CPAC	Coordinator, Grazing Management
M. Ayarza	CIAT	Soil Fertility
R. Sharma	CPAC	Nematode population
Jeanne C. Miranda	CPAC	Mycorrhiza activity
Roberto C. Pereda	CPAC	Weed dynamics
Dimas Resck	CPAC	Soil management
J.E. da Silva	CPAC	Soil organic matter
María José Charchar	CPAC	Disease pressure
Cynthia Gomide	CIAT	Agronomy
Lucio Vivaldi	CPAC	Statistics

Initial results

A. Crop and animal production

Soybeans responded more to the increase in the soil fertility than to land preparation methods during these first two years (Table 16). Yields, however, were reduced by at least 50% in the second year due to a severe dry spell at the flowering time.

Table 16. Effect of fertilization and land preparation on the yields of two soybean varieties planted continuously for two years.

Treatments	1991-92 Variety 1[1]	1991-92 Variety 2[2]
	---------- kg grain/ha	----------
F1	1144 ± 148	250 ± 70
F2	2262 ± 232	1439 ± 1
T1	1684 ± 162	890 ± 38
T2	1722 ± 218	800 ± 32

F1 = 50 kg/ha P_2O_5, 30 kg/ha K_2O, 30% base saturation, 0.5 kg Zn; F2 = 100 kg/ha P_2O_5, 60 kg/ha K_2O, 50% base saturation, 2.8 ton gypsum, 60 kg FTE; T1 = disking; T2 = deep plowing.

Treatments

1. Systems:

   S_1 - Continuous grass only pasture
   S_2 - Continuous grass-legume pasture
   S_3a- Crop-pasture rotation
   S_3b- Pasture-crop rotation
   S_4 - Continuous copping system

2. Fertility:

   F_1 - Without maintenance fertilization
   F_2 - With maintenance fertilization

3. Land preparation:

   T_1 - Conventional (disking)
   T_2 - Flexible land preparation to maintain good soil physical properties

4. Grazing intensity:

   I_1 - High grazing pressure
   I_2 - Low grazing pressure

AREA OF EACH SYSTEM: 0.8 ha
TOTAL AREA: 14.2 ha

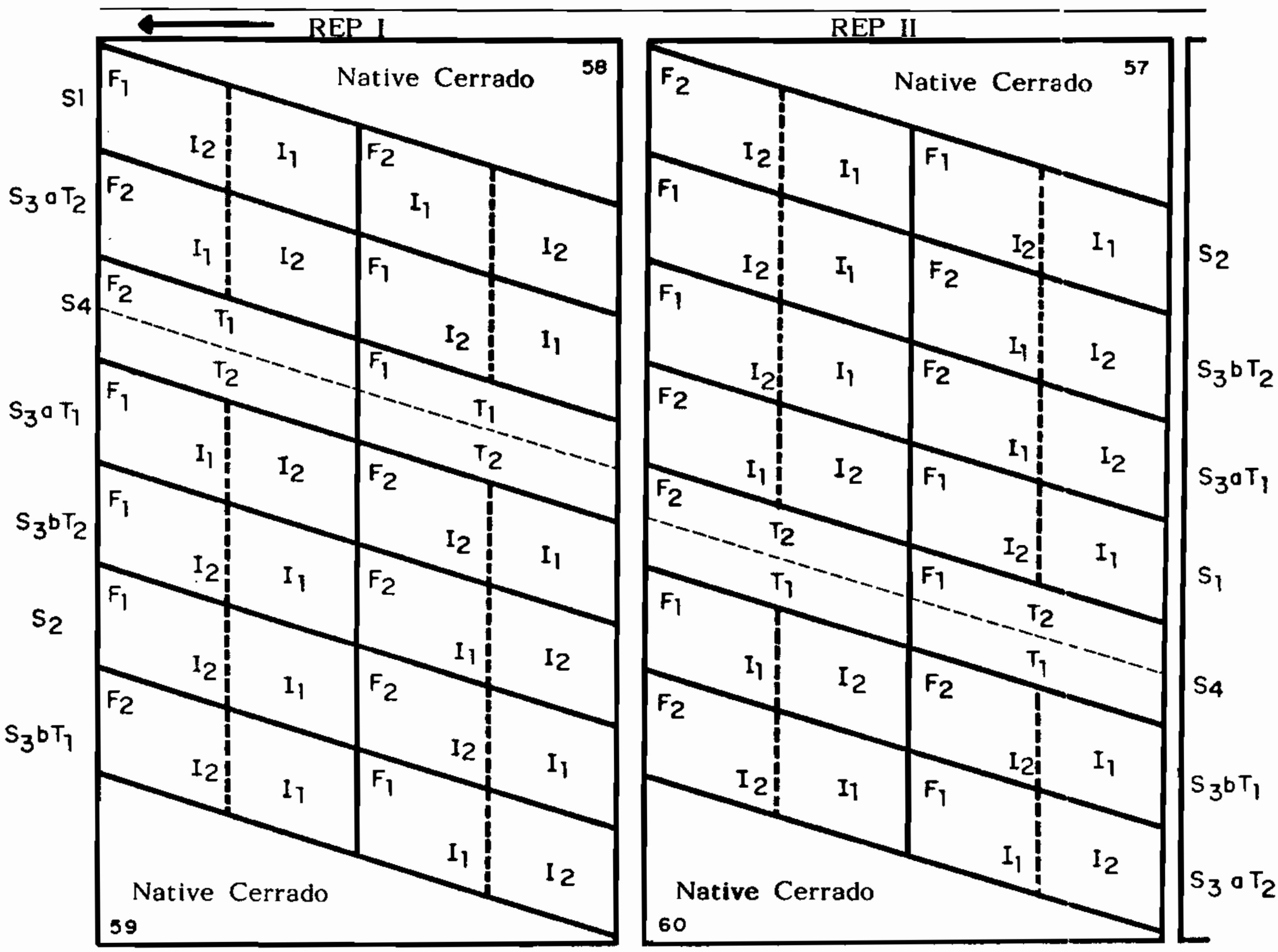

Figure 5. Field layout of the long term experiment planted at CPAC.

Results of the animal evaluation during 144 days showed a superior performance in the legume based pastures treatment. Differences were consistent throughout the wet and the dry periods (Table 17).

Table 17. Liveweight gains (kg/ha) of animals grazing the pasture systems.

Pastures	Fertility level F1	F2
	------- rainy season -------	
A. gayanus	189 (1.6)	121 (1.5)
A. gayanus + legumes cocktail	239 (1.6)	235 (1.7)
	-------- dry season --------	
A. gayanus	- 39 (0.8)	- 44 (0.8)
A. gayanus + legumes cocktail	30 (1.0)	- 4 (0.9)

F1 = 30% base saturation; F2 = 50% base saturation; cocktail = *S. guianensis* cv. Mineirão, *N. wightii*, *C. mucunoides* and *C. brasilianum* BRA 1219.
Numbers in brackets correspond to the stocking rate (AU/ha).

B. Above and below ground biomass production

Fertilization increased soybean above ground biomass production and nutrient accumulation. Determinations made at flowering time showed a three-fold increase in dry matter and nitrogen accumulation in the high fertility treatment compared to the low fertility treatment (Table 18).

Table 18. Total above ground biomass of soybean plants harvested at the flowering time in 1993.

Treatments	Dry matter	Nitrogen accumulated
	------------- kg/ha	-------------
F1	1294 ± 79	29.8
F2	3801 ± 139	97.7
T1	2548 ± 176	---
T2	2510 ± 5	---

Grass biomass production was initially lower in the flexible land preparation treatment due to the diluting effect of ploughing on fertilizer phosphorus availability. The most impressive feature that can be observed at the present is the high proportion of *Stylosanthes guianensis* cv. Minerão in the total biomass of the mixture. This proportion is increasing over time due to the higher animal preference to the grass (Table 19).

Results showed similar root biomass production in the crop and the pasture systems. However root length was twice as much longer in the pasture treatments (Table 20). Soybean root biomass numbers appear to be too high. It is likely that there was an overestimation produced by the sampling scheme.

Weed population estimates are showing a negative relationship between weed population and fertility levels.

Incidence is lower in the high fertility treatment due to the higher competition from the soybean crop.

Below ground biomass of crops and pastures were determined in the same period as the above ground biomass (flowering time).

Changes in soil properties

Land preparation in the cropping treatments and grazing in the pasture systems are influencing the original soil physical properties. The proportion of water stable aggregates > 2mm in the 0-10 cm topsoil was lower in the cropping treatments compared to the pasture systems and the native cerrado control (Figure 6). On the other hand, instantaneous water infiltration (sorptivity) and mechanical impedance (penetrometer resistance) were more affected in the pasture systems, probably due to a superficial soil compaction (Figures 7 and 8).

Monitoring of the population and activity of the mycorrhiza under the different systems is showing a dramatic increase in number and activity in the pasture systems over time (Figure 9). So far, micorrhyzal populations under crops are similar to the native cerrado. Additional observations are also suggesting a preferential dominance of some species under pastures systems.

Table 19. Effect of the fertilization regime and grazing intensity on total above ground biomass produced by the components of the pasture.

Pastures	Grazing intensity	Dry matter (t/ha) Grass	Legume	Total	Legume (%)
October 1992					
A. gayanus	Low	3.3	-	3.3	-
	High	3.3	-	3.3	-
A. gayanus + cocktail	Low	1.9	3.2	5.1	63
	High	1.9	3.1	5.0	62
September 1993					
A. gayanus	Low	3.9	-	3.9	-
	High	3.5	-	3.5	-
A. gayanus + cocktail	Low	0.9	5.4	6.4	85
	High	0.5	3.4	3.9	87

Low intensity: 5 days of grazing; High intensity: 9 days of grazing.

Table 20. Total root biomass and length found in the 0-80 cm soil depth interval in the systems included in the crop-pasture experiment.

System	Crop	Biomass (t/ha)	Length (km/m^2)
Continuous cropping	Soybeans	10.2 ± 0.3	14.1 ± 0.6
Continuous grass	*A. gayanus*	9.8 ± 0.3	30.1 ± 1.2
Continuous grass-ley	*A. gayanus* + cocktail	9.9 ± 0.7	29.7 ± 1.8
Native cerrado	--	9.3 ± 0.4	20.9 ± 1.5

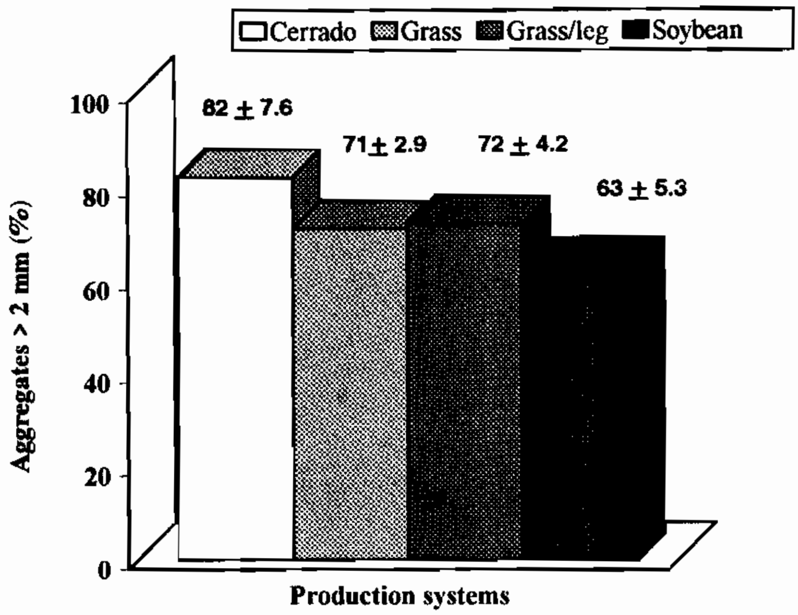

Figure 6. Changes in the water stable aggregates of the soil under several management systems (mean of four observations).

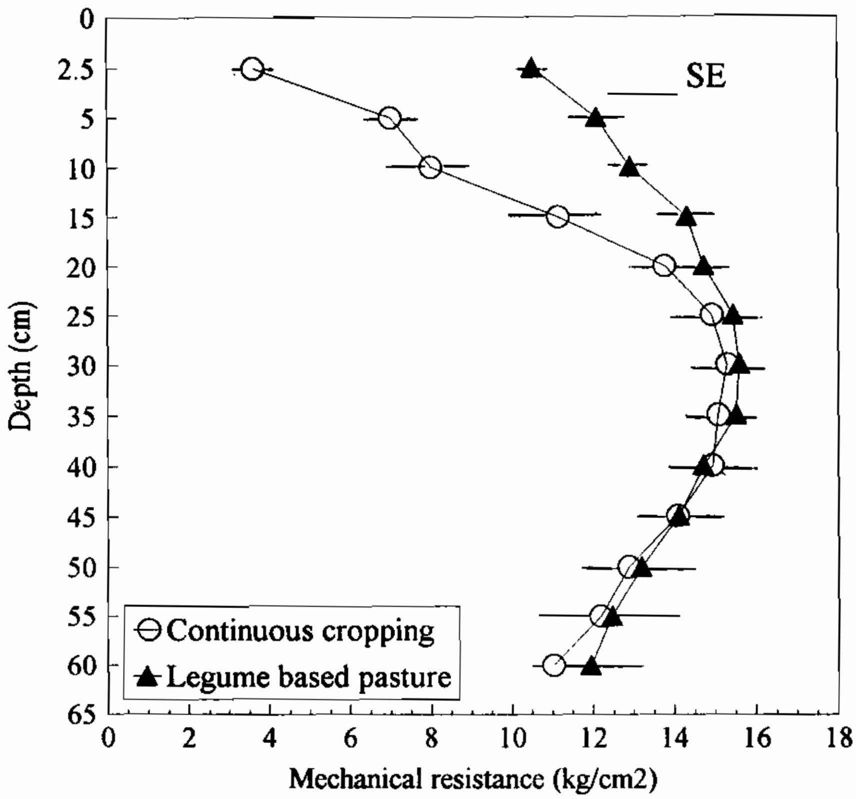

Figure 7. Effect of two management systems on the mechanical resistance of an Oxisol (LVA) of the Cerrados.

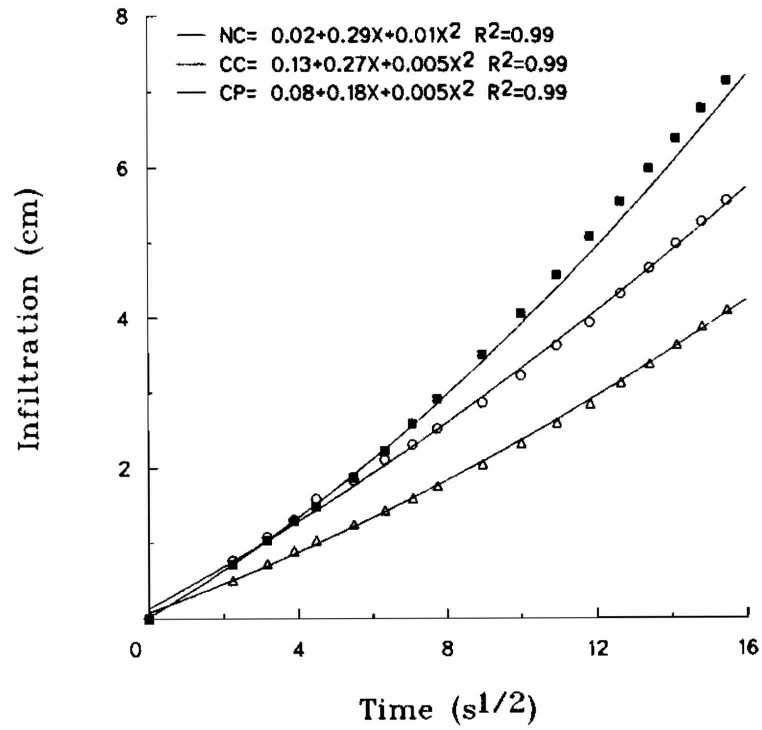

Figure 8. Effects of several management systems (native cerrado = nc, continuous cropping = cc and continuous pasture = cp) on the instantaneous water infiltration sorptivity of an Oxisol of CPAC after two years.

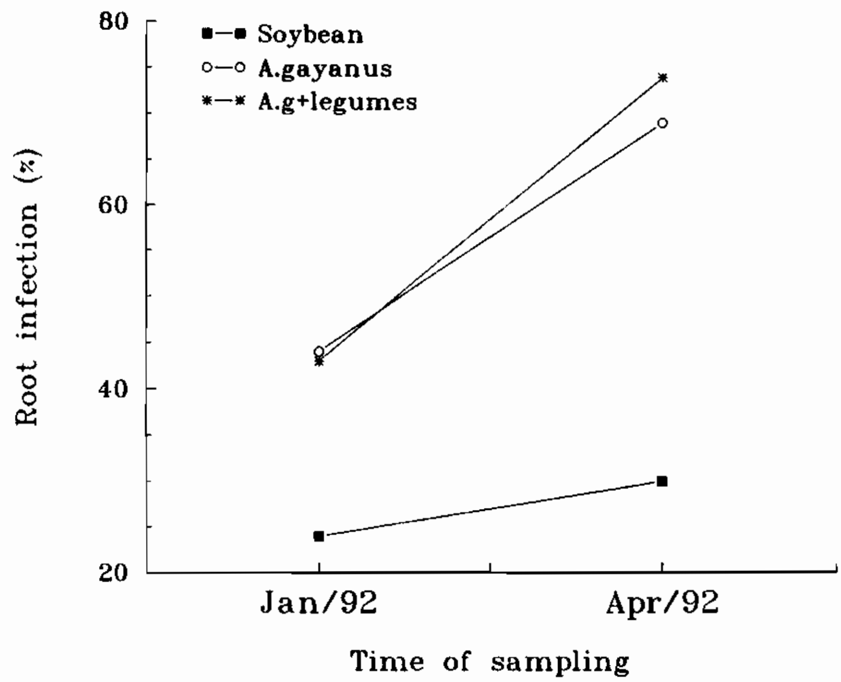

Figure 9. Mycorrhizal root infection found in soybean and pasture root in two sampling dates.

After two years of initiation the results reported here are showing that crops and pastures are producing positive and negative changes in soil properties. Fertilization is increasing crop and pasture yields as well as the amounts and quality of plant residues. Tillage and grazing animals are modifying the soil physical properties. The quantification and the understanding of these changes over time will help to understand the contribution of crop and pasture cycles to the productivity and sustainability of integrated systems.

Special attention will be given in the future to quantification of the dynamics of organic matter dynamics and the soil physical properties in different management systems. These activities will be conducted within a collaborative project with the University of Bayreuth in Germany.

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CHAPTER VI

MANAGEMENT OF NATIVE SAVANNA ON COLOMBIA'S EASTERN PLAINS

SUMMARY

During the last two years, we have:

Botany. Established a single key for the identification of the principal grazing grasses of the natural rangeland of the Eastern Plains of Colombia (EPC) based on vegetative characteristics (leaves, ligule, pilosity, etc.). Finished the key for identification of the principal species of the "Altillanura" of the EPC based on flowers (collaborating with the National University of Colombia, Palmira).

Ecology. Based on a census of the native vegetation of the CNI of Carimagua conducted by E. Escobar of the Universidad Nacional of Colombia and J. Belalcázar (CIAT), we have been able to establish a classification and the characterization of the main groupings of vegetation of the "Altillanura zone" and the ecology of all the species found (150 species, 108 genus, 45 families). This should allow for a better understanding, a better management and, eventually, the improvement of the rangeland.

With the assistance of Dutch students, a preliminary study of native pastures of the "Serrania" has begun: analysis of principal soils, types of vegetation and management by the farmers. Have shown the differences with the flat areas ("Altillanura plana").

Productivity and Dynamics. Additionally, we have completed measurements of productivity, quality and dynamics of the native vegetation of different systems of management through simulation of grazing by successive cuts and with animals important differences were observed between native vegetation communities and management.

Management. In three management tests for natural pastures with animals, we are now testing the hypothesis that grazing must be done at least 15 days after burning in order to keep the vegetation from degrading. Also, grazing by rotation (in order to make 15 to 45 days of regrowth available to the animals) is possible and advantageous for animals as well as vegetation. Productivity of pastures (vegetation and animals), its dynamics and animal behavior are observed.

Inventory. With the collaboration of IGAC (Bogota) and Ecole Nationale Agronomique of Paris-Grignon (France) a study on inventory and classification of the vegetation by remote sensors has been undertaken in the EPC.

Soils macrofauna. Finally, we have provided technical and logistical support to a student from the University of Paris in the inventorying of the macrofauna of soils under native pastures. Soils under native pasture have proven to be very poor in macrofauna in contrast to soils under improved pastures.

INTRODUCTION

During this last year, we have continued the studies on botany and vegetation ecology of the Altillanura and Serrania of the Llanos, the productivity and dynamics of different types of native pastures. We have also continued to test different models of native pasture management with different types and dates of fire, stocking rate, rotation and rest.

With the help of IGAC (Bogota) and the "Institut Agronomique de Paris-Grignon", France, we have classified and inventoried the vegetation of Carimagua with remote sensors in order to establish a methodology for the Llanos.

We have also initiated the inventory of the macrofauna of the soils of Carimagua in native vegetation and some improved pastures.

BOTANY

We have finished the classic key for the identification (on floral characters) of the principal native species (Monocotyledoneae and

Dicotyledoneae) of the Eastern Plains flatlands (Altillanura) of Colombia. These species were collected in the banks, lowlands, forest gallery borders and "morichal" of the native savannas.

153 species (93 genera of 34 families) are described.

Another key was prepared for the principal native grasses of the Eastern Plains of Colombia based on vegetative characteristics.

Also the native vegetation of the serrania was investigated; 177 species (96 genera of 39 families) were identified. From these 177 species, half (84) are not present in the flat plains (Altillanura), from the 53 Poaceae (gramineae) identified in the serrania, 26 are not present in the Altillanura (see Annexe).

ECOLOGY

The analysis of the observations and measures on Carimagua vegetation and soil characterization were continued. With the help of multivariate analysis, the 20 communities of native vegetation were classified in eight groups (Figure 1); each group characterized by soil characteristics, water humidity, characteristic and most common species (Tables 1 and 2). Each species is also characterized by its ecological growth conditions.

Also some characterizations of the serrania were made (Figures 2 to 6). In these figures, we can observe there are some differences of vegetation cover and number of species among the top of the hills, the slops and the lowlands.

Productivity and dynamics

This year, we have finished the studies of vegetation productivity by cuttings (to simulate grazing). The Figures 7 and 8 show the productivity at different heights of cutting (15, 10 and 5 cm) which can correspond at different stocking rates. We can observe that the lowest height (5 cm) produced the highest production.

The vegetation composition and cover were not different for the three cutting heights. Only cuttings at soil level (<5 cm) produce important changes (degradation).

The productivity of the two tests of the Core Experiment was also observed (Figure 9 and Table 3). We can observe:

1. Important differences of liveweight gain (LWG) between Alegria (sandy-loamy soil) and Introducciones II (Clay-loamy soil).

2. During the first year, with a stocking rate of 6 ha/animal in Alegria and 4 ha/animal in Introducciones II, the LWG/day were not different.

3. During the second year, after charging stocking rate in Alegria (also 4 ha/animal) the LWG of the animals in Alegria was very low during the rainy season (0.082 kg/day) and relatively good in Introducciones II (0.245 kg/day).

4. During the dry season of the second year, the LWG in Introducciones II continues to increase (0.126 kg/day) and decreases in Alegria (-0.10 kg/day).

5. During the rainy season of the third year (with the same stocking rate on both sites (4 ha/animal) the animals lose weight in Alegria (-0.022 kg/day) and have a good LWG in Introducciones II.

6. The animals on sandy soil of Alegria, with a stocking rate of 4 ha/animal, have not enough grass to eat (see Table 4 the important decrease of phytomass) and it seems that the vegetation is already degraded.

7. On the native pasture of clay soils (Introducciones II), the LWG is good all year long (even dry season).

MANAGEMENT

A first experiment on old native pasture has given us the following results (Figure 10 and Table 5); we observe:

1. The alternate rotation has not produced more LWG than the system without rotation (63.9 kg LWG/animal/year for medium stocking rate with rotation and 73.3 kg LWG/animal/year without rotation).

2. The higher frequency of fire (every month) produces a LWG in serrated form.

3. It seems that during some dry periods, the animals do not have sufficient forage to eat with the rotative system.

4. We have to burn more surface during the dry periods to make more new regrowths available.

A new experiment with more animals is in progress.

Classification and inventory of vegetation by remote sensing

This study was made with the collaboration of the IGAC (Bogota) and the Institut Nationale Agronomique of Paris-Grignon (France). With the contribution of the French Embassy in Bogota, we bought two images from the SPOT Satellite of the Carimagua in the Llanos. To interpret these images, two steps are necessary:

- Step 1. Studies of the vegetation reflectance with a CIMEL radiometer and its characterization on ground level and then, classification of these vegetation (Table 6 to Table 8).

- Step 2. Identification, classification and mapping of these vegetation test groups with the help of remote senses data (Tables 9 to 12).

On ground level, we have noticed the reflectance of some of the 60 plots and classified them with the help of multivariat analysis techniques (clusters and principal component analyses, Figure 11). We can observe:

- The reflectance differences between the rainy and the dry season.

- The differences between rainy and dry season are more important than for cultivated pastures (in the visible, green and red, it's the content of chlorophyll which is important, and in the near infrared, the phytomass has an important role).

- During the dry season, in the visible, the reflectance is higher for the savannas and cultivated pastures but not for young green savannas. There is more chlorophyll during the rainy season.

After this first step on ground level, the information obtained by satellite was analyzed by computer in the Institut National Agronomique of Paris-Grignon (France) by Colette Girard and based on our ground level observations. The computer treatment gave us two classifications for dry and rainy seasons (March and October).

The first classification allows to distinguish the vegetation according to its age or its management (Tables 9 and 10); forest galleries and water are classified separately.

If a small percentage of pixels was not classified (10.7 and 3.0) because of limited number of classes, the matrix of confusion shows a very good discrimination among classes of vegetation (from 85% to 99% in March and 86% to 100% in September).

For this first classification we can observe, in March, Table 9 (and Image 1 corresponding):

- The small surface occupied by the forest galleries (6.6%) and the wet lowlands (4.04%).

- The importance of grassland fires during the last year (more than 50% of the total surface: classes 1+2+3+4), from which one part can be considered as degraded (overgrazed) and/or exposed to erosion when the slope is more than 2% and/or the ants are very active.

- On the base of the difference of floral composition (probably caused by the spectral effect of the inflorescences of the dominant species), it is possible to distinguish different types of native pastures and different types of soils. For example, *Schizachyrium hirtiflorum*, on sandy soils in the east part of the image, and *Trachypogon vestitus* in the west, on clay soils.

In Table 10 (and the corresponding Image 2), we note a very different vegetation physiognomy at the end of the rainy season. So we can follow the evolution of the vegetation with regard to the dry season:

- The "degraded zones", or little chlorophyllous, with important soil effect (sensitive to erosion), cover 11.2% (classes 5+7+8) of the image. Native pastures burnt during the dry season have generally recovered their vegetation well.

This does not mean that there are less degraded areas. In fact, zones invaded by shrubs and by non-desirable species (unpalatable species or weeds in the cultivated pastures) as well as chlorofitic are also degraded.

- The old pastures (not burnt since more than one year ago) cover a little less than 30% of the total surface of the image (Classes 3+4).

- The cultivated pastures and/or the well-used rangelands (important effect of the chlorophyll) cover 44.35% of the image (Classes 1+2). We can also note that here, as from the ground radiometry (Rippstein et al., 1993), it is not possible to distinguish cultivated pastures (always very chlorofitic even when they are in good condition or with an important effect on the soil when they are degraded) from native well-grazed pastures, so good chlorofitic or from degraded native pastures (with an important effect of soil). Only the analysis by design of the plots (more geometric for the cultures), could permit the distinction between the two types of vegetation.

- We can also note the increase of water surfaces at the end of the rainy season which have doubled (from 0.26 to 0.70%). For the second classification (spectral behavior), 13 classes were formed for each period (Table 11 and 12). With this higher number of classes, the preciseness of the study is lower (good classified pixels). However, almost all the pixels are classified (only 0.26% and 0.88% respectively were thrown out for March and September). Finally, the confusion matrix among the test zones and the clusters shows a better possibility of discrimination of classes in September.

To conclude, we can say that the use of SPOT Satellite images, thanks to their excellent resolution and large scale (1:50.000), allow for a good inventorying of the vegetation in the zones of wet tropical savannas.

However, the use of two missions in the same year and the combination (superpositioning) provide more knowledge and assurance and, naturally, increase the cost (1 mission cost around 5.000 US$).

The timing of the satellite mission is also very important. One mission in the rainy season and another in the dry season should be ideal. If that is not possible, it seems that the image in the rainy season may be more useful than the one in dry season. It would be necessary, however, to be able to analyze the January image with the objective of observing a drier vegetation more contrasted with that which was observed by the ground radiometry (Rippstein et al., 1993).

These analysis show, if they were needed again, the importance of good knowledge of the terrain (if possible with a survey of ground radiometry) with the objective of preventing gross errors and also making more detailed results.

SOIL-FAUNA

A first study of soil fauna, with emphasis on earthworms has been started at the research station of Carimagua by a French student (Thibaud Decaëns) from the University of Paris under the supervision of Patrick Lavelle of ORSTOM (France).

Ten sites have been selected in order to characterize the influence of different types of land management (traditional extensive breeding, intensive breeding on improved pastures, high input cultivation) on the soil macrofauna. The method used is the one recommended by the T.S.B.F. programme. The forest and savanna macrofauna is comparable to that of an other tropical forest or savannas with inferior biomass. However, due to the low earthworms biomasses measured, the traditional savanna management favors the earthworms to the detriment of the termites but does not modify the macrofauna biomass and density in a significant way. The use of fire leads to a momentary but important disruption of the soil fauna; the biomass, the density and the diversity are simultaneously modified. The earthworms remain dominant. After six months, the soil has regained a fauna almost equivalent to the one it had before the fire. If the stocking rate is increased, the importance of the earthworms diminishes and the coleoptera become more present. These modifications are probably due to the modification of the soil microclimate and to the bringing of cow dung. Improved pastures accommodate an important earthworm population composed of species native to the savanna with a high biomass. The macrofauna diversity of these soils is also high. This results from the improving of the quality of the organic matter brought to the soil (litter and cow dung). The annual high input cultivation shows a spectacular decrease, both quantitatively and qualitatively, in the invertebrate populations of the soil. This phenomenon may be explained by the effect of the tilling of the soil, the fertilization and to the decrease of the soil organic matter.

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TABLE 1. Soil and water data of vegetation communities of Carimagua Center

Components	I	II	III	IV	V	VI	VII	VIII	General mean
	GROUPS								
	Communities								
	7-16-15	8-11-12	20-19	17-18	4-3	13-9-14-10	1	2-6-5	
Clay (%)	25.2	28.3	30.4	55.6	51.3	24.5	49.8	43.7	35.6
Sand (%)	29.1	34.9	41.9	11.6	5.5	50.9	6.9	14.7	28.3
Silt (%)	45.4	36.6	27.5	32.6	43.0	24.8	43.4	41.4	36.0
OM (%)	4.0	1.8	0.9	5.1	2.5	1.0	2.8	2.0	2.4
P (ppm)	3.7	1.2	0.9	1.4	0.5	1.3	0.7	0.8	1.4
pH	4.5	4.6	4.7	4.6	4.5	4.5	4.6	4.5	4.6
Al (Meq/100 gr)	2.3	1.6	1.4	4.2	2.1	1.0	2.7	2.1	2.0
Ca (Meq/100 gr)	0.09	0.07	0.09	0.12	0.12	0.07	0.12	0.12	0.09
Mg (Meq/100 gr)	0.06	0.05	0.06	0.08	0.06	0.04	0.06	0.06	0.06
K (Meq/100 gr)	0.05	0.04	0.05	0.07	0.05	0.03	0.05	0.04	0.04
S (ppm)	5.0	3.4	5.5	5.5	5.5	4.9	5.9	6.3	5.1
B (ppm)	0.1	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.2
Zn (ppm)	1.0	0.3	0.3	0.4	0.4	0.2	0.4	0.4	0.4
Mn (ppm)	2.8	1.2	0.4	2.5	3.6	0.8	4.6	3.1	1.9
Cu (ppm)	0.1	0.3	0.2	0.2	0.4	0.2	0.5	0.4	0.3
Fe (ppm)	57.0	72.0	52.8	46.6	66.3	37.7	33.0	51.1	52.8
Water 1: (0-55 cm)									
Dry (%)	24.8	7.7	8.4	26.1	13.9	6.3	14.8	12.2	13.6
Rainy (%)	28.4	18.3	14.6	42.3	23.5	14.5	24.4	19.7	22.2
Water 2: (55-95 cm)									
Dry (%)	21.2	13.8	13.2	26.6	20.5	8.4	19.5	17.4	16.6
Rainy (%)	22.4	17.3	16.4	34.8	24.3	14.3	22.1	20.4	20.6
Water 3: (95-155 cm)									
Dry (%)	21.8	18.8	16.7	28.3	28.4	13.8	26.9	22.9	21.0
Rainy (%)	14.9	19.3	18.7	33.0	32.2	16.0	30.0	25.0	23.2

TABLE 2. Ecological groups of Carimagua (Llanos)

GROUP I
(Vegetation Communities: 7-16-15)
WET SAVANNA

Soils:	Clay-loam (Group Ia) and sandy-loam (Ib). Good level of organic matter (>3%) and P TOT (3-4 ppm). Good level of water (Reserve) during the dry season (16-40%) and rainy season (24-44%) on the upper part (0-55 cm) of the soil.	
Characteristic species:	*Ipomea schombur*	(Convolvulaceae)
	Paspalum convexum	(Poaceae)
	Scleria distans	(Cyperaceae)
Subgroup Ia:	*Gymnopogon fastigiatus*	(Poaceae)
	Lipocarpha sellowiana	(Cyperaceae)
	Scleria pterota	(Cyperaceae)
	Syngonan gracilis	(Eriocaulaceae)
Subgroup Ib:	*Boreria capitata*	(Rubiaceae)
	Diectomis fastigiata	(Poaceae)
	Imperata contracta	(Poaceae)
	Hypogenum virgatum	(Poaceae)
	Thrasya trinitensis	(Poaceae)
More frequent species:	*Paspalum carinatum*	(Poaceae)
	Paspalum convexum	(Poaceae)
	Aristida riparia	(Poaceae)
	Axonopus aureus	(Poaceae)
	Panicum parvifolium	(Poaceae)
	Xyris caroliniana	(Xyridaceae)

GROUP II
(Vegetation Communities: 8-11-12)
DRY BANK SAVANNAS (Silt)

Soils:	Loam-clay or sandy-loam. Low level of organic matter (>2%) and of sulfur (3-4 ppm). High level of Fe (60-80 ppm). Very low reserve of water during the dry season (6-10%) and low level during the rainy season (17-21%).	
Characteristic species:	*Irlbachia alata*	(Gentianaceae)
	Sipanea pratensis	(Rubiaceae)
	Paspalum multicaule	(Poaceae)
More frequent species:	*Andropogon leucostachyus*	(Poaceae)
	Axonopus aureus	(Poaceae)
	Axonopus purpureus	(Poaceae)
	Paspalum carinatum	(Poaceae)
	Rhynchospora confinis	(Cyperaceae)
	Schizachyrium hirtiflorum	(Poaceae)

TABLE 2. Continued

GROUP III
(Vegetation Communities: 19-20)
DRY SAVANNAS

Soils:	Sandy-clayey and silty-clayey. Very low level of organic matter (0.6-1.3%) and of P (1 ppm). Very low level of water reserve during the dry and rainy season.	
Characteristic species:	*Polygala* sp.	(Polygalaceae)
	Rhynchospora bulbosa	(Cyperaceae)
	Trachypogon plumosus	(Poaceae)
	Bulbostylis paradoxa	(Cyperaceae)
More frequent species:	*Aristida riparia*	(Poaceae)
	Leptocoryphium lanatum	(Poaceae)
	Paspalum carinatum	(Poaceae)
	Paspalum parviflorum	(Poaceae)
	Paspalum pectinatum	(Poaceae)
	Rhynchospora confinis	(Cyperaceae)
	Rhynchospora globosa	(Cyperaceae)
	Schizachyrium hirtiflorum	(Poaceae)
	Trachypogon plumosus	(Poaceae)

GROUP IV
(Vegetation Communities: 17-18)
WET LOWLAND SAVANNAS

Soils:	Heavy clay and clay (>50% clay). Very high level of water during dry and rainy season (26% and 42%, respectively). High level of organic matter.	
Characteristic species:	*Climedia rubra*	(Melastomataceae)
	Cuphea micrantha	(Lythraceae)
	Paspalum clavuliferum	(Poaceae)
More frequent species:	*Andropogon leucostachyus*	(Poaceae)
	Aristida capillacea	(Poaceae)
	Axonopus aureus	(Poaceae)
	Cuphea micrantha	(Lythraceae)
	Eragrostis maypurensis	(Poaceae)
	Gymnopogon foliosus	(Poaceae)
	Hyptis atrorubens	(Labiatae)
	Leptocoryphium lanatum	(Poaceae)
	Melochia colombiana	(Sterculiaceae)
	Otachyrium versicolor	(Poaceae)
	Paspalum clavuliferum	(Poaceae)
	Paspalum parviflorum	(Poaceae)
	Rhynchospora globosa	(Cyperaceae)

TABLE 2. Continued

GROUP V
(Vegetation Communities: 3-4)
DRY SAVANNAS ON CLAY SOILS

Soils:	Clay-silty (50% clay and 43% silt). Medium level of water during dry and rainy season (14% and 23%, respectively). P very low (0.5 ppm).	
Characteristic species:	*Aeschynomene elegans*	(Fabaceae)
	Axonopus purpusii	(Poaceae)
	Borreria laevis	(Rubiaceae)
	Calyptrocarya glomerulata	(Cyperaceae)
	Hyptis verticillata	(Labiatae)
	Lindernia diffusa	(Scrophulariaceae)
	Ludwigia leptocarpa	(Onagraceae)
	Mimosa pudica	(Mimosaceae)
	Panicum laxum	(Poaceae)
	Rhynchospora pubera	(Cyperaceae)
More frequent species:	*Axonopus purpusii*	(Poaceae)
	Otachyrium versicolor	(Poaceae)
	Rhynchospora pubera	(Cyperaceae)

GROUP VI
(Vegetation Communities: 9-10-13-14)
DRY SAVANNAS ON SANDY SOILS

Soils:	Sandy-silt, silty-clay and sandy-clay. Very low level of water during dry season (5-6%) and rainy season (14-18%). Low level of organic matter and P.	
Characteristic species:	*Declieuxia fruticosa*	(Rubiaceae)
	Eriosema crinitum	(Fabaceae)
	Hyptis dilatata	(Labiateae)
	Palicurea rigida	(Rubiaceae)
	Vigna candida	(Fabaceae)
More frequent species:	*Andropogon leucostachyus*	(Poaceae)
	Paspalum pectinatum	(Poaceae)
	Rhynchospora confinis	(Cyperaceae)
	Schizachyrium hirtiflorum	(Poaceae)

TABLE 2. Continued

GROUP VII
(Vegetation Communities: 1)
DRY SAVANNAS ON CLAY-SILTY SOILS

Soils:	Clay-silty (50% clay and 43% silt). Medium level of water during dry season (15%) and rainy season (25%). Low level of organic matter (2.9%) and P (0.7 ppm).	
Characteristic species:	*Aeschynomene hystrix*	(Fabaceae)
	Curatella americana	(Dilleniaceae) - shrub
	Eriosema rufum	(Fabaceae)
	Galactia glaucescens	(Fabaceae)
	Sida spinosa	(Malvaceae)
	Vigna hoockeri	(Fabaceae)
	Imperata brasiliensis	(Poaceae)
	Setaria geniculata	(Poaceae)
More frequent species:	*Axonopus aureus*	(Poaceae)
	Aristida capillacea	(Poaceae)
	Gymnopogon foliosus	(Poaceae)
	Imperata brasiliensis	(Poaceae)
	Rhynchospora globosa	(Cyperaceae)
	Schizachyrium hirtiflorum	(Poaceae)
	Setaria geniculata	(Poaceae)
	Trachypogon vestitus	(Poaceae)
	Thrasya petrosa	(Poaceae)

GRUPO VIII
(Vegetation Communities: 2-5-6)
DRY SAVANNAS

Soils:	Clay-silty (45%-45%). Medium level of water during dry season (12%) and low level during rainy season (20%). Low level of P (0.5 - 1.4 ppm).	
Characteristic species:	*Galaxia glaucescens*	(Fabaceae)
	Otachyrium versicolor	(Poaceae)
More frequent species:	*Andropogon bicornis*	(Poaceae)
	Aristida capillacea	(Poaceae)
	Axonopus purpusii	(Poaceae)
	Gymnopogon foliosus	(Poaceae)
	Otachyrium versicolor	(Poaceae)
	Paspalum pectinatum	(Poaceae)
	Rhynchospora globosa	(Cyperaceae)
	Trachypogon vestitus	(Poaceae)

TABLE 3. Core Experiment. Comparison of liveweight gain (lwg) on native pasture with improve management by rotative fire (every four months)

	On sandy soils (Alegría)			On clay soils (Introduction II)		
	Rainy season	Dry season	All year	Rainy season	Dry season	All year
FIRST YEAR (1991-1992)						
- kg lwg/animal (200 kg lw)	37.0	-0.9	36.1	32.0	-6.0	26.0
- kg lwg/animal/day (No.days)	0.211 (175)	-0.009 (105)	0.129 (280)	0.228 (140)	-0.057 (105)	0.106 (245)
- kg lwg/ha	6.2*	-0.15*	6.0*	8.0**	-1.5**	6.5**
SECOND YEAR (1992-1993)						
- kg lwg/animal (200 kg lw)	20.0	-14.0	6.0	60.0	13.2	73.2
- kg lwg/animal/day (No.days)	0.082 (245)	-0.1 (140)	0.016 (385)	0.245 (245)	0.126 (105)	0.209 (350)
- kg lwg/ha (4 ha/animal)	5.0	-3.5	1.5	15.0	3.3	18.3
THIRD YEAR (March-October 1993)						
- kg lwg/animal	-4.6			62.5		
- kg lwg/animal/day (No.days)	-0.022 (210)			0.357 (175)		
- kg lwg/ha (4 ha/animal)	-1.2			15.6		

Stocking rate: * 6 ha/animal
** 4 ha/animal

TABLE 4. Above phytomass before burning CORE Experiment in Carimagua. Native pasture

ALEGRIA			INTRODUCCION II		
Date	Parcel	Phytomass (g MS/m²)	Date	Parcel	Phytomass (g MS/m²)
25/05/91	1 a/	481.3 ± 48.4	18/07/91	1 a/	935.7 ± 182.8
26/08/91	2 b/	341.9 ± 41.3	28/11/91	2 b/	328.3 ± 35.2
03/12/91	3 b/	232.2 ± 38.0	20/04/92	3 b/	326.3 ± 33.4
02/04/92	4 b/	215.1 ± 81.9	30/07/92	4 b/	170.9 ± 106.5
18/08/92	1 c/	152.6 ± 33.4			

Observations: a/ Old savannas >3 years without burning
b/ Parcel 2, 3, 4: before burning but under grazing
c/ After 1 year grazing (4 ha/animal)

TABLE 5. Comparison of different systems of native vegetation management. Liveweight (LWG) gain

Season	ALTERNATIVE ROTATION (FIRE EACH MONTH)						WITHOUT ROTATION (FIRE EACH FOUR MONTHS)		
	Medium stocking rate (4 ha/animal)			High stocking rate (2 ha/animal)			Medium stocking rate (4 ha/animal)		
	kg LWG/anim	kg LWG/anim/day	kg LWG/ha	kg LWG/anim	kg LWG/anim/day	kg LWG/ha	kg LWG/anim	kg LWG/anim/day	kg LWG/ha
RAINY (Apr-Dec) 1992	59.0 a	0.249 a (237 days)	14.7	37.7 a	0.159 a (237 days)	18.9	16/04 - 17/12 60.0 a	0.245 a (245 days)	15.0
DRY (Dec-Apr) 1992-1993	4.7 b	0.042 b (112 days)	1.2	1.7 b	0.015 b (112 days)	0.85	13.2 a	0.126 a (105 days)	4.9
ALL YEAR 1992-1993	67.7 a	0.183 a (349 days)	15.9	39.5 b	0.113 b (349 days)	22.7	79.7 a	0.228 a (350 days)	19.9

* Read the comparison horizontally

** The same letter indicates there is not significant difference (P=5%), DUNCAN test

TABLE 6. Classification of the vegetation in order of ground reflectance in the visible and near infrared in dry season

Groups	Reflectance (%) in three bands (CIMEL)			Types of vegetation
	Green (500-590 mm)	Red (615-680 mm)	Near I.R. (790-890 mm)	
1	9.1	11.4	30.0	Native pastures and old cultivated pastures soil non-visible
2	9.7	10.4	38.6	Young (5 months) *Brachiaria* sp (soil visible)
3	8.0	10.6	24.7	Native pastures or old cultivated pastures with visible soil
4	10.4	13.4	34.4	Young cultivated pastures (with visible soil: 15-30%)
5	7.4	8.6	27.5	Native pastures lowland with soil and bush
6	10.7	12.2	42.2	Young cultivated pastures but with visible soil (10-25%)

TABLE 7. Classification of the vegetation in order of ground reflectance in the visible and near infrared in rainy season

Groups	Reflectance (%) in three bands (CIMEL)			Types of vegetation
	Green (500-590 mm)	Red (615-680 mm)	Near I.R. (790-890 mm)	
1	9.2	9.9	33.1	Native and cultivated pastures; >1 year old; variable biomass
2	7.8	8.6	29.2	Native and cultivated pastures ≥1 year; important biomass
3	8.3	8.9	35.5	Native and cultivated pastures ≥1 year; medium biomass very green aspect
4	7.0	7.7	25.1	Native pastures and *A. gayanus* >1 year
5	8.7	8.3	38.7	Cultivated pastures >1 year old; biomass variable
6	9.8	11.8	27.4	Young native pastures (2-12 months)

TABLE 8. Comparison of the terrestrial reflectance (CIMEL) for native and cultivated pastures. Dry and rainy season

Vegetation	Season	Reflectance in three bands (%)		
		Green (500-590 mm)	Red (615-680 mm)	Near I.R. 790-890 mm)
Old native savanna (>2 years)	Dry	8.5	10.6	26.8
	Rainy	7.5	8.3	30.8
Young native savanna (1-3 months after fire)	Dry	6.0	6.8	10.2
	Rainy	9.1	11.5	29.4
Young native savanna (5-6 months)	Dry	8.3	11.1	24.4
	Rainy	9.8	11.5	34.8
Young native savanna (Serrania)	Dry	8.3	10.7	22.4
	Rainy	7.8	8.9	22.7
Andropogon gayanus (>1 year)	Dry	7.0	8.8	23.8
	Rainy	9.0	7.0	38.1
Brachiaria humidicola (>5 years pastured)	Dry	7.9	9.5	25.0
	Rainy	7.5	8.1	27.8
Brachiaria decumbens (>5 years pastured)	Dry	10.0	11.9	32.5
	Rainy	10.1	9.8	35.1
Brachiaria dictyoneura (Young: <1 year)	Dry	10.0	11.7	35.7
	Rainy	8.8	9.4	32.9

TABLE 9. Vegetation of the Llanos. According to management practices. SPOT Satellite Image. CNI ICA/CIAT window, Carimagua/Colombia. ***Dry season (March)***

	Vegetation classes and management practices	Surface	Good classified pixels of test-zones
		---- percentage ----	
1.	Recent burning (0-1 month), bare soil + ashes	1.06	97.7
2.	Recent burning (1-2 months), bare soil without ashes	1.20	98.5
3.	Savanna >5 months after burning. Clay soils	27.74	85.3
4.	Open savanna (soil visible: ant-hills) degraded and cultivated pastures overgrazed	20.47	93.0
5.	Savanna >5 months after burning. Sandy-limo-soils with *Schizachyrium hirtiflorum*	9.43	99.1
6.	Bare soils or recent ploughing	2.66	97.5
7.	Wet grassland (lowlands)	4.04	99.8
8.	Dry savannas (very old burning)	15.82	90.0
9.	Gallery forest	6.61	99.9
10.	Free water + rivers	0.26	100.0
	TOTAL	89.32 10.68	

TABLE 10. Vegetation of the Llanos. According to management practices. SPOT Satellite Image. CNI ICA/CIAT window, Carimagua/Colombia. ***Rainy season (September)***

	Vegetation classes and management practices	Surface	Good classified pixels of test-zones
		---- percentage ----	
1.	Regrowth after burning during the dry season (dense chlorophyll savanna)	9.62	88.1
2.	Savanna ≥ 1 year after burning	34.73	98.8
3.	Savanna ≥ 1 year after burning (one the whole chlorophyll)	17.40	86.7
4.	Dry savanna with important biomass (very old burning, >1 year)	11.17	99.6
5.	Open savanna, young savanna well grazed or degraded cultivated pastures (soil visible)	8.35	100.0
6.	Wet lowlands + subsidence zones of river and lake	1.61	99.8
7.	Young savanna, young or degraded cultivated pastures	1.08	99.8
8.	Bare soil or degraded cultivated pasture	1.78	99.5
9.	Gallery forest + lowlands near the rivers	10.48	100.0
10.	Free water (lake) + large rivers	0.70	97.7
	TOTAL	96.92 3.08	

TABLE 11. Vegetation types of the flat zones of the Llanos. According to spectral vegetation behavior. SPOT Satellite Image. Window on the CNI ICA/CIAT, Carimagua/Colombia. ***Dry season (March)***

	Vegetation	Surface	Good classified pixels of test-zones
		----- percentage -----	
1.	Rather chlorophyllous vegetation (low lands + native pasture after burning)	16.89	69.5
2.	Moderately chlorophyllous vegetation (regrowth ≥ 12 months after burning, native pastures ± humid or on clay soils)	9.27	53.0
3.	Moderately chlorophyllous vegetation (regrowth ≥ 12 months, plateau between rivers on clay soil, vegetation without flowers)	8.00	67.9
4.	Dense moderately chlorophyllous vegetation (native pastures or cultivated grazed pastures)	7.44	90.4
5.	Little chlorophyllous vegetation (dry vegetation, high grasses with inflorescence)	5.25	86.5
6.	Heterogeneous little chlorophyllous vegetation (importance of soil: erosion, anthills)	4.52	88.9
7.	Heterogenous rather chlorophyllous vegetation (importance of soil: erosion, anthills, presence of shrubs on the hills(?). Vegetation of *Trachypogon vestitus* in flower)	2.75	44.1
8.	Heterogeneous moderately chlorophyllous vegetation (herbaceous + shrubby vegetation; bare soil; also shrubby lowlands and cultivated pastures: *Andropogon gayanus*)	3.10	84.5
9.	Little chlorophyllous vegetation + bare soil	2.74	53.0
10.	Rather chlorophyllous vegetation (cultivated pastures and lowland savanna good grazed)	1.76	46.3
11.	Hygroscopic rather chlorophyllous vegetation (± shrubby lowlands)	0.58	97.3
12.	High chlorophyllous vegetation (cultivated pastures or regrowth after burning in the lowlands)	0.12	100.0
13.	Background: no grazed zones (forest, water, some lowlands)	37.39	96.8
	TOTAL	99.74 0.26	

TABLE 12. Vegetation types of the flat zones of the Llanos. According to spectral vegetation behavior. SPOT satellite Image. Window on the CNI ICA/CIAT, Carimagua/Colombia. ***Rainy season (September)***

	Vegetation	Surface	Good classified pixels of test-zones
		------ percentage ------	
1.	Moderately chlorophyllous vegetation (native pasture, regrowth after burning >1 year)	14.61	89.0
2.	Rather chlorophyllous vegetation (regrowth after burning ≥1 year)	14.04	85.0
3.	Dense chlorophyllous vegetation (regrowth A.B. ≥1 year or old cultivated pastures; soil ± clay)	12.44	81.7
4.	Little chlorophyllous vegetation (old savanna; regrowth >1 year and liable to flooding area; clay soils)	10.71	77.1
5.	Rather chlorophyllous vegetation on sandy soils (regrowth after burning ≤1 year)	7.79	87.1
6.	Very chlorophyllous vegetation (cultivated pastures >1 year or regrowth after burning <1 year; clay soils)	6.21	87.2
7.	Little chlorophyllous vegetation: cut or heavy grazed (important effect of soil)	5.15	88.5
8.	Little chlorophyllous vegetation (old dry savanna; regrowth >1 year after burning; influence of the non chlorophyllous inflorescence)	4.50	86.6
9.	Very chlorophyllous vegetation (cultivated pastures >1 year, not heavy grazed)	1.35	95.5
10.	Little or not chlorophyllous vegetation (bare soil or overgrazed)	1.26	97.7
11.	Very little chlorophyllous vegetation (cultivated pastures with dark inflorescence, flooded areas, zural)	0.69	92.6
12.	Without chlorophyllous vegetation (dry forage or recent burning, soil >40%)	0.49	100.0
13.	Background: no grazed (lake, forest, ...)	19.91	94.7
	TOTAL	99.12 0.88	

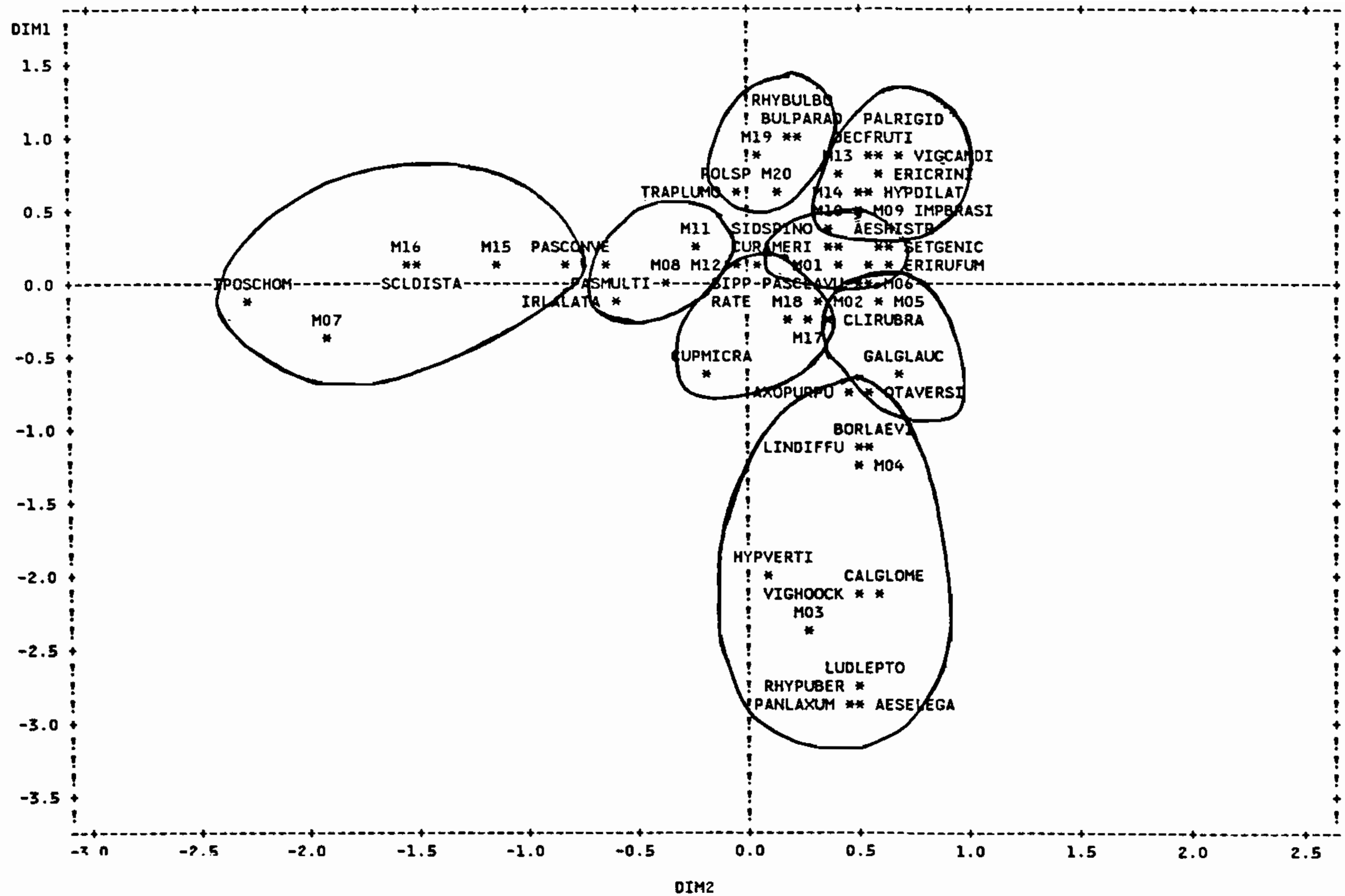


FIGURE 1. Native vegetation of Carimagua
Characteristic species of the eight principal vegetation groups
(Correspondence Analysis)

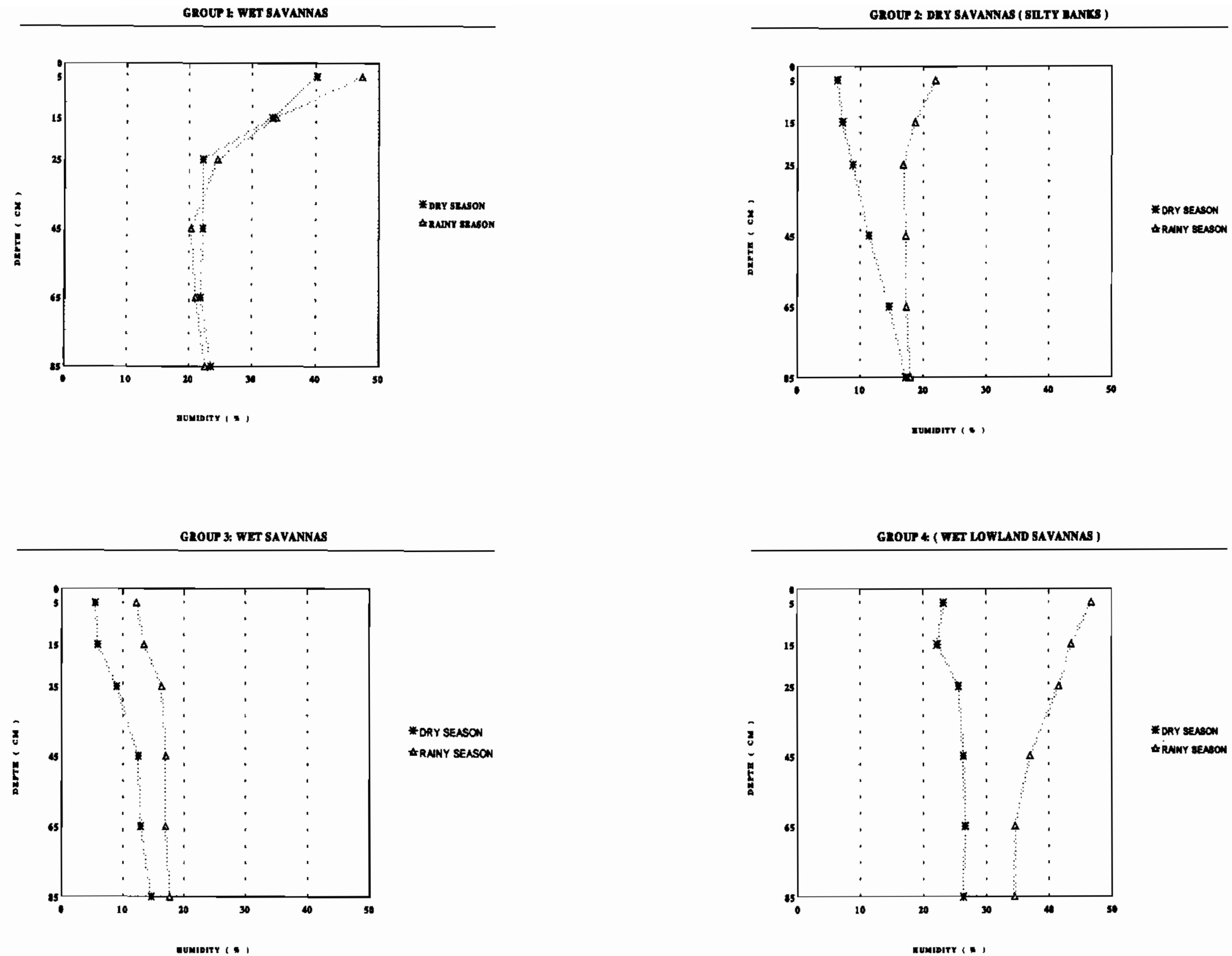


Figure 2. Humidity profile. Dry and rainy season

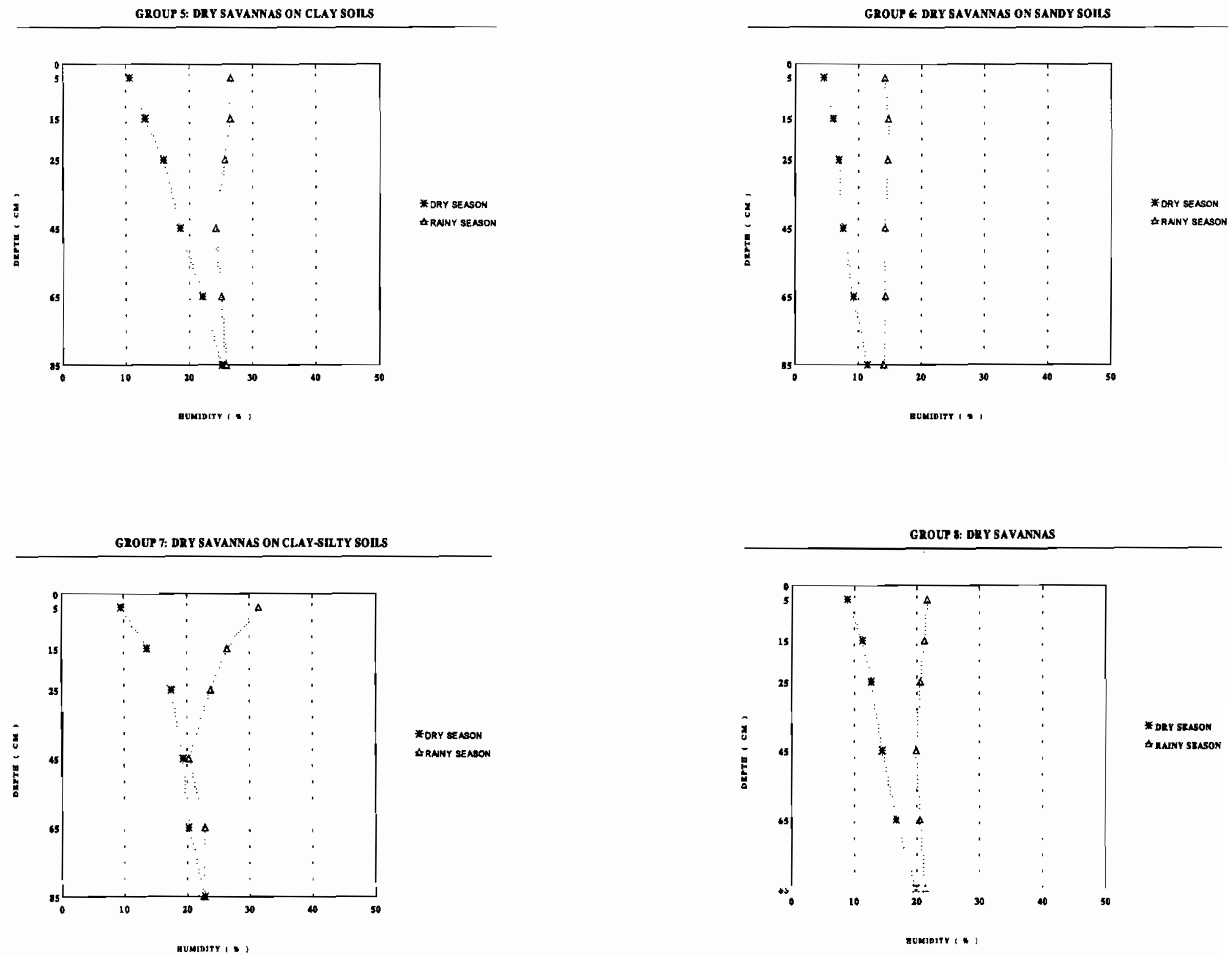


Figure 2. (Continued)

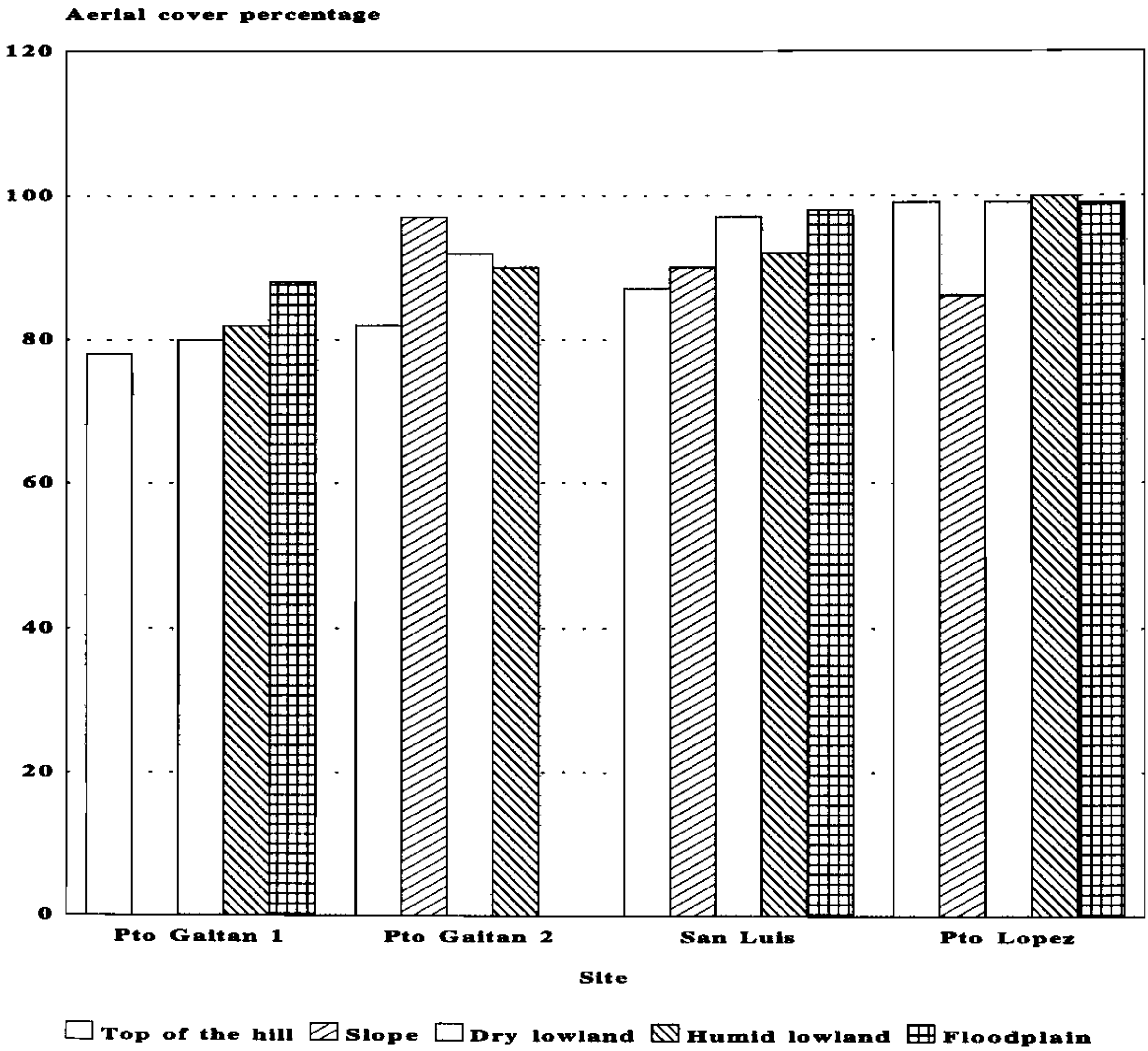


Figure 3. Vegetation of serrania. Site en aerial cover percentage

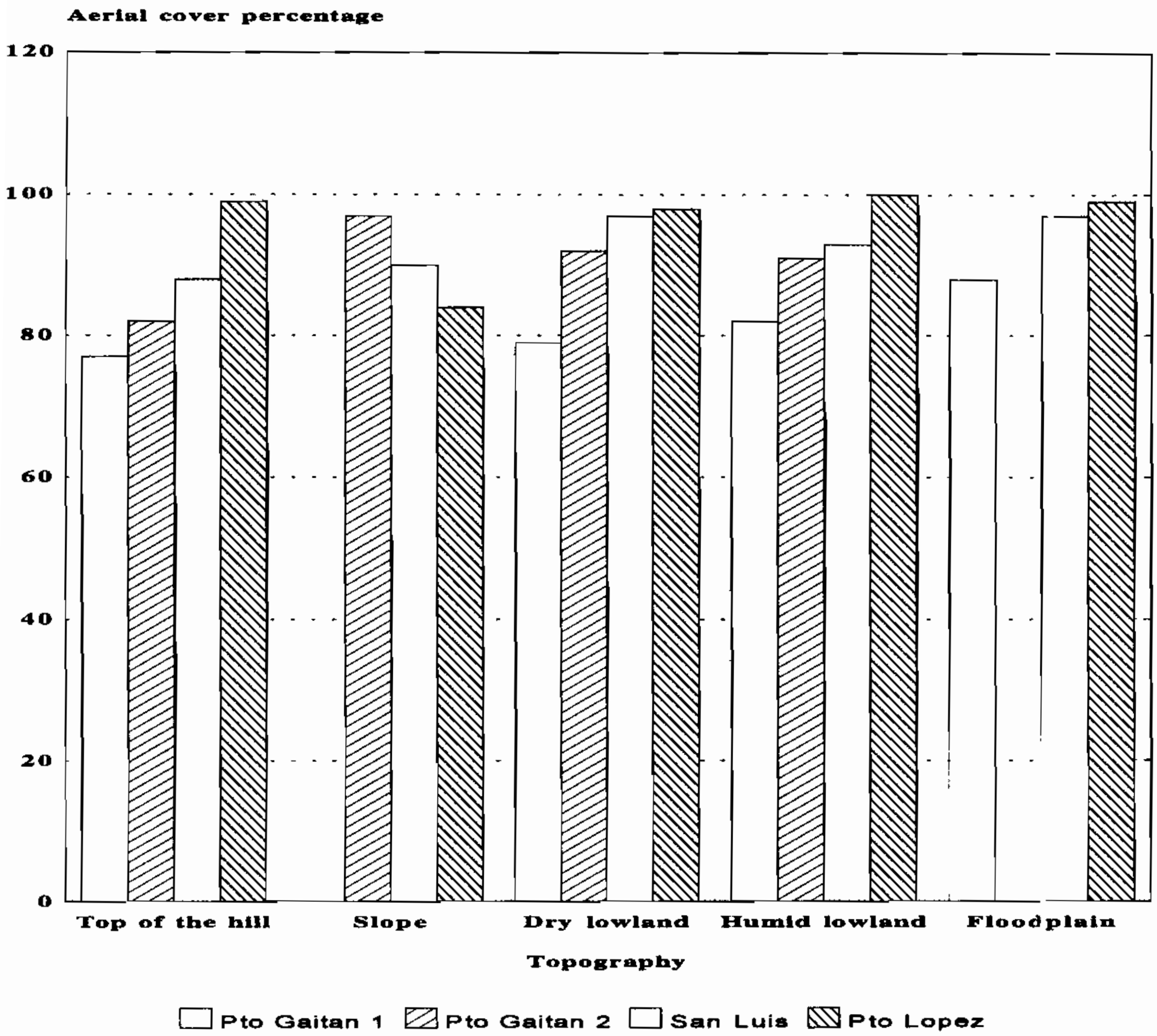


Figure 4. Vegetation of serrania
Topography and aerial cover percentage

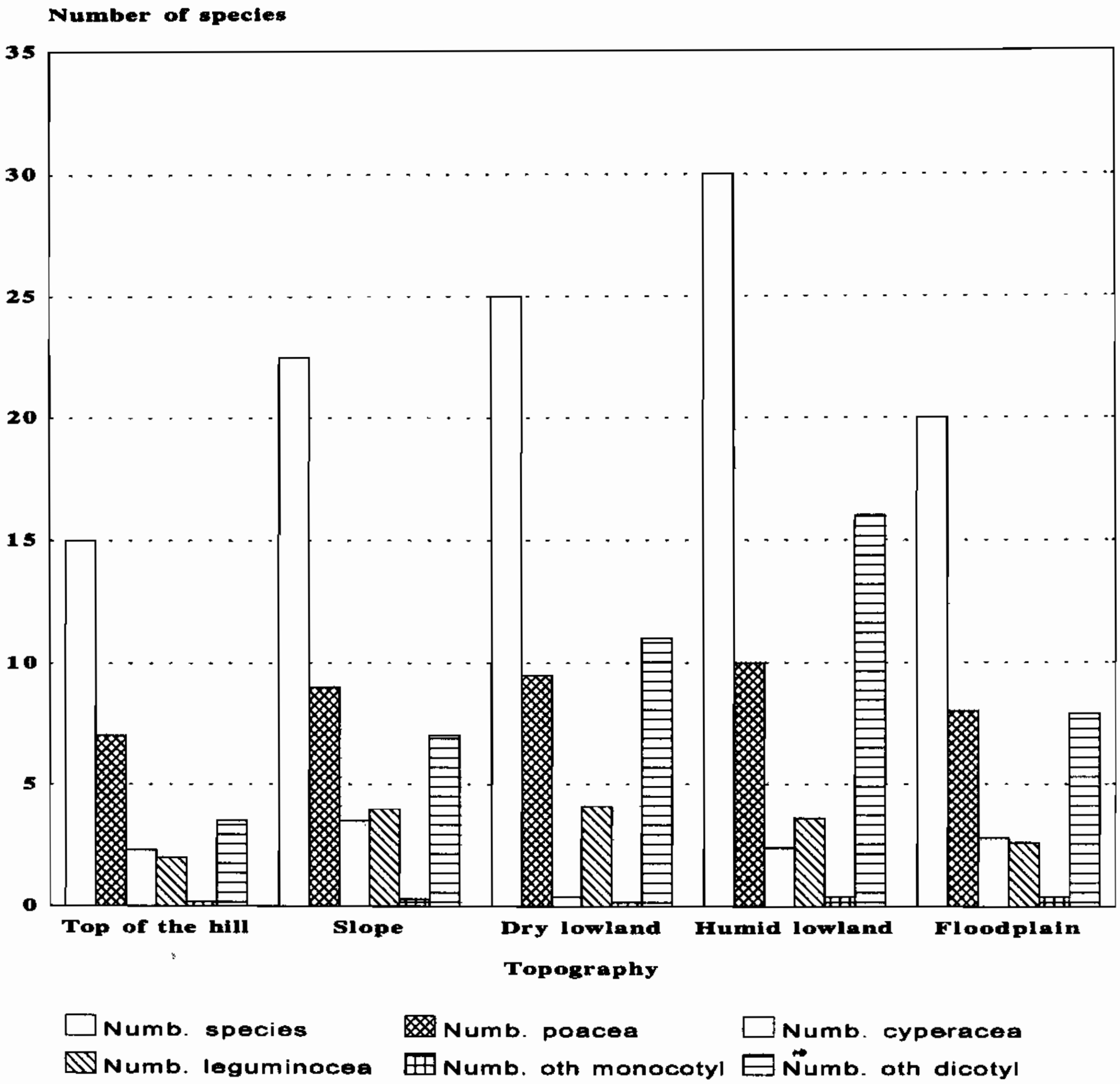


Figure 5. Vegetation of serrania Topography and number of species

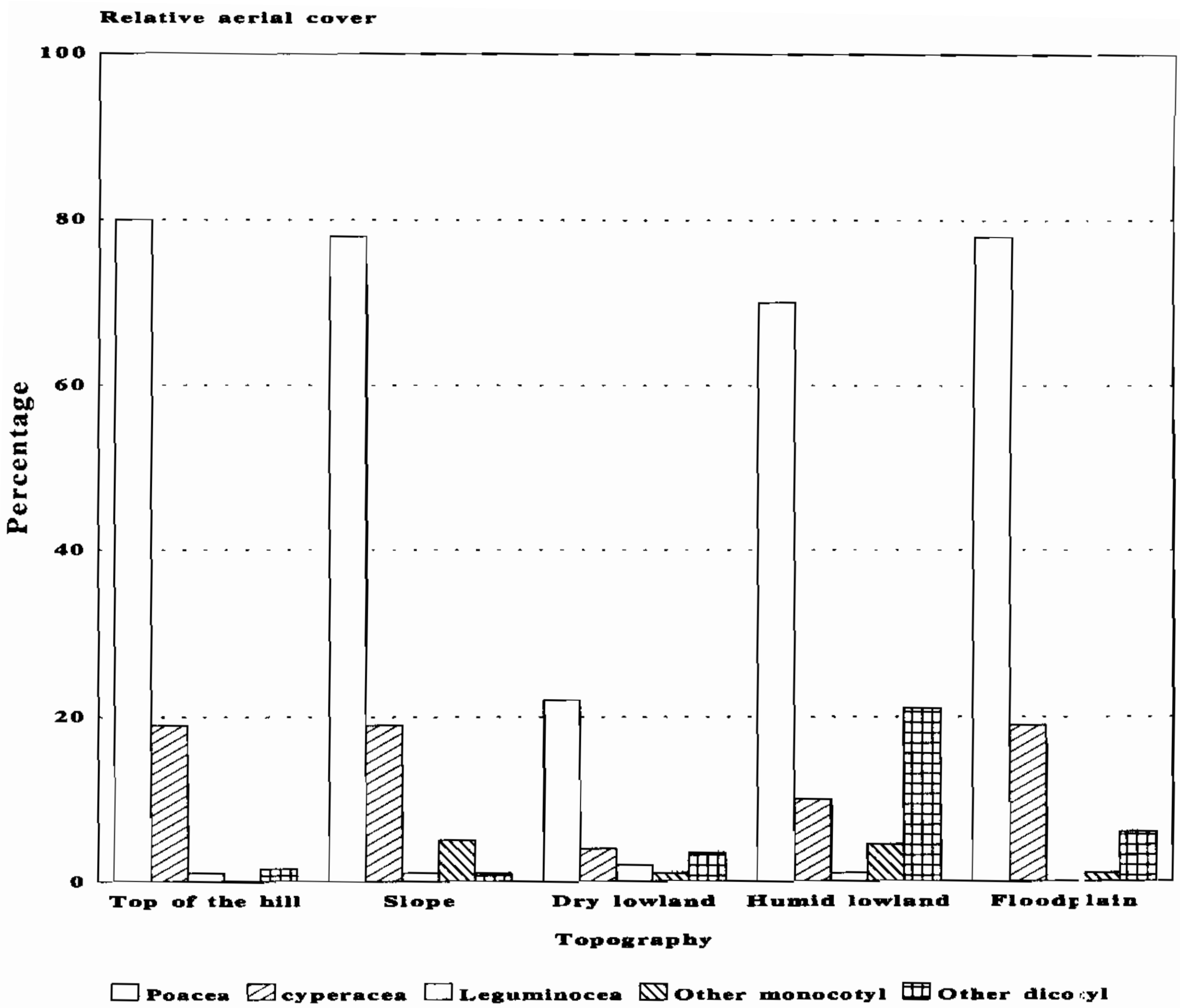


Figure 6. Vegetation of serrania. Topography and relative aerial cover (Point quadrat)

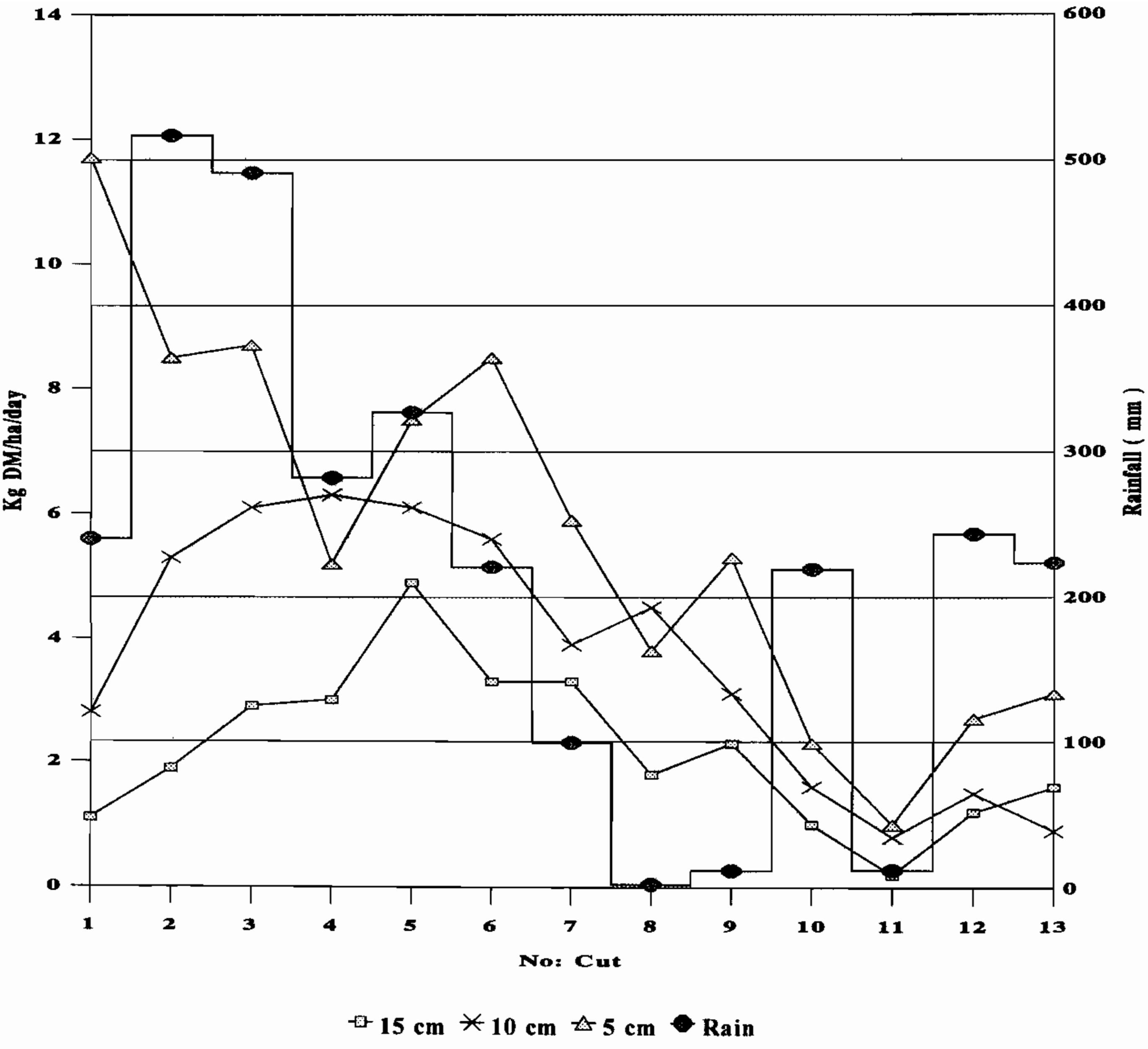


Figure 7. Productivity of native savannas. Comparison of cutting heights (Every 4 weeks)

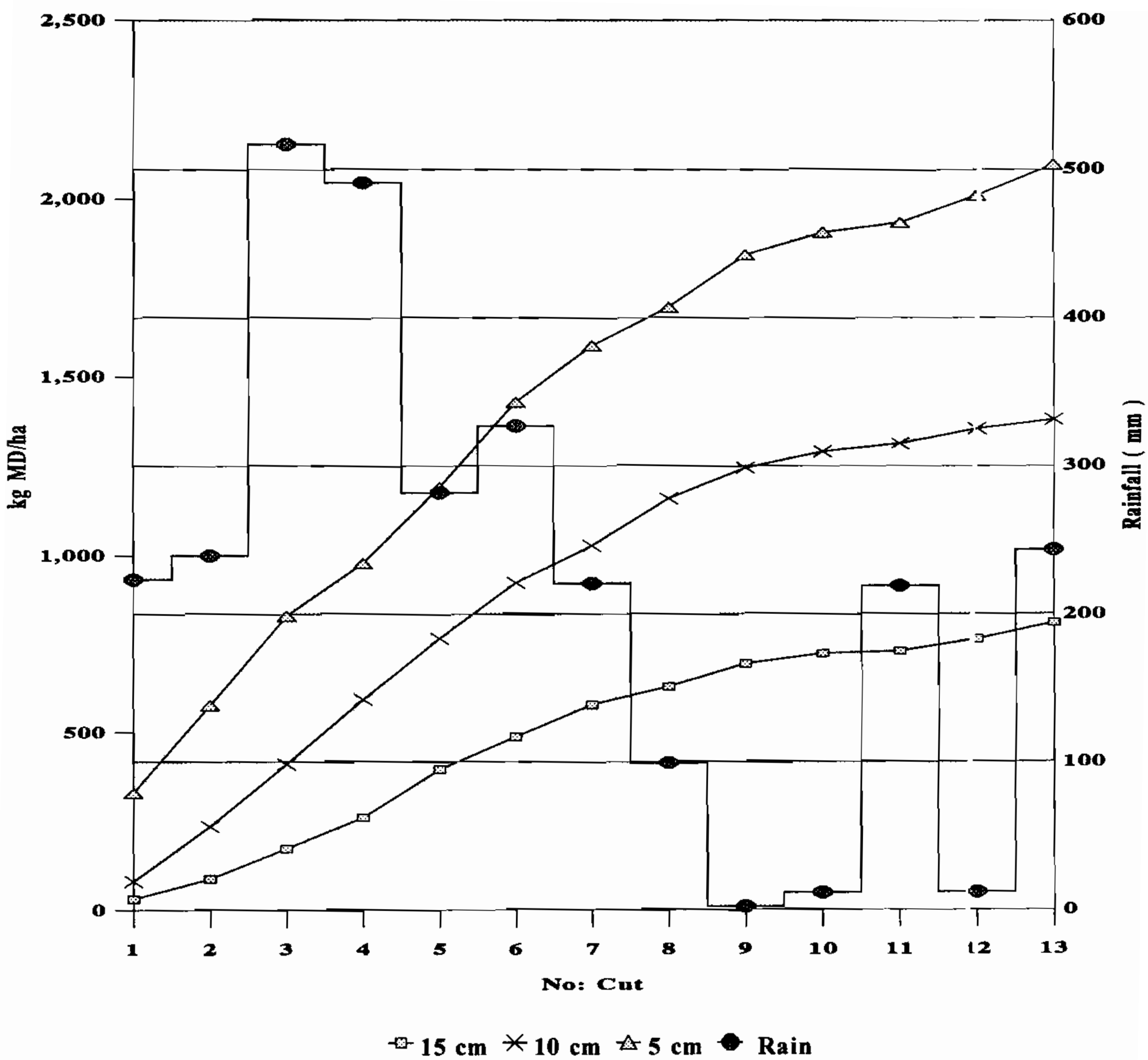
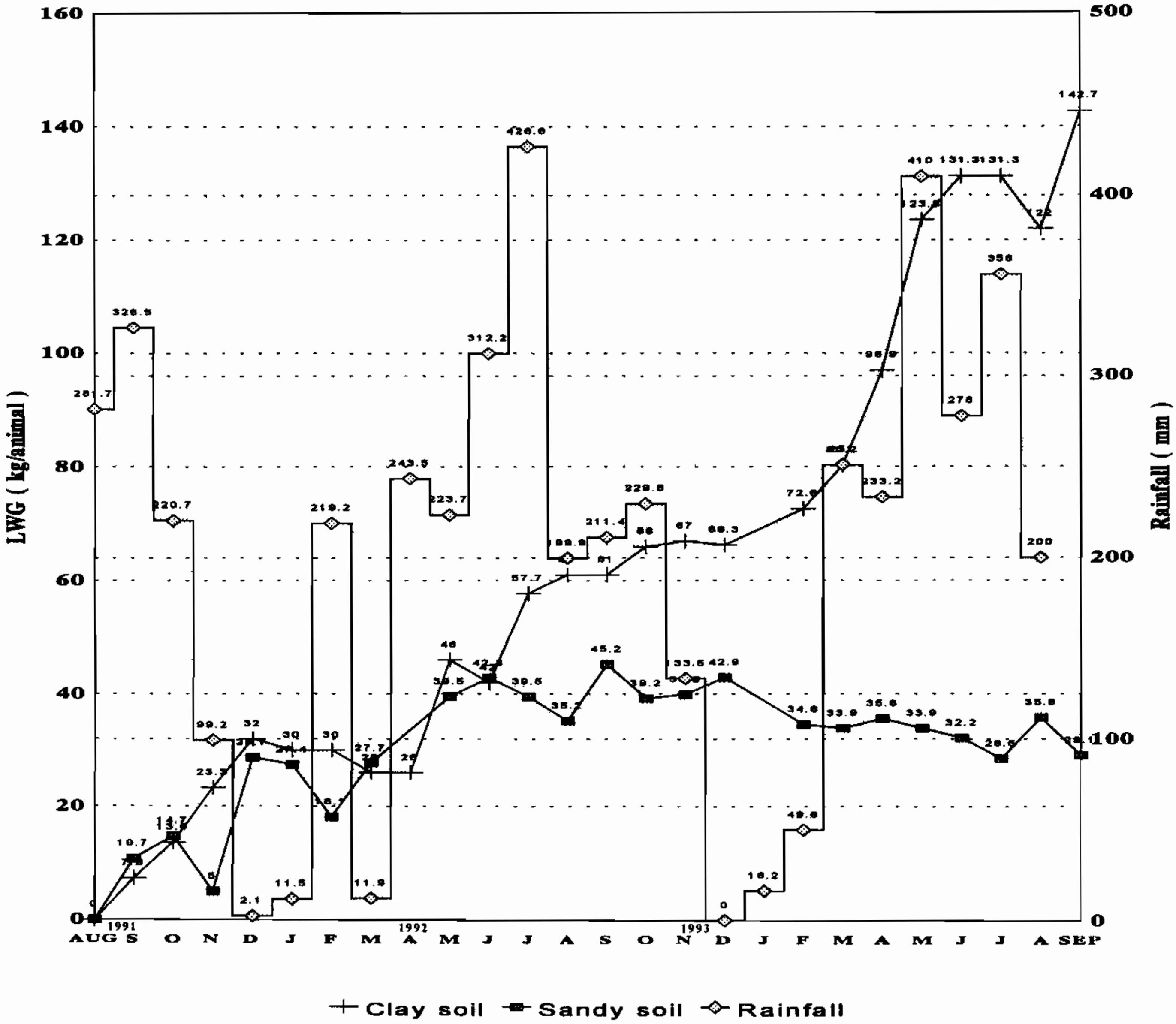


Figure 8. Production of native savannas comparison of cutting heights (Every 4 weeks)



Stocking rates:	1991: 4 ha/anim	6 ha/anim
	1992: 4 ha/anim	4 ha/anim
	1993: 4 ha/anim	4 ha/anim

Figure 9. **Productivity of two types of vegetation (On clay sandy soil) Liveweight gain on native pasture with improved management Core experiment Carimagua Llanos Colombia**

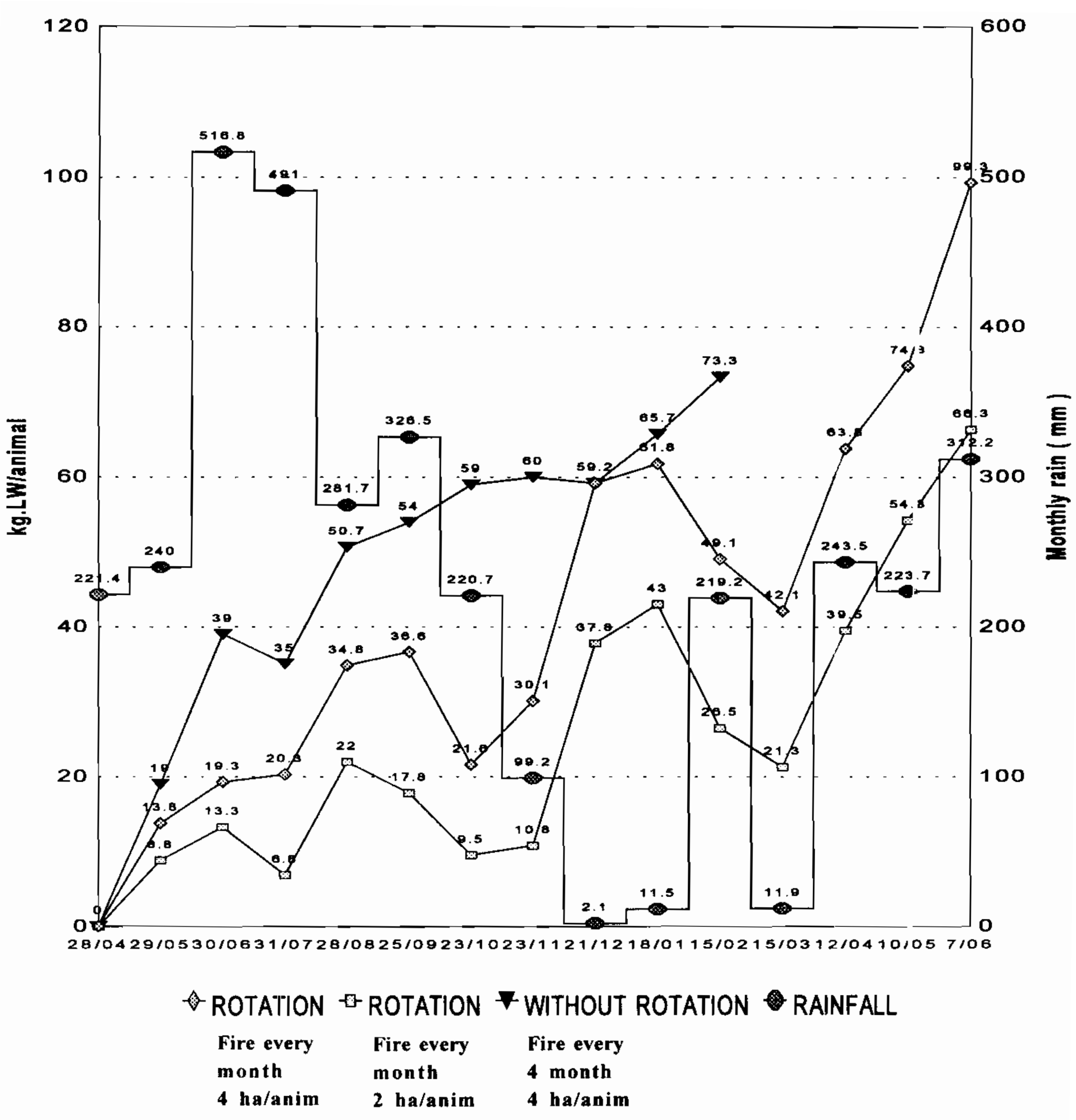


Figure 10. Native savanna management systens comparison liveweight gain

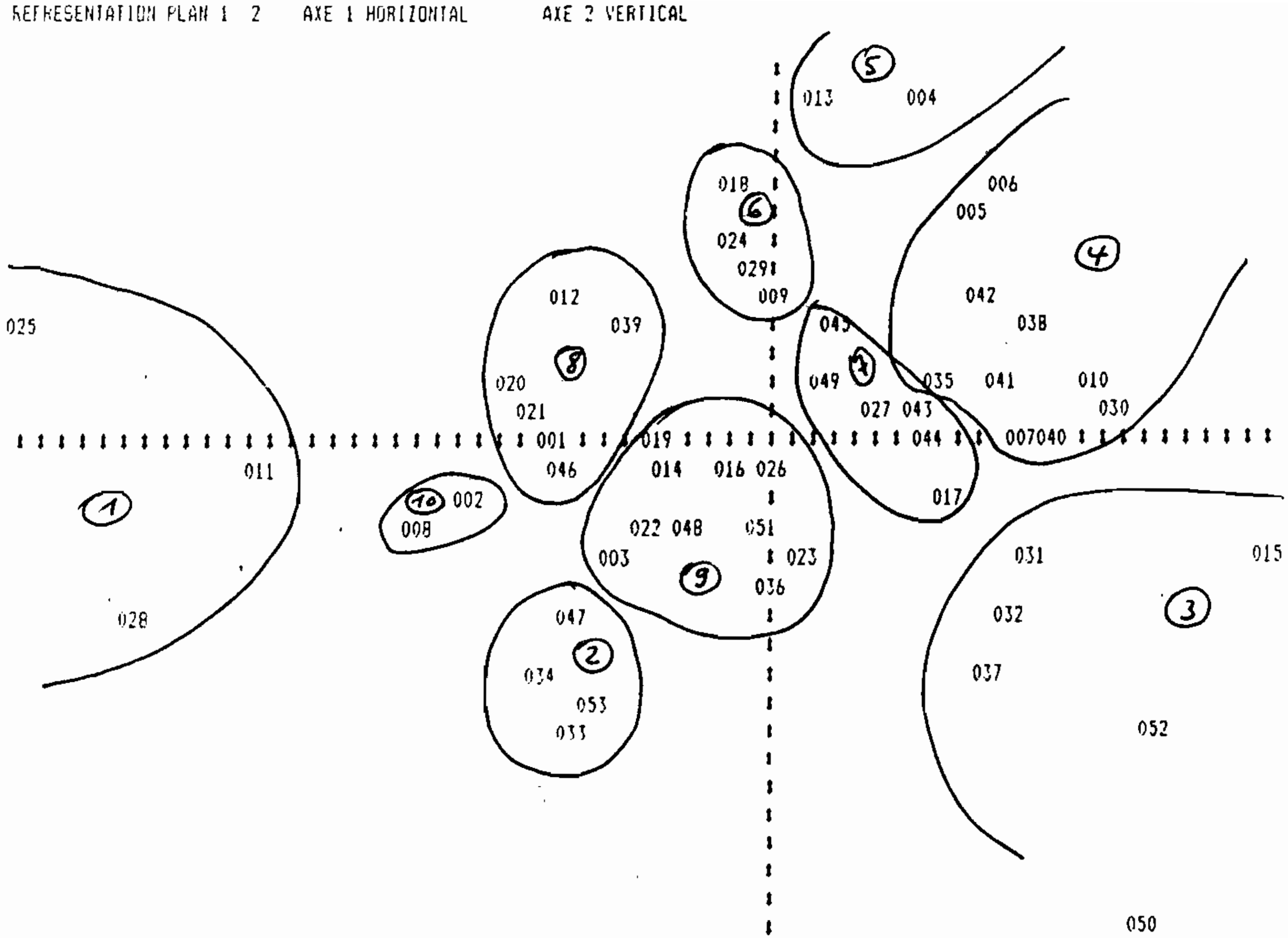


FIGURE 11. Vegetation classification of Carimagua through reflectance at ground level (Principal Component Analysis)

ANNEXE
SPECIES FROM THE SERRANIA (Collected from Dutch Students)

	FAMILY	SPECIES
1	ACANTHACEAE	*Ruellia geminiflora*
2	AMARANTHACEAE	*Alternanthera* sp
3	AMARYLLIDACEAE	*Curculigo scorzoneraefolia*
4	ANNONACEAE	*Xylopia* sp
5	ARACEAE	*Caladium macrotiles*
6	ARISTOLOCHIACEAE	*Aristolochia nummularifolia*
7	CAESALPINIACEAE	*Chamaecrista* sp
8		*Chamaecrista cultrifolia*
9		*Chamaecrista desvauxii*
10		*Chamaecrista disphylla*
11		*Chamaecrista hispidula*
12		*Chamaecrista kunthiana*
13		*Chamaecrista rotundifolia*
14	COMPOSITAE	*Calea colombiana*
15		*Calea sessiliflora*
16		*Composite* sp
17		*Erechtites valerianaefolia*
18		*Eupatorium* sp
19		*Eupatorium amygdalinum*
20		*Ichthyothere terminalis*
21		*Stilpnopappus pittieri*
22	CONVOLVULACEAE	*Ipomea fistulosa*
23		*Merremia aterensis*
24	CYPERACEAE	?
25		*Bulbostylis paradoxa*
26		*Cyperus brevifolius*
27		*Cyperus flavecens*
28		*Cyperus flavus*
29		*Dichromena ciliata*
30		*Rhynchospora barbata*
31		*Rhynchospora confinis*
32		*Rhynchospora corymbosa*
33		*Rhynchospora globosa*
34		*Rhynchospora podeosperma*
35		*Rhynchospora pubera*
36		*Rhynchospora subplumosa*
37		*Scleria distans*
38	DILLENIACEAE	*Curatella americana*
39	ERISTOLACEAE	*Erythroxylum* sp
40	EUPHORBIACEAE	*Croton trinitatis*
41		*Euphorbia communis*
42		*Euphorbia hirta*
43		*Phyllanthus* sp
44		*Phyllanthus niruri*
45	FABACEAE	*Centrosema angustifolium*
46		*Centrosema venosum*
47		*Clitoria* sp
48		*Clitoria guianensis*
49		*Crotalaria* sp
50		*Crotalaria nitidula*
51		*Desmodium barbatum*
52		*Eriosema* sp
53		*Eriosema crinitum*
54		*Eriosema rufum*
55		*Eriosema simplicifolium*
56		*Galactia glaucescens*
57		*Galactia jussiaeana*
58		*Indigofera lespedezioides*
59		*Macroptilium monophyllum*
60		*Stylosanthes guianensis*
61		*Vigna linearis*
62		*Zornia* sp
63	FLACVORTIACEAE	*Casearia sylvestris*
64		*Casearia ulmifolia*
65	GENTIANACEAE	*Irlbachia alata* subsp. *alata*
66		*Schultesia* sp
67	GUTTIFERAE	*Vismia dealbata*
68	HAEMODORACEAE	*Schiekia orinocensis*
69	IRIDACEAE	*Cypella linearis*
70	LABIATAE	*Hyptis* sp
71		*Hyptis atrorubens*
72		*Hyptis brachiata*
73		*Hyptis capitata*
74		*Hyptis conferta*
75		*Hyptis dilatata*
76		*Hyptis verticillata*
77	LYTHRACEAE	*Cuphea calophylla*
78	MALPIGHIACEAE	*Byrsonima* sp
79		*Byrsonima crassifolia*
80		*Byrsonima verbascifolia*
81	MALVACEAE	*Pavonia* sp
82		*Peltaea speciosa*
83		*Sida acuta*
84		*Sida linifolia*
85	MELASTOMATACEAE	*Clidemia rubra*
86		*Desmocellis villosa*
87		*Miconia* sp
88		*Miconia rubiginosa*
89		*Miconia rufescen*
90		*Pterogastra mayor*
91		*Tococa guianensis*
92	MENISPERMEACEAE	*Cissampelos ovalifolia*
93	MIMOSACEAE	*Mimosa pudica*
94	MYRTHACEAE	*Myrcia guianensis*
95		*Psidium* sp
96		*Psidium maribense*
97		*Psidium salutare*
98	OCHNACEAE	*Sauvagesia erecta*
99	ONAGRACEAE	*Ludwigia decurrens*
100	PALMAE	*Mauritia minor*

101	PASSIFLORACEAE	*Passiflora foetida*	141		*Paspalum contractum*
102		*Passiflora foetida* var. *elli*	142		*Paspalum convexum*
103	POACEAE	?	143		*Paspalum minus*
104		*Andropogon* sp	144		*Paspalum multicaule*
105		*Andropogon bicornis*	145		*Paspalum parviflorum*
106		*Andropogon gayanus*	146		*Paspalum pectinatum*
107		*Andropogon hypogynus*	147		*Paspalum plicatulum*
108		*Andropogon leucostachyus*	148		*Paspalum stellatum*
109		*Andropogon selloanus*	149		*Sacciolepis myuros*
110		*Andropogon virgatus*	150		*Schizachyrium* sp
111		*Aristida capillacea*	151		*Schizachyrium brevifolium*
112		*Aristida riparia*	152		*Schizachyrium hirtiflorum*
113		*Aristida ternipes*	153		*Setaria geniculata*
114		*Aristida tincta*	154		*Thrasya petrosa*
115		*Axonopus* sp	155		*Trachypogon* sp
116		*Axonopus affinis*	156		*Trachypogon plumosus*
117		*Axonopus anceps*	157		*Trachypogon vestitus*
118		*Axonopus aureus*	158	POLYGALACEAE	*Polygala paniculata*
119		*Axonopus chrysoblepharis*	159	RUBIACEAE	*Borreria capitata*
120		*Axonopus purpusii*	160		*Declieuxia fruticosa*
			161		*Sabicea colombiana*
121		*Chusquea pinifolia*	162		*Sabicea villosa*
122		*Coelorachis ramosa*	163		*Sipanea pratensis*
123		*Ctenium planifolium*	164		*Spermacoce* sp
124		*Digitaria neesiana*	165		*Spermacoce capitata*
125		*Elyonurus candidus*	166	SCROPHULARIACEAE	*Buchnera pusilla*
126		*Eragrostis maypurensis*	167		*Lindernia diffusa*
127		*Gymnopogon* sp	168	SOLANACEAE	*Solanum* sp
128		*Gymnopogon fastigiatus*	169	STERCULIACEAE	*Bittneria mollis*
129		*Gymnopogon foliosus*	170		*Melochia colombiana*
130		*Hypogynium virgatum*			
			171		*Melochia af. pyramidata*
131		*Leptocoryphium lanatum*	172		*Melochia villosa*
132		*Mesosetum pittieri*	173	TURNERACEAE	*Turnera af. pumilea*
133		*Otachyrium versicolor*	174		*Turnera ulmifolia*
134		*Panicum* sp	175	XIRIDACEAE	*Xyris* sp
135		*Panicum parvifolium*	176		*Xyris caroliniana*
136		*Panicum stenodes*	177		*Xyris caroliniana* var. *mayor*
137		*Paspalum* sp			
138		*Paspalum acuminatum*			
139		*Paspalum carinatum*			
140		*Paspalum clavuliferum*			

PUBLICATIONS 1992-1993

Ayarza, M.A. e L. Vilela. 1993. Rotacão de culturas e pastagens em um solo de Cerrado. Estudo de caso. Resumos XXIV Congresso Brasileiro de Ciência do Solo, Goiânia, Goiás, Brasil. Vol. III. p. 121-122.

Ayarza, M.A., I.M. Rao, R.J. Thomas, M.J. Fisher, C.E. Lascano, and P. Herrera. 1993. Standing root biomass and root distribution in *Brachiaria decumbens/Arachis pintoi* pastures under grazing. Proceedings of the XVII International Grasslands Congress, Palmerston North, New Zealand/ Queensland, Australia, Feb 8-21, 1993. (In press).

Baruch, Z. and M.J. Fisher. 1992. Effecto del método de siembra y de la textura del suelo sobre el crecimiento y desarrollo de *Arachis pintoi*. [Effect of the method of seeding and soil texture on the growth and development of *Arachis pintoi*]. In: Red Internacional de Evaluación de Pastos Tropicales. 1a. Reunión Sabanas, 23-26 noviembre de 1992, Brasilia, Brasil. (E.A. Pizarro, ed.). Documento de Trabajo No. 117, CIAT, Cali, Colombia. p. 527-538.

Bolaños, M.C., R.J. Thomas, and R. Sylvester-Bradley. 1993. Serological relationships among *Bradyrhizobium* strains for tropical forage legumes. In New horizons in nitrogen fixation. Palacios, R. Mora, J. and Newton, W.E. (eds.), Kluwer Academic Pubs., Dordrecht, p. 597.

Decaëns, T. 1993. Impact des pratiques agricoles sur la macrofaune des sols dans quelques pâturages et cultures des Llanos Orientaux de Colombie. D.E.S.S. Université de Paris XII, 55 p. + Annexes.

Escobar, E., J. Belalcázar, G. Rippstein. 1993. Clave de las principales plantas de sabana de la altillanura de los Llanos Orientales en Carimagua, Meta, Colombia. CIAT (Centro Internacional de Agricultura Tropical); Universidad Nacional de Colombia and CIRAD-EMVT. Cali, Colombia. 92 p.

Fisher, M.J., C. Lascano, R.R. Vera, and G. Rippstein. 1992. Integrating the native savanna resource with improved pastures. In Pastures for the Tropical Lowlands. CIAT's Contribution. CIAT, Cali, Colombia. p. 75-100.

Fisher, M.J. and P. Cruz. 1993. Some ecophysiological aspects of Arachis pintoi. In Biology and agronomy of *Arachis pintoi* (P.C. Kerridge, ed.). CIAT, Cali, Colombia. (In press).

Fisher, M.J., C.E. Lascano, R.J. Thomas, M.A. Ayarza, I.M. Rao, G. Rippstein, and J.H.M. Thornley. 1993. An integrated aproach to understand soil-plant-animal interactions on grazed legume-based pastures on tropical acid soils. Proceedings of the XVII International Grasslands Congress, Palmerston North, New Zealand/ Queensland, Australia, Feb 8-21, 1993. (In press).

Franco, M.A., G. Ocampo, E. Melo, and R.J. Thomas. 1993. Catalogue of Rhizobium strains for tropical forage legumes, 5th edition. CIAT Working Document No. 14, Cali, Colombia. 123 p.

Hoyos, P., R.R. Vera and J. I Sanz. 1992. Relaciones entre la textura y las características químicas en suelos oxisoles de la altillanura plana, Llanos Orientales de Colombia. In Red Internacional de Evaluación de Pastos Tropicales, RIEPT, 1ra. Reunión Sabanas, Documento de Trabajo No. 117, CIAT, Cali, Colombia. p. 465-472.

Hoyos, P. and R.R. Vera. 1992. Efecto de la fertilización con S, P, K, Mg en la frecuencia de pastoreo de la asociación *Brachiaria dictyoneura* CIAT 6133 + *Desmodium ovalifolium* CIAT 13089. In Red Internacional de Evaluación de Pastos Tropicales, RIEPT, 1ra. Reunión Sabanas, Documento de Trabajo No. 117, CIAT, Cali, Colombia. p. 473-478.

Hoyos, P., R.R. Vera, C. Lascano and M.A. Franco. 1992. Manejo del pastoreo por productores de la altillanura plana de los Llanos Orientales de Colombia. In Red Internacional de Evaluación de Pastos Tropicales, RIEPT, 1ra. Reunión Sabanas, Documento de Trabajo No. 117, CIAT, Cali, Colombia. p. 679-684.

Lascano, C.E., B.L. Maass, and R.J. Thomas. 1993. Multipurpose trees and shrubs at CIAT. Proceedings of a consultative meeting, ICRAF, Nairobi, June 2-5, 1992.

Miles, J.W., R.J. Thomas, C.E. Lascano, M.J. Fisher, R.R. Vera, and J.I. Sanz. 1993. Evaluation of *Stylosanthes* for selected farming systems of tropical America. Proceedings of a workshop on *Stylosanthes* as feed and fallow. Kaduna, Nigeria, Oct 26-31, 1992. (In press).

Mohamed Saleem, M.A. and M.J. Fisher (1993). Role of ley farming in crop rotations in the tropics. Proceedings of the XVII International Grasslands Congress, Palmerston North, New Zealand/Queensland, Australia, Feb 8-21, 1993. (In press).

Pizarro, E.A., R. Amaral and R.R. Vera. 1992. *Panicum maximum*: efecto de la época de diferimiento en producción y calidad. In Red Internacional de Evaluación de Pastos Tropicales, RIEPT, 1ra. Reunión Sabanas, Documento de Trabajo No. 117, CIAT, Cali, Colombia. p. 675-678.

Rao, I.M., W.M. Roca, M.A. Ayarza, E. Tabares and R. García. 1992. Somaclonal variation in plant adaptation to acid soil in the tropical forage legume *Stylosanthes guianensis*. Plant and Soil. 146:21-30.

Rao, I.M., M.A. Ayarza, R.J. Thomas, M.J. Fisher, J.I. Sanz, J. Spain, and C.E. Lascano. 1992. Soil-plant factors and processes affecting sustainable production in acid soils of lowland tropics. In Abstracts of the International Crop Science Congress. Ames, Iowa, U.S.A. p. 109.

Rao, I.M., M.A. Ayarza, R.J. Thomas, M.J. Fisher, J.I.Sanz, J.M. Spain, and C.E. Lascano. 1992. Soil-plant factors and processes affecting productivity in ley farming. In Pastures for the tropical lowlands: CIAT's contribution. CIAT, Cali, Colombia. p. 145-75.

Rao, I.M., M.A. Ayarza, V. Borrero and R. García. 1993. Plant nutritional disorders of tropical forage species. In RIEPT, manual on agronomic evaluation. (In press).

Rao, I.M., R.S. Zeigler, R. Vera and S. Sarkarung. 1993. Selection and Breeding for acid-soil tolerance in crops: Upland rice and tropical forages as case studies. (English). BioScience 43(7):454-465.

Rao, I.M., M.A. Ayarza, R.J. Thomas, M.J. Fisher, C. Lascano and V. Borrero. 1993. Adaptation responses of tropical grass-legume associations to acid soils. Proceedings of the XVII International Grassland Congress, Palmerston North, New Zealand/Queensland, Australia, Feb 8-21, 1993. (In press).

Rippstein, G., J. Sionneau, G. Escobar y G. Ramírez. 1993. Uso de radiometría terrestre para el estudio y el inventario de los pastos de los Llanos Orientales de Colombia (proposed for publication in IGAC Review, 1993).

Sanz, J.I., S. Weil, and A.A. Jones. 1992. The mineralogy and potassium reserves of a soil from Carimagua, Colombia. Geoderma 52:291-302.

Sanz, J.I., M. Ayarza, I.M. Rao, R. Thomas, and M. Fisher. 1992. Integrated crop-pasture systems for tropical savannas of Latin America. In: Abstracts of the International Crop Science Congress. Ames, Iowa, U.S.A. p. 36.

Sanz, J.I., D.L. Molina, and M. Rivera. 1993. El arroz se asocia con pasturas en la altillanura Colombiana. Arroz en las Américas Centro Internacional de Agricultura Tropical (CIAT), V. 14(1):89.

Thomas, R.J. 1992. The role of the legume in the nitrogen cycle of productive and sustainable pastures. Grass and Forage Science, 47:133-142.

Thomas, R., I.M. Rao, M. Ayarza, J.I. Sanz, M. Fisher, and C. Lascano. 1992. How much pasture legume is needed to avoid depletion of soil reserves?. In Abstracts of the International Crop Science Congress. Ames, Iowa, U S.A. p. 47.

Thomas, R.J., C.E. Lascano, J.I. Sanz, M.A. Ara, J.M. Spain, R.R. Vera, and M.J. Fisher. 1992. The role of pastures in production systems. **In** Pastures for the Tropical Lowlands: CIAT's Contribution. Centro Internacional de Agricultura Tropical, CIAT. p. 121-144.

Thomas, R.J. 1993. How much nitrogen fixation is needed to avoid depletion of soil reserves in pastures. **In** New horizons in nitrogen fixation. Palacios, R., Mora, J. and Newton, W.E. (eds.), Kluwer Academic Pubs., Dordrecht. p. 749.

Thomas, R.J. 1993. Rhizobium requirements, nitrogen fixation and nutrient cycling in forage *Arachis*. **In** The Biology and Agronomy of Forage *Arachis*, CIAT, Cali, Colombia. (In press).

Thomas, R.J. and N.M. Asakawa. 1993. Nitrogen fixation by three tropical forage legumes in an acid-soil savanna of Latin America. **In** New horizons in nitrogen fixation. Palacios, R., Mora,J.and Newton, W.E. (eds.), Kluwer Academic Pubs., Dordrecht. p. 750.

Thomas, R.J. and N.M. Asakawa. 1993. Decomposition of leaf litter from tropical forage grasses and legumes. Soil Biology and Biochemistry 25:1351-1361.

Thomas, R.J., M.J. Fisher, C.E. Lascano, and P. Argel. 1993. *Arachis pintoi* - the tropical white clover. **In** New horizons in nitrogen fixation. Palacios, R., Mora, J., and Newton, W.E. (eds.), Kluwer Academic Pubs., Dordrecht. p. 751.

Thomas, R.J., M.J. Fisher, M.A. Ayarza, and J.I. Sanz. 1993. Productivity of acid tropical soils in Latin America and the role of forage grasses and legumes. Advances in Soil Science. (In press).

Thomas, R.J., M.J. Fisher, C.E. Lascano, I.M. Rao, M.A. Ayarza, and N.M. Asakawa. 1993. Nutrient cycling via forage litter in tropical grass/legume pastures. Proceedings of the XVII International Grasslands Congress, Palmerston North, New Zealand/Queensland, Australia, Feb 8-21, 1993. (In press).

Thornton. P.K. and M.J. Fisher. 1993. A conceptual model of the relationship between grasses and legumes in tropical pastures under grazing. Tropical Grasslands (submitted).

Toutain, B., B. Peyre de Fabregues, G. Robergé, A. Bigot, et G. Rippstein. 1992. Revue des recherches et de l'utilisation des *Stylosanthes* en Afrique de l'ouest (a review of research and use of *Stylosanthes* in West Africa). Séminaire régional sur l'utilisation de *Stylosanthes* en Afrique de l'ouest. Kaduna (Nigéria), 26-31 Octobre, 1992. ILCA, Addis Ababa, Ethiopia. (Sous presse).

Vera, R.R. 1992. Usos de Pasturas Tropicales en las Sabanas Neotropicales. (Español). Trabajo presentado en el II Curso sobre "Producción e Investigación en Pastos Tropicales", Maracaibo, Venezuela, 28-30 de abril de 1992. (Fotocopiado).

Vera, R.R. 1992. Introduction. **In** Pastures for the Tropical Lowlands: CIAT's Contribution. CIAT, Cali, Colombia. p. v-vii.

Vera, R.R. 1992. Conclusions. **In** Pastures for the Tropical Lowlands: CIAT's Contribution. CIAT, Cali, Colombia. p. 177-182.

Vera, R.R., R. Thomas, L. Sanint and J.I. Sanz. 1992. Development of Sustainable Ley-Farming Systems for the Acid-Soil Savannas of Tropical America. (English). Simpósio Internacional sobre Ecología e Agricultura Sustentável nos Trópicos, Rio de Janeiro, Brasil, 3-6 de fevereiro de 1992, published in Anais da Academia Brasileira de Ciencias 64 (supl. 1):105-125.

Vera, R.R., C.A. Ramírez and H. Ayala. 1993. Reproduction in continuously underfed Brahman cows. Animal Production 57:193-198.

Volverás, B. and M.J. Fisher. 1993. Efecto de las pasturas mejoradas sobre la producción de arroz tolerantes a suelos ácidos en las Llanos Orientales de Colombia. VI Congreso Colombiano de la Ciencia del Suelo, Manizales, 1991. (In press).

Yonkeu, S., G. Rippstein, et J.F.B. Ottou. 1992. Etude de l'évolution de la végétation herbacée des parcs à foin du ranch de Gounjel (Compagnie Pastorale), Adamaoua, Cameroun (Study of changes in the herbaceous vegetation of rangeland at the Gounjel ranch. Adamawa, Cameroon). Revue Elev.Méd.Vét.Pays Trop., 45(1):91-96.

Yonkeu, S., E. Teodenken Pamo, et G. Rippstein. 1992. An evaluation of different accessions and varieties of *Stylosanthes* introduced in Adamaoua Plateau-Cameroon. Séminaire régional sur l'utilisation de *Stylosanthes* en Afrique de l'ouest. Kaduna (Nigéria), 26-31 Octobre, 1992. ILCA, Addis Ababa, Ethiopia. (Sous presse).

Zeigler, R.S., S. Sarkarung, J.I. Sanz, and D.L. Molina. 1992. Upland rice germplasm development and production system research at CIAT. Published in the issue of the International Rice Commission Newsletter.

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